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DISTRIBUTION AND ECOLOGICAL RISK ASSESSMENT OF HEAVY METALS IN ROADSIDE SOIL ALONG THE HEMMAT HIGHWAY OF TEHRAN, IRAN

The impact of land use and a distance from the highway on heavy metal concentration in soils along the highway has been investigated. 28 soil samples were collected in August 2014 from the roadside soils of the Hemmat highway of Tehran, Iran. The results showed that the mean concentrations of Pb, Cr, Ni, Zn and Cd were 144, 17.20, 18.91, 86.84, 3.86 mg/kg^{-1}, respectively. With exception for Cd, the concentrations of the heavy metals decreased upon increasing distance from the highway that shows the background amount of cadmium in the soil area was high. The values of the enrichment factor (*EF*) showed that Ni, Zn and Cr have a natural source ($EF < 10$) and Pb and Cd have an anthropogenic source ($EF > 10$). The anthropogenic sources are emphasized for these heavy metals, thus indicating the strong human influence. The mean values of geoaccumulation index (I_{geo}) for Pb, Zn, Cd were high at residential, under-construction and green space land uses. The ecological risk index (*RI*) for roadside soils was higher than 300, indicating that sampling sites had a considerable ecological risk. The potential ecological risk index for single metal decreases in the following sequence: Cd > Pb > Ni > Zn > Cr.

1. INTRODUCTION

Pollution of urban soils with heavy metals is one of the important issues due to their wide sources, toxicity, non-biodegradable and accumulative properties. Heavy metals may be derived from domestic wastes, industries and transportations [1]. Soil physico-chemical properties such as pH, soil organic matter (SOM), cation exchange capacity (CEC) can impact the accumulation of heavy metals in soils [2].

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Roads are the second largest non-point source of pollution creation in the cities. The role of cars and road transports to the global emission of atmospheric pollutants is increasing [3]. Emissions from road operations cause many human health effects and environmental pollutions of air, water and soil pollution [4]. Sources of heavy metals in urban soils and urban road dusts, are anthropogenic sources and include traffic emission (vehicle exhaust, tire wear, street surface, brake wear), industrial emission (power plants, coal combustion, metallurgical industry, etc.) and pavement surface and atmospheric deposition [5].

Christoforidis et al. [6] have shown that the roadside soil samples of the city of Kavala (Greece) from the urban and industrial area contained significant levels of metals (Pb, Cu, Zn, Ni, Cr, Cd, As and Hg) compared to the values from the control site. Faiz et al. [7] have studied the metal pollution level in dust generated on the Islamabad Expressway of Pakistan whereas Cu and Pb had anthropogenic sources. Li et al. [8] investigated the heavy metal contamination of street dusts in Hong Kong. The result of their studies proved that street dusts had highly elevated Zn concentration, particularly along the main trunk roads. The source of Zn in the street dusts may be traffic, especially vehicle tires [8]. Islam et al. [9] assessed levels of metals (Cr, Ni, Cu, As, Cd, Pb) in seven different land use soils in Bangladesh and obtained that ecological risk of the land uses were moderate to very high. As indicated by the ecological risks of each element, As and Cd are responsible for the pollution [9]. Some researchers showed that total trace element levels in all roadside soils even agricultural soils decreased rapidly with increasing distances from the road [10, 11].

In Iran, with the rapid industrialization and population growth during the last two decades, the heavy metal pollution in urban soils and road dusts has turned into a serious issue. Saeedi et al. [12] studied heavy metals (Pb, V, Zn, Ni, Co, Cr, Cd, and Mn) contamination in highway side soils, Tehran, Iran, and the heavy metal contents excluding Cr, Mn and Co were higher than acceptable values in soils.

The main aim of this study was to evaluate the concentration and ecological risk degrees of Cd, Cr, Ni, Pb and Zn and determine properties such as pH, SOM, and CEC of roadside soil from the Hemmat highway of Tehran.

2. MATERIALS AND METHODS

For land use, 7 stations located at ca. 1 km from each other on both sides of the Hemmat highway were selected. At each station, the soil sampling was conducted at intervals of 0–10, and 10–20 m, so a total of 28 soil samples were collected in July 2014 from the roadside soils (Fig. 1).

Determination of metal concentration. The collected samples were air-dried at room temperature, grounded and sieved through 63 μm nylon sieve. For the total heavy metal

content analysis, 500 mg of each of the dried samples was digested with $HClO_4$, HCl, HNO_3 and HF (Merck brand) [13].

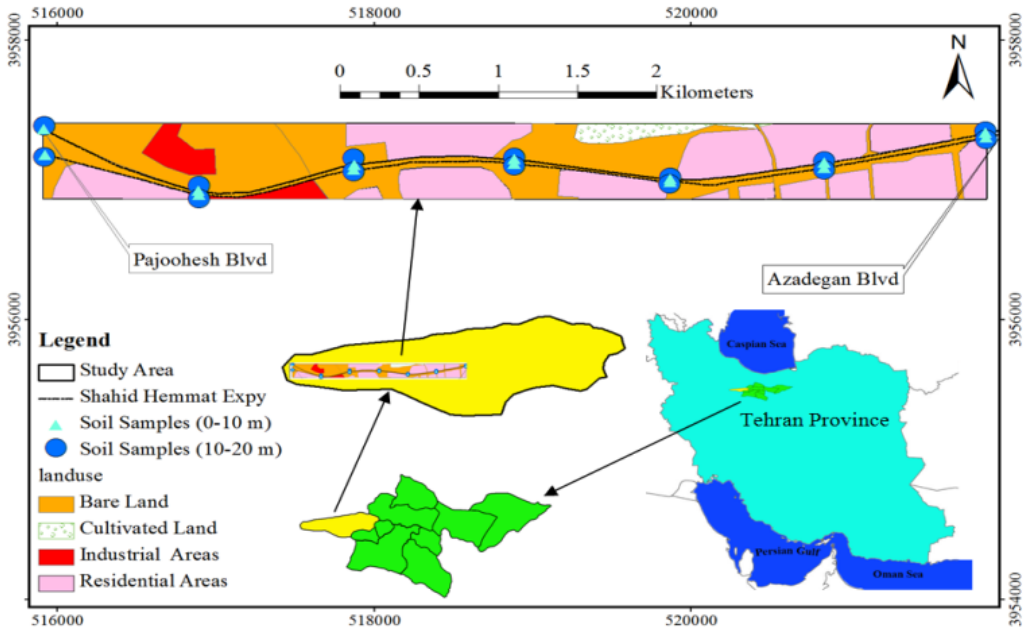

Fig. 1. Map of the study area with sampling stations

For this purpose, a dry sample was weighed into a Teflon beaker and 5 cm^3 of HF (23 mol/dm^3) were added to each sample and then boiled slowly on a hot plate in reflux for 20 min, and 5 cm^3 of HNO_3 (14 mol/dm^3), 5 cm^3 of $HClO_4$ (12 mol/dm^3), and 5 cm^3 of HCl (12.5 mol/dm^3) were added until the sample was digested. The digested remains were then transferred to a volumetric flask and were diluted with distilled water to a final volume of 25 cm^3. The digested samples were analyzed for Cd, Ni, Pb, Cu, Zn and Cr by the atomic absorption spectrophotometry (Shimadzu, AA-700 series). All glassware was acid washed for 24 h in 1.5 M HNO_3 and rinsed several times with twice distilled water before use.

Determination of soil organic matter content. For determination of SOM, the Walkley and Black method was used [14, 15]. 2 g of a dry sample (ground to < 250 μm) was transferred to a 500 cm^3 Erlenmeyer flask and added 10 cm^3 of 0.167 mol/dm^3 $K_2Cr_2O_7$ was added and then 20 cm^3 of concentrated H_2SO_4 and swirl gently to mix. After 30 minutes suspension was diluted with about 200 cm^3 of water to provide a clearer suspension for the endpoint. After that 10 cm^3 of 85% H_3PO_4 were added using a suitable dispenser, and 0.2 g of NaF and 10 drops of ferroin indicator with 0.5 mol/dm^3 Fe^{2+} were titrated to a burgundy endpoint.

Determination of cation exchange capacity. For determination of the CEC, the Bower method was used. 4 g of soil sample with 33 cm^3 of sodium acetate was placed in centrifuge tube and then pH was adjusted to 8.2. The soil suspension was shaken for 5 min and after that centrifuged until the supernatant liquid was clear. The supernatant was then vented completely. Excess salt of sodium acetate was washed for 4 times by adding 33 cm^3 of ethanol. The adsorbed sodium was replaced by three extractions with 33 cm^3 of 1 mol/dm^3 ammonium acetate, shacked, centrifuged and liquid was collected in a 100 cm^3 volumetric flask. At the end, sodium concentration was measured using a flame photometer [16].

Determination of pH and evaluation of pollution level of heavy metals. For determination of soil pH, 50 g of soil sample were mixed with 125 cm^3 of deionized water (ratio 1:2.5) and kept for 12 h at room temperature. Then pH was measured using a pH--meter Hana brand [15]. Pollution level of heavy metals in soils was evaluated using the geoaccumulation index (I_{geo}), enrichment factors (*EF*) and ecological risk indexes (*IR*) [10, 17]. I_{geo} was used to evaluate the degree of elemental pollution in the soils from the study area. It was calculated using the formula given by Müller [18]:

$$I_{geo} = \log\left(\frac{C_n}{1.5B_n}\right) \tag{1}$$

where C_n represents the measured concentration of the element n (mg/kg) and B_n is the value of background element n in the soil (mg/kg). The factor 1.5 in the equation is used as the possible variation in background values because of lithogenic effects and weathering [18].

The geoaccumulation index consists of seven grades/classes: $I_{geo} \leq 0$ – unpolluted (class 0), $0 < I_{geo} < 1$ – from unpolluted to moderately polluted (class 1), $1 < I_{geo} < 2$ – moderately polluted (class 2), $2 < I_{geo} < 3$ – polluted (class 3), $3 < I_{geo} < 4$ – heavily polluted (class 4), $4 < I_{geo} < 5$ – from heavily to very heavily polluted (class 5), $I_{geo} \geq 5$ – very heavily polluted (class > 5) [18].

The enrichment factor (*EF*) is the best tool to differentiate the metal source of anthropogenic origin from a natural origin. It was calculated as follows [19]:

$$EF = \frac{C_x}{C_n} \tag{2}$$

where, C_x represents the measured element concentration in urban soil (mg/kg), C_n is its concentration in average natural soil (mg/kg).

Five contamination categories are recognized with respect to the enrichment factor: $EF < 2$ – deficiency to a minimal enrichment, *EF* from 2 to 5 – moderate enrichment, *EF* from 5 to 20 – significant enrichment, *EF* from 20 to 40 – very high enrichment, $EF > 40$ extremely high enrichment [20]. $EF > 10$ suggests that the sources are more likely to be anthropogenic [21].

Ecological risk (*Er*) is introduced to assess the degree of trace elements contamination in soils. *Er* and ecological risk index in a given region (*RI*) [22] were calculated using the following equations:

$$Er = T_i \frac{C_i}{C_0} \tag{3}$$

$$RI = \sum_{i=1}^{n} Er \tag{4}$$

where, n is the number of heavy metals, T_i is the toxic response factor for a given substance (for Cd, Cr and Zn T_i equals 30, 2 and 1, respectively, and 5 for Pb, Cu and Ni [23]), C_i represents metal concentration in surface dusts (mg/kg) and C_0 is the regional background value of heavy metals in surface dusts in this study (mg/kg).

The *Er* was divided into 5 grades [22]: low ($Er < 40$, Er_l), moderate ($40 \leq Er < 80$, Er_m), considerable ($80 \leq Er < 160$, Er_c), high ($160 \leq Er < 320$, Er_h), very high ($Er > 320$, Er_v).

The *RI* was divided into 4 grades [22]: low ($RI < 150$, RI_l), moderate ($150 \leq RI \leq 300$, RI_m), high ($300 \leq RI < 600$, RI_h), very high ($RI > 600$, RI_v).

Statistical analysis and spatial distribution maps. Statistical techniques such as simple statistical analysis, Pearson's correlation coefficient analysis and cluster analysis (CA) were performed using SPSS software version16. In order to model the spatial distribution, Arc GIS 9.3 software was used.

3. RESULTS AND DISCUSSION

3.1. STATISTICAL ANALYSIS

A simple statistical analysis (mean, standard deviation (*SD*), skewness, and kurtosis) was carried out to describe the total heavy metal contents in roadside soil samples (Table 1).

Table 1

Descriptive statistics of the heavy metals in roadside soils [mg/kg]

Metal	Minimum	Maximum	Mean	*SD*	Skewness	Kurtosis	Background [24]
Pb	53.58	370.38	144	89.90	1.067	0.25	100
Cr	10.39	45.90	17.20	9.02	1.95	3.37	75
Ni	10.50	28.13	18.91	6.62	–0.02	–1.83	40
Zn	12.99	173.74	86.84	46.72	–0.07	–0.46	200
Cd	0.44	7.94	3.86	2.02	–0.42	–0.48	0.8

Total Pb, Cr, Ni, Zn, Cd content was 53.58–370.8, 10.39–45.90, 10.50–28.13, 12.99–173.74, 0.44–7.94 mg/kg, respectively, with a mean of 144±89.90, 17.20±9.02,

18.91±6.62, 86.84±46.72, 3.86±2.02 mg/kg, respectively. The mean concentrations of Pb and Cd were considerably higher than the background level and at the same time the mean concentrations of these heavy metals were higher than those found in roadside soils from other regions of Tehran [25].

The skewness and kurtosis values were also determined to identify the heavy metals with the normal or abnormal distribution. Pb, Cr and Cd total concentrations produce the same general abnormal distribution. The skewness coefficients of Pb and Cr were much higher than zero, revealing the positively skewed distribution. This in turn indicated that some relatively high values of Pb and Cr existed in the samples. Pb and Cr exhibited rather positively skewed data, but Ni, Zn and Cd demonstrated negatively skewed data. The skewness coefficients of Ni and Zn were close to zero, indicating that they followed normal distributions.

Table 2

Descriptive statistics of heavy metals depending on the distance from the roadside [mg/kg]

Distance [m]	Metal	Minimum	Maximum	Mean	*SD*	Skewness	Kurtosis
0–10	Pb	55.29	370.38	174.25	107.90	0.59	–1.171
	Cr	10.39	45.90	18.81	10.42	1.64	2.28
	Ni	11.45	28.13	19.32	6.74	–0.05	–1.97
	Zn	18.23	173.74	89.41	46.77	–0.11	–0.141
	Cd	0.44	5.83	3.78	1.96	–0.85	–0.663
10–20	Pb	53.58	218.47	113.75	56.33	0.64	–1.06
	Cr	10.97	38.71	15.60	7.42	2.62	7.8
	Ni	10.50	27.20	18.51	6.73	0.002	–1.97
	Zn	12.99	168.89	84.27	48.29	–0.032	–0.391
	Cd	0.56	7.94	3.95	2.14	–0.149	–0.22

Relationships between the concentrations of heavy metals and the distance from the road are presented in Table 2. The mean concentrations of Pb, Cr, Ni, Zn, and Cd ranged from 174.25±107.90, 18.81±10.42, 19.32±6.74, 89.41±46.77 and 3.78±1.96 mg/kg (0–10 m from the road) to 113.75±56.33, 15.60±7.42, 18.51±6.73, 84.27±48.29 and 3.95±2.14 mg/kg (10–20 m from the road), respectively. The mean concentrations of Pb, Cr, Ni and Zn showed a decreasing trend upon increasing distance from the roadsides influenced by the traffic, while the mean concentrations of Cd increased upon increasing distance from the road. Similarly, Chen et al. [10] showed decreasing of Cu, Pb and Zn concentrations upon increasing distance from the roadsides, while As, Cr and Ni concentrations were independent the traffic. Bai et al. [11] showed that the influences of the vehicle emissions clearly reached 250 m away from the road, showing more serious contamination for Cd and Pb near the road.

In Table 3, the descriptive statistics of the heavy metal concentration (mg/kg) in roadside soils according to the land use type are presented. The highest mean concentrations of Pb, Ni, Zn and Cd were 163.85±98.65; 26.33±0.68; 124.65±26.03; 5.22±1.03 mg/kg, respectively, and found in residential land use while the highest mean concentration of Cr (21.61±16.2 mg/kg) was found at natural land. The highest concentrations of Pb, Cu, Ni and Cr depended on residential road land use and the lowest ones were related to the sample without any special land use.

Table 3

Descriptive statistics of heavy metals in roadside soils depending on the type of land use [mg/kg]

Land use	Metal	Minimum	Maximum	Mean	*SD*	Skewness	Kurtosis
Green space	Pb	68.09	264.21	121.2	65.62	1.753	3.22
	Cr	11.06	29.35	15.83	6.03	1.95	4.06
	Ni	11.32	24.80	15.21	5.92	1.41	–0.04
	Zn	68.06	173.74	113.8	39.04	0.77	–0.8
	Cd	3.67	5.78	4.66	0.74	0.14	–1.29
Residential area	Pb	53.59	296.79	163.85	98.65	0.115	–1.52
	Cr	10.39	29.23	16.40	6.99	1.54	2.34
	Ni	25.45	27.20	26.33	0.68	0.20	–1.42
	Zn	92.05	152.67	124.65	26.03	–0.15	–1.92
	Cd	3.36	6.20	5.22	1.03	–1.38	1.83
Under construction	Pb	75.90	370.38	163.61	97.55	1.58	2.44
	Cr	11.01	28.44	15.89	5.85	1.73	2.82
	Ni	18.87	28.13	22.46	3.32	0.69	–0.65
	Zn	75.88	93.56	84.63	6.87	–0.07	–1.75
	Cd	2.56	7.94	4.46	1.66	1.44	2.45
Natural	Pb	53.58	327.17	128.47	111.13	1.51	1.38
	Cr	10.97	45.90	21.61	16.2	1.05	–1.37
	Ni	10.50	13.29	11.7	1.08	0.58	–1.06
	Zn	12.99	19.45	16.04	2.99	.054	–3.05
	Cd	0.44	0.95	0.65	0.19	0.66	–0.61

3.2. SPATIAL DISTRIBUTION OF HEAVY METALS AND SOIL CHARACTERIZATION

Geospatial methods are the suitable tools in understanding the location of the pollutants which also provide us with a comprehensive picture about their spatial distribution over a study area [20].

Distribution patterns of the main pollutant metals in the roadside soils of Hemmat highway are visualized by a set of concentration maps obtained by processing data in Table 2 and 3 with the Arc GIS 9.3 program (Fig. 2). Concentrations of lead were the

highest ones among those of heavy metals examined in this study, after that concentrations of Zn were also high. Chandrasekaran et al. [20] showed that Cr and Co displayed similar spatial distribution patterns and they were from the same sources, whereas V, Mn, Cr, Ca, and K showed comparatively lower concentration in the soil samples.

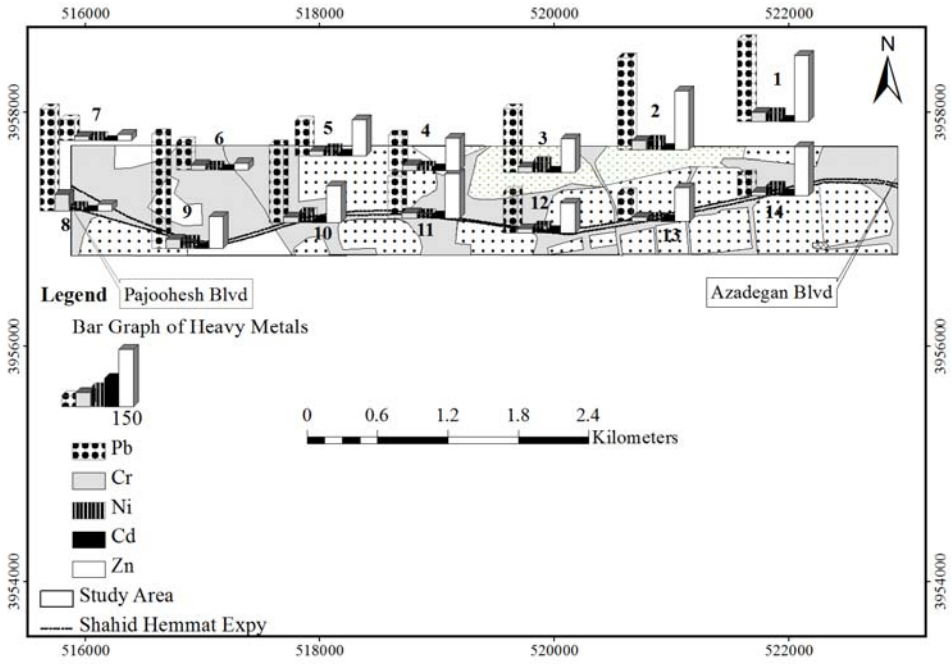

Fig. 2. Distribution map of heavy metals in the roadside soils of Hemmat highway, Tehran, Iran

CEC values for roadside soils of the study area show considerably wide variation from 4.83 to 21.19 meq/dm^3 due to the variations in the clay and organic matter contents of soil sand. The average value of CEC in the soils was 13.16 meq/dm^3.

Table 4

Soil characterization in the study area

Value	pH	CEC [meq/dm^3]	SOM [%]
Average	7.63	13.16	1.34
Maximum	8.3	21.19	2.89
Minimum	7.1	4.83	0.44

A highly productive soil will produce more total biomass than a less productive soil and if much of this biomass remains in the field then the soil is likely to have a higher

organic matter content than a less productive soil. Thus, the soil organic matter is related to the productivity of a soil and hence maintaining organic matter is an objective of many sustainable crop production systems. Since organic matter has a much higher CEC than clay minerals in the soils, a low organic matter content can greatly influence the CEC of soils under study. SOM values for surface soils of study area ranged from 0.44 to 2.89% thus exhibiting wider variation (Table 4). Soil texture, SOM, and carbonate (e.g., $CaCO_3$) showed a close relation to the distribution of the metal fractions which will be changed once these above soil properties are modified [16].

3.3. CORRELATION OF METALS, ENRICHMENT FACTOR, GEOACCUMULATION INDEX AND ECOLOGICAL RISK

Pearson correlation coefficients were calculated (Table 5) in order to establish inter-element relationship in roadside soil samples. Pb concentration was significantly and positively correlated with that of Cr ($r = 0.807$, $p < 0.01$) and Ni ($r = 0.807$, $p < 0.05$), which could indicate common contamination sources for these metals. Moreover, Zn concentration was significantly and positively correlated with Ni ($r = 0.636$, $p < 0.01$) and Cd ($r = 0.657$, $p < 0.01$). Ni concentration showed good correlation with Cd ($r = 0.468$, $p < 0.05$).

Mayuri et al. [26] reported Pb concentration significantly and positively correlated with Cr ($r = 0.83$, $p < 0.01$) and Ni ($r = 0.55$, $p < 0.05$). Zn concentration showed good correlation with Ni ($r = 0.93$, $p < 0.01$). Ni concentration showed good correlation with Cd ($r = 0.85$, $p < 0.01$).

Table 5

Correlation matrix of heavy metals in roadside soil of the Hemmat highway

Metal	Pb	Cr	Ni	Zn	Cd	pH	CEC	SOM
Pb	1							
Cr	0.807[b]	1						
Ni	0.392[a]	0.022	1					
Zn	0.208	–0.037	0.636[b]	1				
Cd	–0.114	–0.378	0.468[a]	0.657[b]	1			
pH	0.012	–0.124	0.030	0.222	0.158	1		
CEC	–0.253	–0.161	–0.229	–0.097	–0.164	–0.180	1	
SOM	–0.308	–0.217	–0.116	–0.114	–0.155	–0.203	0.842[b]	1

[a]Correlation is significant at the 0.05 level (2-tailed).
[b]Correlation is significant at the 0.01 level (2-tailed).

SOM was significantly and positively correlated with CEC ($r = 0.842$, $p < 0.01$). It can be recognized as a major source for heavy metals due to its strong complexing capacity for metallic pollutants [2, 27]. But heavy metals in this study (Pb, Cd, Cr, Ni and

Zn were not significantly correlated with SOM (Table 5), which might be ascribed to lower SOM levels in the this study area. This is in agreement with the results reported by Zhang et al. [2] who presented that SOM was not considered to represent the main carrier of heavy metals in the Yellow River Delta.

Enrichment factor (*EF*) is a good tool to distinguish the metal source of anthropogenic origin from naturally origin in the environment [28]. *EF*s are generally lower than 10 for Ni, Zn and Cr, suggesting that these elements have a natural source in the studied soils [24]. On the other hand, urban soils are contained much higher with Pb and Cd thus exhibiting high *EF*s ($EF > 10$) and suggesting an anthropogenic origin for these elements and strong human influence from various urban activities such as traffic. As indicated in Table 6, the *EF* of all the studied metals for the entire sites was in the descending order of Pb > Cd > Zn > Ni > Cr.

Table 6

Enrichment factor for heavy metals in the soils of the study area

Metal	Minimum	Maximum	Mean	*SD*	Median
Pb	10.36	71.64	27.85	17.39	22.12
Cr	1.00	4.43	1.66	0.87	1.33
Ni	0.93	2.49	1.68	0.59	1.74
Zn	1.12	15.03	7.51	4.04	7.79
Cd	1.29	23.35	11.36	5.93	12.28

The geoaccumulation index (I_{geo}) was calculated for the studied metals and the minimum, maximum and mean of the computed results and pollution level intensity for each of the metals are given in Table 7.

Table 1

Geoaccumulation index for heavy metals in the soils of study area

Metal	Minimum	Maximum	Mean	Class	Intensity of the pollution
Pb	2.79	5.58	3.96	4	heavily polluted
Cr	–0.58	1.56	0.01	1	from unpolluted to moderately polluted
Ni	–0.69	0.73	0.07	1	
Zn	–0.42	3.32	1.98	2	moderately polluted
Cd	–0.21	3.96	2.55	3	polluted

The mean values of I_{geo} for Pb ($3 < I_{geo} < 4$) indicated that these roadside soils were heavily polluted (class 4); while as far as Cr and Ni were concerned, most of the samples were categorized as unpolluted to moderately polluted. The values of I_{geo} for Zn and Cd indicated that the samples were moderately polluted. The mean values of I_{geo} decreased in the order of Pb > Cd > Zn > Ni > Cr. The I_{geo} values for all metals viz. Pb, Zn, Cd in sites with natural use were very low (i.e., I_{geo} of Cd for sites 13 and 14 was –0.21 and

–0.09, respectively), while I_{geo} values of Pb, Zn, Cd metals for other land use (residential area, under construction and green space) were high because these groups of metals were significantly influenced by the urban traffic.

Table 8 summarizes the ecological risk factors (*Er*) and ecological risk indexes (*RI*) based on the mean metals concentrations in roadside soils. The *RI* for roadside soils was higher than 300 ($300 < RI < 600$), indicating that sampling sites having a high ecological risk. The ecological risk for each metal decreases in the following sequence: Cd > Pb > Ni > Zn > Cr (Table 8). Thus, Cd made the highest contribution to the total risk while Cr has the lowest contribution. The risk index showed a decreasing trend with increasing distance from the road on both sides in the Hemmat highway. In general, the Hemmat highway has a high ecological risk index. According to the land use type, the highest ecological risk was found in the residential area followed by under-construction land use while natural land use exhibited the lowest ecological risk (Table 8). The anthropogenic sources are emphasized for the heavy metals, thus indicating the strong human influence in residential area.

Table 8

Ecological risk (*Er*) and indices (*RI*)

Metal	Total *Er*	*Er* at a distance of 0–10 m	*Er* at a distance of 10–20 m	*Er* in green space	*Er* at residential area	*Er* under construction area	*Er* at natural area
Pb	139.27	168.25	110.01	117.18	158.46	158.23	124.25
Cr	3.32	3.63	3.01	3.06	3.17	3.07	4.17
Ni	8.38	8.56	8.20	6.74	11.67	9.96	5.18
Zn	7.51	7.73	7.29	9.84	10.78	7.32	1.39
Cd	340.84	333.47	348.21	411.40	460.15	396.64	57.06
RI	499.32	521.91	476.73	548.21	644.23	572.21	192.05

4. CONCLUSION

The Tehran urban area has been affected by human activity leading to a high accumulation of heavy metals such as Pb and Cd. Except for Cd the mean concentrations of Pb, Cr, Ni and Zn showed a decreasing trend upon increasing distance from the roadsides, that shows the background amount of cadmium in the soil area is high. The highest concentration of heavy metals viz. Pb, Cd, Ni and Cr pertained to residential–road land use and the lowest concentration of the heavy metals was related to the sample with any special land use. Enrichment factor (*EF*) showed that Ni, Zn and Cr, have a natural source while Pb and Cd have an anthropogenic sources. The mean values of geoaccumulation index (I_{geo}) for Pb indicated that soils were heavily polluted; while regarding Cr

and Ni were unpolluted to moderately polluted. Considering Zn and Cd, soil samples were moderately polluted and polluted, respectively. In general, the Hemmat highway had a considerable potential ecological risk. The ecological risk factor for single metal decreases in the following sequence: Cd > Pb > Ni > Zn > Cr. Results of combined multivariate statistical analyses and the distribution maps of the pollutant metals showed that traffic represents the most important contamination source for the studied urban environment.

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