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Assessment of heavy metal contamination in urban soil (Tuzla District, Istanbul, Turkey)

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ABSTRACT

In this study, the heavy metal contamination in the soils of the selected upstate area of Tuzla District, which is located in the Anatolian side of Istanbul, Turkey, was investigated. The current status of the soil was evaluated using geo-accumulation index (I_{geo}), enrichment factor (EF), potential ecological risk (E_r), risk index (RI), and pollution load index (PLI). The average values of I_{geo} for Cu, Pb, Zn, Cd, and Hg were found as 0.310, –0.013, 0.424, –0.115, and 0.087, respectively. According to the I_{geo} classifications, the soil qualities of the study area were determined to be uncontaminated, and uncontaminated to moderately contaminated. The average EF values of these metals were determined to be between 2 to 5, which means that the soil was in moderate enrichment categories. The E_r risk of the soil at the sampling points were defined generally as low ecological risk categories except for the SL1 and SL2 sampling points. SL1 and SL2 were detected to have moderate ecological risk. In addition, the average PLI was found as 1.76, and according to this PLI value, the contamination of study area soil was identified as moderately polluted to unpolluted. Consequently, the results of the study indicated that some locations in the study area were affected by anthropogenic activities.

Keywords: Metal pollution; Pollution indexes; Risk index; Soil contamination

1. Introduction

Urban soils support biodiversity and provide a foundation for infrastructure. Since they act as both a sink and a source of pollutants that may directly or indirectly affect human health, urban soils are important elements in maintaining environmental quality. Therefore, it can be said that they are the key components of urban ecosystems [1]. Heavy metals are one of the most common contaminants in urban soils.

Toxic elements such as Pb, Cd, Cr, Hg, and As, essential elements such as Cu, Zn, Co, Mn, and Ni are the main heavy metal pollutants of urban soils. The heavy metal sources from anthropogenic activities in an urban environment can be listed as traffic emissions, industrial activities, municipal waste disposal, coal power generating plants, and mining and smelting operations, etc [2]. Road traffic (vehicular exhaust emissions) is the possible source of Cu, Pb, Zn, and Cd in urban soils [3,4]. Another source of these heavy metals is the non-exhaust vehicle emissions such as tires and clutch wear [3]. Dust from the tire wear contains Zn, Cd, Co, Cr, Cu, Hg, Mo, Ni, and Pb. The most abundant heavy metal from tire wear is reported to be Zn [5]. The anthropogenic Hg contamination sources are the chloralkali process,

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cement production, mining and smelting, coal burning, and oil refining [6].

If heavy metals are accumulated excessively in the urban soils, they may pose a deterioration to the soil ecosystem, a threat to human health, and produce many other environmental problems. This issue raises concerns about heavy metal contaminated soils in urban environment management [7]. The heavy metal concentrations and their risk assessment in soils are very important issues for human health. Up to now, the heavy metal concentrations and their ecological risk assessments of the urban soils were studied by numerous researchers in the world [8–14]. In such studies, it was reported that urban soil contamination by heavy metals were associated with anthropogenic sources such as industrial activities and traffic emissions. The risk evaluation for soils contaminated by heavy metals in urban areas was carried out using pollution indices such as the EF, geo-accumulation index (I_{geo}), potential ecological risk, etc.

In this study, it was aimed to perform a preliminary assessment of heavy metal pollution (Cu, Pb, Zn, Hg, and Cd) in the topsoil of the upstate area of the Tuzla District, Istanbul, Turkey on an example of a university campus (Istanbul Okan University's Tuzla Campus). Although the selected study area in this work, Istanbul Okan University's Tuzla Campus, was a pristine area outside the district, it has proximity to an airport (the Sabiha Gökçen Airport) and a racetrack (formula 1 (F1) racetrack). Nowadays, there are a limited number of published papers on heavy metal contamination in soils located around international airports [15].

2. Materials and methods

2.1. Study area

The Tuzla District is a small town located on the Anatolian side of Istanbul, and located on a cape on the Marmara Sea on the eastern border of the city (40°50′31.20″ N 29°17′42.00″ E, with a total area of 124,588 km^2, and population of 255,468 thousand). It is the last point on the Anatolian side of Istanbul, which is the largest metropolitan of Turkey. This district away from the city is known for its maritime schools, various universities, shipyards, airports, and formula 1 racetrack. In Tuzla district, there are also five organized industrial sites.

Tuzla Campus of Istanbul Okan University, which is the selected study area in Tuzla district, has ten faculties, a vocational school, eight training centers and various facilities (coffee shop, wellness center, etc). This university campus hosts approximately 14,000 people (students, teaching staff, and administrative staff). The campus area covers about 160,000 m^2. The Sabiha Gökçen Airport, which is an international airport, and the formula 1 (F1) racetrack are about 9 and 1 km away from the campus area, respectively. The closest organized industrial site to the campus area is about 8 km away from the campus, which is Tuzla Organized Industrial Site. The other organized industrial sites are at a distance varied from 14 to 16 km away from the study area.

2.2. Geological background of the study area

The study area is located on the Anatolian side of Istanbul. The Istanbul Paleozoic Sequence (IPS) consists of the Ordovician to lower carboniferous aged, non-metamorphic sedimentary rocks and these rocks cover large areas on both sides of the Bosphorus. The oldest of the IPS is characterized by the fluviatile, lacustrine and possibly lagoonal deposits of the Kocatongel, Kurtkoy and Kinaliada formations [16,17]. The Kurtkoy formation is the oldest formation in the study area and consists mainly of light and dark purple arkosic sandstone, conglomerate and siltstone [16]. The Kurtkoy formation is unconformably overlain by the Quaternary alluvial deposits and artificial fills. In the study area, alluvial deposits are transported by different streams and deposited along their riverbeds. Alluvial deposits are composed of unconsolidated coarse- and fine-grained gravels, sands, silts and clays, organic soils and their mixtures. They have a very heterogeneous and catastrophic stratigraphy in the vertical direction as in the horizontal direction. On the surface of the southern part of the study area, there are artificial fills formed from lithological units and excavation waste of the same region. It is generally composed of gravel-sand-silt-clay mixtures. The study area and the sample locations are given in Fig. 1.

2.3. Soil sampling and chemical analysis

Surface soil samples (0–20 cm depth) were collected from 10 different sampling sites in April 2018 from the Tuzla Campus of Istanbul Okan University in Istanbul-Tuzla district, Turkey. Besides, one reference soil sample was also collected from a rural area that is close to the soil sampling area. Fig. 1 shows the study area and location of the sampling sites.

Soil samples collected from the study area were transported to the laboratory storing in clean polyethylene bags. The soil samples were air-dried, then sieved through a 0.5 mm (30 mesh BS) stainless steel sieve. The concentrations of heavy metals (Cu, Pb, Zn, Hg, Cd, and Sc) in the soil samples were determined using inductively coupled plasma mass spectrometry at Acme Analytical Laboratory in Vancouver, Canada. Around 5% of the samples were analyzed as internal and external control samples. The variability was determined to be <10%.

2.4. Ecological risk and pollution indexes

2.4.1. Geo-accumulation index (I_{geo})

The I_{geo} has been successfully utilized for the assessment of soil pollution in recent years. This index presents the stage of soil contamination using a comparison with the present and pre-industrial concentrations. The I_{geo}, which was recommended by Muller, can be calculated by Eq. (1) [18,19]:

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

where C_n is the measured concentration of the elements in the soil samples, and B_n is the geochemical reference value. The constant 1.5 given in the equation is used to consider the potential differences in the reference values since they are influenced by natural fluctuations and anthropogenic influence [20,21]. Table 1 presents Muller's classification for the assessment of the level of contamination.

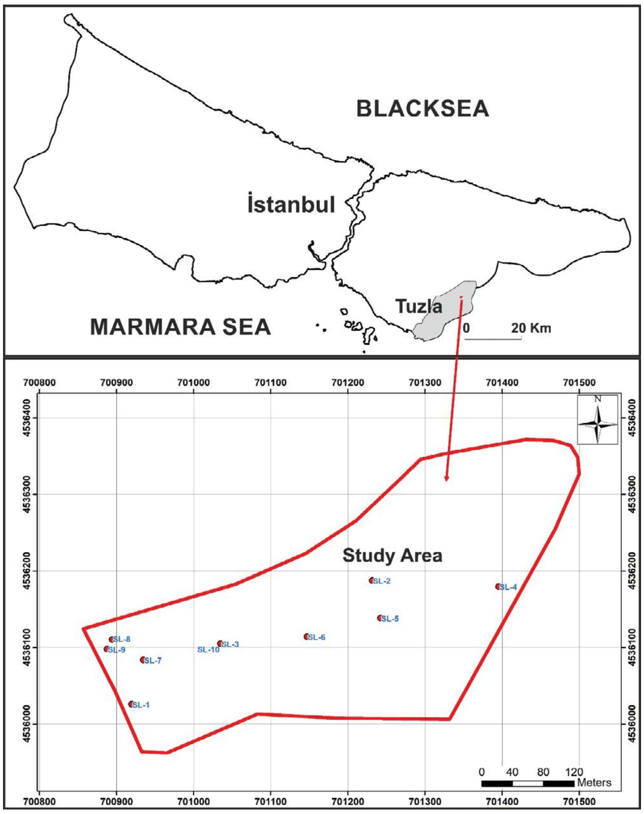


Fig. 1. Study area and location of sampling sites in Tuzla-Istanbul.

2.4.2. EF, ecological risks, and pollution load index

The EF is commonly used for the determination of the potential impact of the heavy metals on the soil samples. In addition, EF is also used for the identification of the sources as natural or anthropogenic sources for heavy metals. The EF of an element in a studied sample is based on the standardization of a measured element against a reference element. The reference element is often characterized by low occurrence variability, with the most commonly used elements being Al, Fe, Ti, Sc, Si, Sr, and K. In this study, Sc was selected as the reference element.

A value of EF close to 1 indicates natural origin, whereas values higher than 10 are considered to originate mainly from anthropogenic sources. The EF analysis is shown in Table 1. The EF of each heavy metal was calculated according to Eq. (2) [22]:

$$EF = \frac{\left(\frac{C_x}{C_{\text{ref}}}\right)\text{sample}}{\left(\frac{C_x}{C_{\text{ref}}}\right)\text{background}} \quad (2)$$

where (C_x/C_{ref}) is the ratio of concentrations between heavy metal and a reference metal in the sample and background soil.

The evaluation of the ecological risk index (RI) of heavy metals, which was originally introduced by Hakanson [23], was conducted in the soil samples' contamination studies. The RI was calculated from Eqs. (3)–(5):

$$\text{RI} = \sum_{i=1}^{m} E_r \quad (3)$$

$$E_r = T_r \times C_f \quad (4)$$

$$C_f = \frac{C_s}{C_n} \quad (5)$$

where C_s and C_n are the heavy metal sample and background concentrations, respectively, E_r is the ecological risk of each element, and RI shows the ecological risk of multiple elements. Hakanson [23] defined T_r as a "toxic-response factor" for a given substance and demonstrated this value for Cu, Pb, Zn, Hg, and Cd to be 5, 5, 1, 40, and 30, respectively. The E_r and RI values and the means of these values are given in Table 1.

Table 1
I_{geo} classifications, categories of EF values, potential ecological risk categories of E_r and RI values, pollution level of PLI value

I_{geo} classifications		
I_{geo} value	Class	Soil quality
$I_{geo} \leq 0$	0	Uncontaminated
$0 < I_{geo} \leq 1$	1	Uncontaminated to moderately contaminated
$1 < I_{geo} \leq 2$	2	Moderately contaminated
$2 < I_{geo} \leq 3$	3	Moderately to heavily contaminated
$3 < I_{geo} \leq 4$	4	Heavily contaminated
$4 < I_{geo} \leq 5$	5	Heavily to extremely contaminated
$5 < I_{geo}$	6	Extremely contaminated
Enrichment categories of EF values		
EF value		Enrichment category
EF ≤ 2		Minimal enrichment
2 < EF ≤ 5		Moderate enrichment
5 < EF ≤ 20		Significant enrichment
20 < EF ≤ 40		Very high enrichment
40 < EF		Extremely high enrichment
E_r and RI values		Ecological risk category
$E_r < 40$		Low potential ecological risk
$40 \leq E_r < 80$		Moderate potential ecological risk
RI < 150		Low ecological risk
150 ≤ RI < 300		Moderate ecological risk
300 ≤ RI < 600		Considerable ecological risk
600 < RI		Very high ecological risk
PLI		
0 < PLI ≤ 1		Unpolluted
1 < PLI ≤ 2		Moderately to unpolluted
2 < PLI ≤ 3		Moderately polluted
3 < PLI ≤ 4		Moderately to highly polluted
4 < PLI ≤ 5		Highly polluted
5 < PLI		Very highly polluted

The pollution load index (PLI) was used to effectively determine whether metal contamination was present at the sample location or not, and aimed at providing a measure of the degree of the overall contamination at the sampling site [24]. To calculate the PLI in the samples, the following formula was used:

$$\text{PLI} = \sqrt[n]{C_{f1} \times C_{f2} \times C_{f3} \times \ldots\ldots \times C_{fn}} \tag{6}$$

where C_f is the contamination factor, and n is the number of elements. Generally, a PLI value > 1 indicates a polluted soil, whereas <1 indicates no pollution [25]. More detailed information on PLI values, which was reported by Jorfi et al. [26], is given in Table 1. C_f is calculated using Eq. (5).

3. Result and discussion

3.1. Metal concentrations

The concentrations of heavy metals (Cu, Pb, Zn, Hg, and Cd) and reference metal (Sc) in the soil samples are presented in Table 2. In addition, the spatial distributions of concentrations of the studied metals (Cu, Pb, Zn, Hg, and Cd) are given in Fig. 2. As can be seen in Table 2, the mean concentrations of Cu, Pb, Zn, Hg, Cd, and Sc were calculated as 50.48, 34.29, 122.57, 0.05, 0.16, and 3.62 mg/kg, respectively. The mean concentrations of heavy metals in the soils of the selected study area were compared with the soils of Istanbul and neighbor province/district of Tuzla, the soils around various international airports in the world, different international soil guidelines, Europe soils, world soil, and earth's crust average values. These data are given in Table 3.

As can be seen from Table 2, the heavy metal (Cu, Pb, Zn, Hg, and Cd) concentrations in the sampling sites of SL1 are higher than those in the other sampling sites. The Zn concentrations in the sampling sites of the SL1, SL8, SL2, SL4, and SL10 were higher than those in the other soil samples in the study area, which were 396.00, 214.00, 103.00, 84.00, and 95.00 mg/kg soil, respectively. Cu concentrations in the sampling sites of the SL1, SL2, and SL8 were higher than those in the other soil samples, which were 188.20 mg/kg soil, 59.70 mg/kg soil, and 57.70 mg/kg soil, respectively.

Table 2
Mean values of the metal concentrations (mg/kg) in the soil samples

Sampling point	Cu	Pb	Zn	Hg	Cd	Sc
SL1	188.20	53.40	396.00	0.06	0.40	2.40
SL2	59.70	34.10	103.00	0.04	0.20	3.00
SL3	32.30	24.80	68.00	0.03	0.10	4.60
SL4	36.10	45.80	84.00	0.15	0.10	3.10
SL5	29.30	38.40	85.00	0.04	0.20	2.80
SL6	23.20	26.40	53.70	0.03	0.10	4.50
SL7	23.30	30.00	60.00	0.04	0.09	3.60
SL8	57.70	36.60	214.00	0.04	0.10	3.00
SL9	21.60	30.90	67.00	0.03	0.09	4.40
SL10	33.40	22.50	95.00	0.03	0.20	4.80
Mean	50.48	34.29	122.57	0.05	0.16	3.62

When the mean concentrations of heavy metals in the soils of the selected study area were compared with the other districts/areas of Istanbul and neighbor province/district of Tuzla, it was seen that the mean concentrations of Cu, Pb, Zn, and Cd in the soils of the selected study area were lower than those in the soil samples taken from various sites of Europian and Anatolian Sides of Istanbul [27], Gebze-Kocaeli (Neighbor province of Tuzla) [28], and Dilovası district of Gebze-Kocaeli where intensive industrialization takes place [29]. On the other hand, the mean concentrations of these heavy metals, except for the mean value of Cd, were higher than those in the soils in the Avcilar district (Europian Side of Istanbul) [30]. The mean concentrations of Cu and Pb were higher than those in the soils around industrial regions in Istanbul (Europian Side of Istanbul) [31].

When the mean concentrations of Cu, Pb, Zn, Hg, and Cd in the soils of the selected study area were compared with those in the soils around various international airports in the world, it was seen that the mean concentrations of Cu, Pb, and Zn were higher than those in the soils around International Hatay Airport, Hatay [32] and Queen Alia International Airport, Amman [33]. The mean concentrations of Cu and Zn in the soils of the study area were higher than those in the soils around the International Athens Airport "El. Venizelos [15,34], and Delhi (IGI) Airport, Delhi [35], respectively (Table 3).

When the mean concentrations of heavy metals in the soils of the selected study area were compared with different international soil guidelines (soil quality guidelines of Swedish, Canada, and Dutch) [37–39], it was seen that the mean concentrations of Cu, Pb, Zn, Hg, and Cd did not exceed their limits for the international soil guidelines listed in Table 3. The mean concentration of Cu was only higher than the target values of the Dutch soil guidelines [39].

The mean concentrations of Cu, Pb, Hg, and Cd in the soils of the selected study area were found to be higher than the values of Cu, Pb, Hg, and Cd in Europe soils [40]. In this study, the mean concentrations of Hg present in the soil samples were found to be lower than those in the world soil [41], and the Earth's crust mean values [42]. However, the mean concentrations of Cu, Pb, and Zn present in the soil samples exceed the world soil and the Earth's crust mean values, suggesting Cu, Pb, and Zn contamination probably by anthropogenic activities. Accordingly, it can be said that the emissions associated with the existence of the airport and the racetrack may be contributed to the enrichment of Cu, Pb, and Zn in the soils of the study area. Massas et al. [15,34], in their studies which were carried out for the investigation of heavy metal enrichment in soils nearby the international Athens airport, reported that the busy airplane traffic at the airport, the aircraft maintenance, and the traffic load within and around the airport may lead to the increase of the concentrations of Cu, Pb, and Zn in the soils in vicinity of the airport. According to the results of the study of Vander Wal et al. [43], the exhaust emissions of different aircraft contain N, S, Na, Ca, Zn, Ba, Sn, Cr, and Al in various amounts. In a study on levels of the airborne particulate matter at around El Prat, Barcelona Airpot by Amato et al. [44], it was revealed that the high organic carbon levels, Ba, Zn, Mo, and Cu may be originated from the smoke in the runway, dust from the tire wear of aircraft, and dust from the brake wear of aircraft.

Table 3
Comparison of heavy metal concentrations in the study area

Istanbul and neighbor province/ district of Tuzla	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Hg (mg/kg)	Cd (mg/kg)	References
Istanbul-Tuzla (Anatolian side of Istanbul)	50.27	33.88	122.10	0.05	0.16	This study
Istanbul-Avcilar (Europian side of Istanbul)	26.75	21.23	80.89	0.03	0.16	[30]
Istanbul-Around of industrial regions (Europian side of Istanbul)	30.5	17.70	207.60	No data	0.46	[31]
Various districts of Istanbul (Europian and Anatolian side of Istanbul)	25.26–71.03	27.4–51.55	47.46–81.61	No data	0.53–1.02	[27]
Gebze-Kocaeli (N.P.T.)	95.88	246	632	0.10	4.41	[28]
Dilovası district of Gebze-Kocaeli (N.P.T.)	6.85–111.24	15.33–444.27	56.01–2,580	0.02–0.51	0.03–2.05	[29]
Vicinity of the international airports in the world	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Hg (mg/kg)	Cd (mg/kg)	References
Queen Alia International Airport (Amman, Jordan)	1.91	26.00	25.70	No data	2.33	[33]
International Athens airport "El. Venizelos" (Greece)	27	79	95.2	No data	No data	[15,34]
Shanghai Airport (Shanghai, China)	25	81	186	No data	1.9	[36]
International Hatay Airport (Turkey)	1.0–5.35	0.04–1.45	0.10–3.14	No data	0.06–0.70	[32]
Delhi (IGI) Airport (India)	21.3	37.5	97	No data	2.26	[35]
Different soil guidelines	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Hg (mg/kg)	Cd (mg/kg)	References
Swedish limits for soil (slightly serious)	<100	<80	<350	<1	<0.4	[37]
Canadian soil guidelines (land use: residential)	63	140	200	6.6	10	[38]
Dutch soil guidelines (target values)	36	85	140	0.3	0.8	[39]
Dutch soil guidelines (intervention values)	190	530	720	10	12	[39]
Europe soils, world soil and earth's crust	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Hg (mg/kg)	Cd(mg/kg)	References
Europe soils	13.01	15.03	No data	0.04	0.09	[40]
World soil	14	25	62	0.1	1.1	[41]
Earth's crust average value	39	17	67	0.08	0.1	[42]

N.P.T.: Neighbor Province of Tuzla.

3.2. Ecological risk and pollution indexes

In this study, I_{geo}, EF, ecological risk index (E_r and RI) and PLI were calculated according to the heavy metal concentrations of the soil samples. The I_{geo} values are given in Table 4, and the mean I_{geo} values of Cu, Pb, Zn, Cd, and Hg were determined to be 0.310, –0.013, 0.424, –0.115, and –0.087, respectively. These results indicated that the soil contamination levels for Cu and Zn were determined to be uncontaminated to moderately contaminated since the I_{geo} values were found to be between 0 and 1. On the other hand, soil contamination levels for Pb, Cd, and Hg were found to be uncontaminated since the I_{geo} values of these metals were calculated to be lower than 0. The I_{geo} results and the spatial distribution of I_{geo} of all the metals are given in Table 4 and Fig. 3, respectively.

The EF values are used as an indicator of soil pollution in the last years. Therefore, the EFs of each metal were calculated for all the soil samples using the local reference soil sample. Sc was selected as a reference metal, and its concentrations in the soil samples were used for the EF values, which are given in Table 5. The EF mean values of Cu, Pb, Zn, Cd, and Hg were calculated as 3.55, 2.08, 3.65, 2.21, and 2.23, respectively. The EF mean values of all the investigated heavy metals in the soil samples were determined to be between 2 to 5, which means moderate contamination. These results showed that the sources of Cu, Pb, Zn, Cd, and Hg were probably from anthropogenic activities [45].

To assess the soil contamination, the ecological risk of each heavy metal (E_r) and potential ecological risk index (RI) values were calculated and listed in Table 6. The spatial distribution of the RI in the soils of the study area is shown in Fig. 4. The mean values of E_r for Cu, Pb, Zn, Cd, and Hg were 11.96, 7.69, 2.50, 47.40, and 65.33, respectively. According to the RI values given in Table 6, the ecological risk levels were determined to be low, except for SL1 and SL4. Also, moderate ecological risk levels were defined for SL1 and SL4 with respect to the calculated RI values.

The location of SL1 was close to a car washing service. The moderate ecological risk level for SL1 may be attributed to the proximity of the sampling site SL1 to the car washing service. As stated by Rai et al. [46], vehicle washing activities cause environmental heavy metal contamination. Wastewater generated during the car washing activities contains heavy

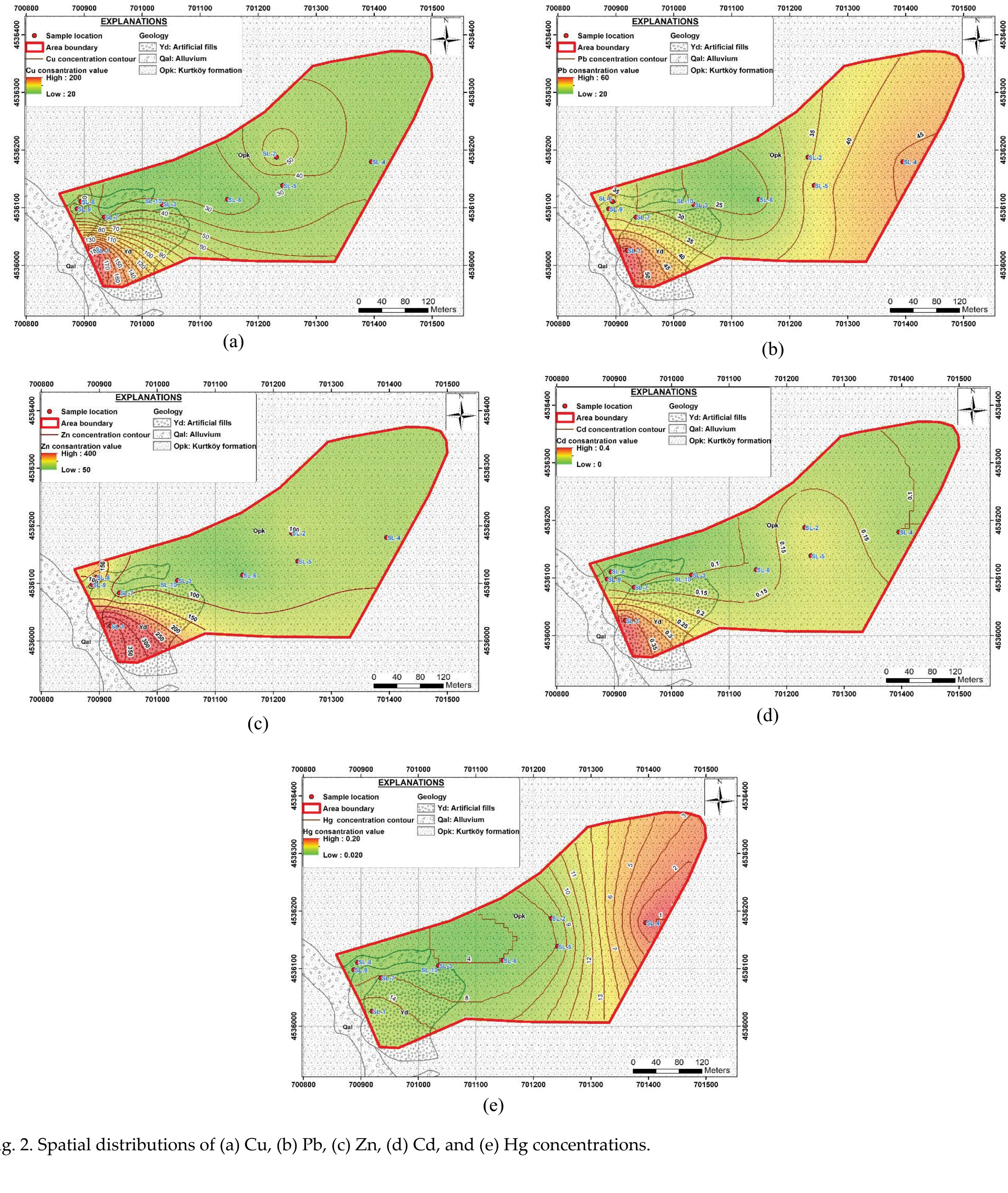


Fig. 2. Spatial distributions of (a) Cu, (b) Pb, (c) Zn, (d) Cd, and (e) Hg concentrations.

metals such as Cu, Pb, Zn, and Cd arising from the washing of worn brake linings, tires, vehicle exhausts, and fluid leakages [47–49]. The location of S4 was close to the entrance gate of the university campus. The motor vehicles that stop, start, and accelerate at the entrance gate of the university campus may help to explain the moderate ecological risk level for the soil sample (SL4) around the entrance of the university campus. As stated by Adamiec et al. [5], the emission of particles occurs during rapid braking. The most excessive brake wear appears at traffic lights, intersections, corners, and during forced braking [5]. The brake dust and tire dust particles may accumulate on the road surface and be resuspended. They accumulate in roadside soils that cause heavy metal contamination [50]. Fe, Cu, Ba, and Pb are the

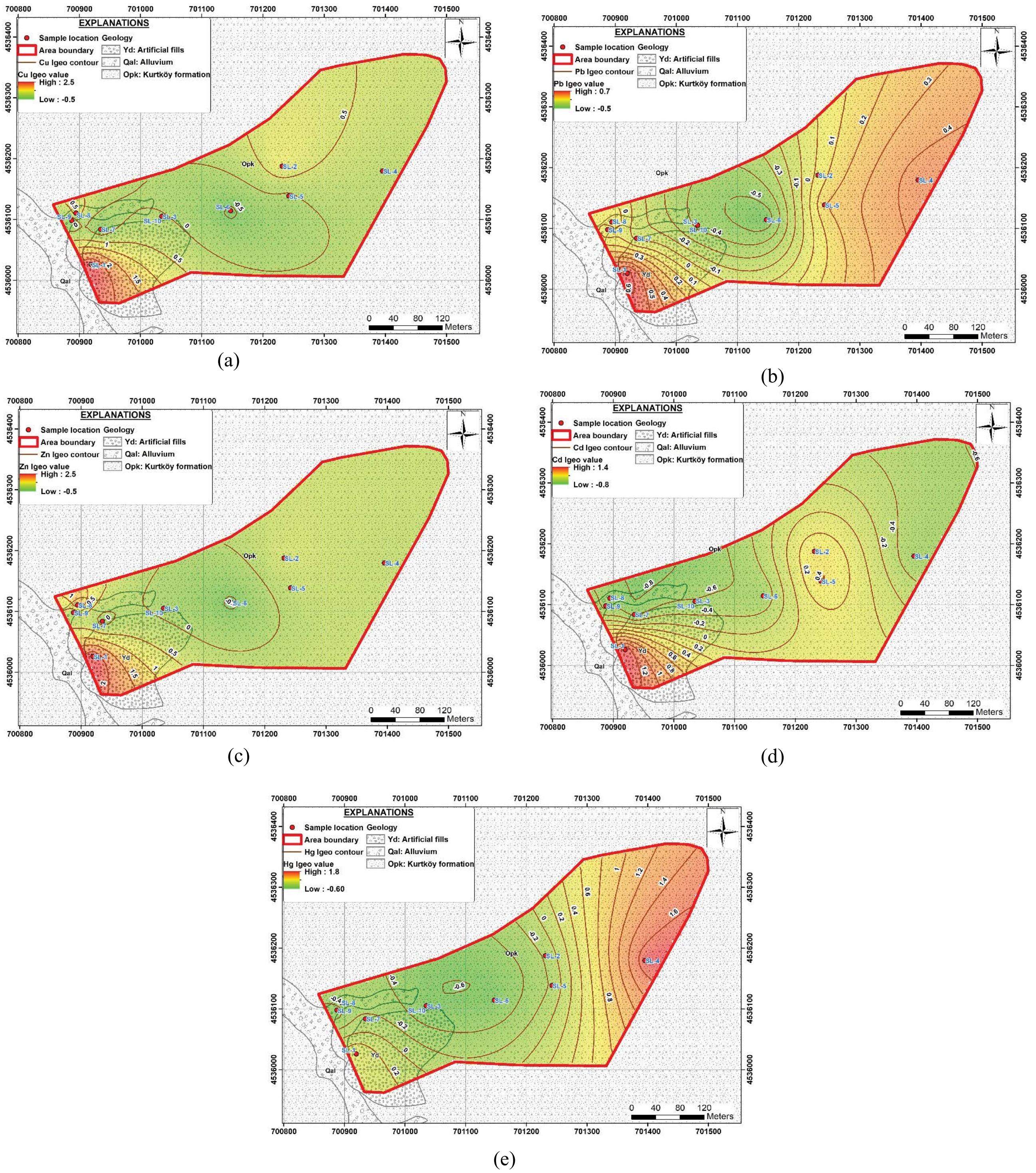


Fig. 3. Spatial distributions of I_{geo} values for (a) Cu, (b) Pb, (c) Zn, (d) Cd, and (e) Hg.

most important chemical constituents of brake wear [51]. Zn is associated with brake lining particles [52]. The sources of Cu and Zn are tire abrasion as well as lubricants and the corrosion of vehicular parts [53]. Zn was the most abundant heavy metal from tire wear [54]. According to Thorpe and Harrison [50], tire wear is a major contributor to Zn in the urban environment. The abrasion of tires and brake lining wear are among the possible sources of Cd [54].

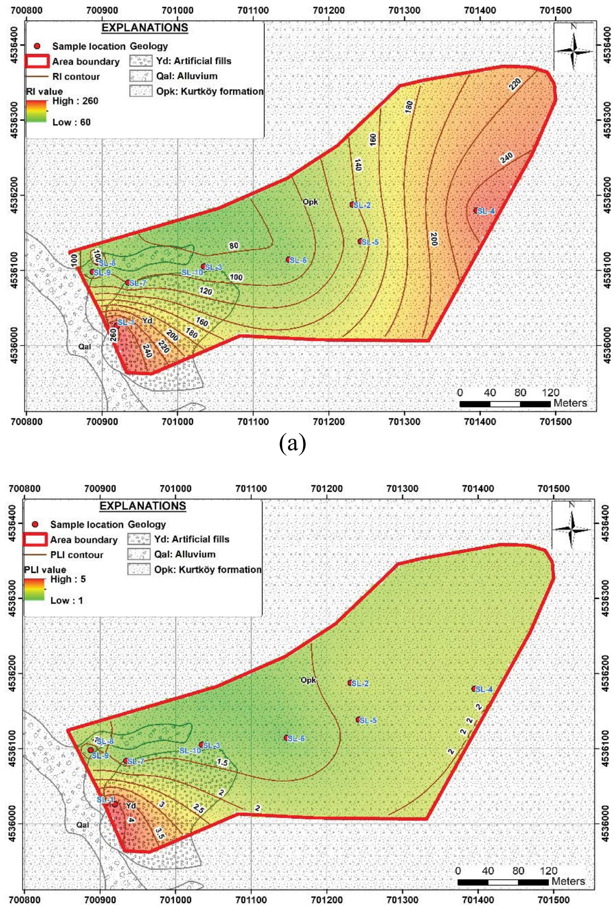
The PLI is generally used to effectively compare the sample location of the metal contamination. Also, this index is used for providing a measure of the degree of the overall contamination at a sampling site [18]. Table 7 shows the results of

Table 4
I_{geo} results

Sampling point	Cu	Pb	Zn	Cd	Hg
SL1	2.572	0.675	2.430	1.415	0.415
SL2	0.916	0.028	0.487	0.415	–0.170
SL3	0.029	–0.432	–0.112	–0.585	–0.585
SL4	0.190	0.453	0.193	–0.585	1.737
SL5	–0.111	0.199	0.210	0.415	–0.170
SL6	–0.448	–0.341	–0.453	–0.585	–0.585
SL7	–0.442	–0.157	–0.293	–0.737	–0.170
SL8	0.866	0.130	1.542	–0.585	–0.170
SL9	–0.551	–0.114	–0.134	–0.737	–0.585
SL10	0.078	–0.572	0.370	0.415	–0.585
Mean	0.310	–0.013	0.424	–0.115	–0.087

Table 5
EF values

Sampling point	Cu	Pb	Zn	Cd	Hg
SL1	16.35	4.39	14.82	7.33	3.67
SL2	4.15	2.24	3.08	2.93	1.96
SL3	1.46	1.06	1.33	0.96	0.96
SL4	2.43	2.92	2.43	1.42	7.10
SL5	2.18	2.71	2.73	3.14	2.10
SL6	1.08	1.16	1.07	0.98	0.98
SL7	1.35	1.64	1.50	1.10	1.63
SL8	4.01	2.41	6.41	1.47	1.96
SL9	1.02	1.39	1.37	0.90	1.00
SL10	1.45	0.92	1.78	1.83	0.92
Mean	3.55	2.08	3.65	2.21	2.23



(a)

(b)

Fig. 4. Spatial distributions for (a) RI and (b) PLI.

Table 6
Ecological risk factors (E_r) and the potential ecological risk index (RI) of Cu, Pb, Zn, Hg, and Cd in the soil samples

	E_r					RI	Ecological risk
	Cu	Pb	Zn	Cd	Hg		
SL1	44.60	11.97	8.08	120.00	80.00	264.65	Moderate ecological risk
SL2	14.15	7.65	2.10	60.00	53.33	137.23	Low ecological risk
SL3	7.65	5.56	1.39	30.00	40.00	84.60	Low ecological risk
SL4	8.55	10.27	1.71	30.00	200.00	250.54	Moderate ecological risk
SL5	6.94	8.61	1.73	60.00	53.33	130.62	Low ecological risk
SL6	5.50	5.92	1.10	30.00	40.00	82.51	Low ecological risk
SL7	5.52	6.73	1.22	27.00	53.33	93.81	Low ecological risk
SL8	13.67	8.21	4.37	30.00	53.33	109.58	Low ecological risk
SL9	5.12	6.93	1.37	27.00	40.00	80.41	Low ecological risk
SL10	7.91	5.04	1.94	60.00	40.00	114.90	Low ecological risk
Mean	11.96	7.69	2.50	47.40	65.33	134.89	–

the PLI for the investigated metals at these sample locations and the spatial distribution of the PLI are presented in Fig. 4. PLI values of the soil samples were found to be higher than 1, and lower than 2 except for SL1. The PLI value of SL1 (close to the car washing service) was calculated to be between 4 to 5. According to the PLI classifications, the contamination level of SL1 was determined to be very highly polluted and other locations were found to be moderately to unpolluted level.

Table 7
Results of C_f and PLI of the soil samples

	C_f					PLI
	Cu	Pb	Zn	Cd	Hg	
SL1	8.92	2.39	8.08	4.00	2.00	4.25
SL2	2.83	1.53	2.10	2.00	1.33	1.89
SL3	1.53	1.11	1.39	1.00	1.00	1.19
SL4	1.71	2.05	1.71	1.00	5.00	1.98
SL5	1.39	1.72	1.73	2.00	1.33	1.62
SL6	1.10	1.18	1.10	1.00	1.00	1.07
SL7	1.10	1.35	1.22	0.90	1.33	1.17
SL8	2.73	1.64	4.37	1.00	1.33	1.92
SL9	1.02	1.39	1.37	0.90	1.00	1.12
SL10	1.58	1.01	1.94	2.00	1.00	1.44
Mean	2.39	1.54	2.50	1.58	1.63	1.76

4. Conclusion

In this study, the concentrations of heavy metals (Cu, Pb, Zn, Hg, and Cd) in the soils of the selected study area, which is located around the airport and organized industrial site, and close to the racetrack, in Tuzla-Istanbul were determined. The contamination levels of the heavy metals and potential ecological risks were assessed. The mean concentrations (mg/kg) of heavy metals showed a descending order of Zn (122.57) > Cu (50.48) > Pb (34.29) > Cd (0.16) > Hg (0.05), which were found to be higher than the earth's crust average value except for the mean concentration of Hg. However, when the mean values of heavy metals were compared with the different international soil guidelines (soil quality guidelines of Swedish, Canada, and Dutch), it was seen that the mean values of the studied heavy metals did not exceed the values of the Swedish, Canadian and Dutch soil quality guidelines. On the other hand, the mean value of Cu was found to be higher than the target values of the Dutch soil guidelines.

The EF values indicated moderate contamination for Cu, Pb, Zn, Cd, and Hg. The RI values suggested a low ecological risk level for all the sampling sites except for the sampling sites SL1 and SL4. According to the PLI values, in the studied area, the contamination levels were found to be moderately to the unpolluted level except for SL1. The SL1 was defined as a very highly polluted area, of which location was near the car washing service. It can be stated that this sampling site (SL1) was under heavy metal contamination pressure.

Consequently, based on the potential ecological risk (RI) and pollution (PL) indexes, it may be said that since the heavy metals (Cu, Pb, Zn, Hg, and Cd) pose a low ecological risk, and the studied area is moderate to unpolluted, the soils of the study area were not affected prominently by airport and racetrack close to the study area.

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