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Assessment of Heavy Metal Risk in Urban Soils of the Kan Area (District 5), Tehran, Iran: A Multi-Index Approach

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ABSTRACT

The objective of this study was to quantify the concentrations and spatial variability of heavy metals in soils at urban stations in Kan (District 5, Tehran, Iran). Eight composite soil samples (40 points) were collected using a five-point (10×10 m) design and analyzed after four-acid total digestion (HCl-HNO3-HF-HClO4) by inductively coupled plasma mass spectrometry (ICP-MS). Contamination and risk were evaluated using the pollution load index (PLI), contamination factor (CF), geoaccumulation index (Igeo), modified degree of contamination (mCd), potential ecological risk index (PER), and the mean effects range–median quotient (mean-ERM-Q) as a screening tool for mixture toxicity. Exploratory inter-element relationships were further examined using correlation analysis. In addition, screening carcinogenic risk for Pb was estimated. Results showed, lead had the widest range (26–129 mg/kg), with hotspots at the traffic intersection and nearby urban activity nodes, while Cu peaked at stations influenced by localized workshop-related activities. The correlation matrix showed positive associations for Co-Ni, Cr-Ni, Cr-Zn, Cu-Zn, and Cd-Pb (unadjusted $p < 0.05$), suggesting mixed lithogenic and urban co-enrichment patterns. CF and Igeo identified Pb as the dominant pollutant (CF>6 and Igeo>2 at hotspot stations). PLI ranged from 0.84 to 1.48, indicating overall low-to-moderate pollution with spatially concentrated enrichment. PER values remained below the commonly used threshold of 150, suggesting low ecological risk overall, whereas mean-ERM-Q values (0.200–0.389) fell in the 0.11–<0.5 class, corresponding to an estimated ~21% probability of toxicity. Screening ILCR for Pb ranged from 1.12E-05 to 5.58E-05, and all stations remained within the commonly used acceptable risk-management range of 1E-06 to 1E-04. These findings provide baseline evidence of hotspot-driven metal enrichment in Kan soils and support targeted monitoring and management in rapidly urbanizing districts.

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INTRODUCTION

Heavy metal contamination of environmental media is a major global concern because many toxic elements are persistent, non-biodegradable, and capable of accumulating in ecosystems and food chains (Khan et al., 2021; Shariati and Shariati, 2025). Numerous monitoring studies have reported elevated concentrations of heavy metals in agricultural and urban soils due to mining activities, industrial emissions, traffic, wastewater irrigation, waste disposal, and intensive use of agrochemicals (Hou et al., 2025; He et al., 2024). Urban soils are particularly important sinks for metals because atmospheric deposition and urban runoff continuously introduce contaminated particles from multiple anthropogenic sources. In urban environments, major inputs

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include traffic-related emissions (especially non-exhaust particles from brake, tyre, and road wear), industrial and commercial activities, construction materials, waste burning, and legacy contamination from the historical use of leaded gasoline and lead-based paints (Piscitello et al., 2021; Centers for Disease Control and Prevention, 2024). These contaminants can be resuspended as fine soil and dust particles, increasing human exposure through inhalation and inadvertent ingestion—particularly among children—while chronic exposure has been linked to neurological, renal, skeletal, and carcinogenic health effects (World Health Organization, 2025; Kotnala et al., 2025). Consequently, evaluating contamination levels and associated risks of soil-borne metals is essential for effective urban environmental management. In Iran, rapid urbanization, industrialization, and intensive land use have increased concerns about soil contamination by potentially toxic elements (Faraji et al., 2023). Previous studies have reported moderate to very high ecological risks in several agricultural, industrial, and urban areas, with Cd and Pb frequently contributing to exceedances of environmental guideline values (Faraji et al., 2023; Keshavarzi et al., 2019). Tehran, the largest metropolitan area in Iran, has often been identified as a hotspot of metal pollution. Investigations of street dust and roadside soils have shown enrichment of Cd, Cu, Pb, and Zn, with pollution load index (PLI) values frequently exceeding 1, indicating anthropogenic contamination mainly related to traffic and urban activities (Taghavi et al., 2019; Mahmoudabadi et al., 2015). A recent meta-analysis of urban dust also highlighted strong human influences on metal accumulation in major Iranian cities, while pointing out the need for more detailed soil assessments in some districts of Tehran (Khademi et al., 2023).

The Kan catchment, located in the northwestern part of Tehran Province, is a mountainous watershed that provides important environmental and ecosystem services to the metropolitan region. Within this watershed, the Kan area in District 5 has experienced rapid urban development, expansion of transportation infrastructure, recreational activities, and localized agriculture. Previous research in the Kan catchment has mainly focused on soil quality, erosion processes, and geomorphological controls on land degradation (Derakhshan Babaei et al., 2021), while information on heavy metal contamination in surface soils remains limited. Considering the increasing urban activities, traffic corridors, and runoff pathways in this district, surface soils may receive metal inputs from atmospheric deposition, road dust, and local service-related activities. In addition to ecological impacts, contaminated soils can pose potential human health risks through soil ingestion, dermal contact, and inhalation of resuspended particles, particularly for toxic elements such as Pb. To address the lack of detailed data for this rapidly developing district, the present study investigates heavy metal contamination in surface soils of the Kan area. The objectives are to: (i) determine the concentrations and spatial variability of ten potentially toxic elements (As, Zn, Mn, Cd, Cr, Cu, Ni, Pb, Fe, and Co); (ii) evaluate contamination levels and potential ecological risk using multiple indices; and (iii) estimate screening carcinogenic risk for Pb using an ILCR-based human health risk assessment framework.

MATERIAL AND METHODS

Stations Description and Sampling

The study was conducted in the Kan area located in District 5 of Tehran Province (northwestern Tehran, Iran), within the Kan catchment. Soil sampling was conducted in September 2025 from the surface layer (0–20 cm) (eight stations). All stations were geo-referenced using a handheld GPS, and the geographical coordinates and site descriptions are provided in Table 1. At each station, a composite sampling method was adopted to ensure representativeness; five subsamples were collected from a 10×10 m plot (corners and centers) and mixed thoroughly to form a single composite sample.

Table 1. Description of surface soils in the Kan area (Tehran)

Station	Location Name	Land Use / Potential Source	Latitude	Longitude
S1	Armaghan Park	Urban Green Space / Recreational	35°76′ 33″	51° 28′ 18″
S2	Intersection of Ghaem & Rahim St.	High Traffic / Vehicular Emissions	35° 45′ 29″	51° 16′ 44″
S3	Saraasiab Hosseiniyeh	Religious-Public Gathering / Mixed	35° 45′ 34″	51° 16′ 38″
S4	Saraasiab (near bathhouse)	Residential / Traditional Service	35° 45′ 45 ″	51° 16′ 30″
S5	Opposite Battery Workshop	Industrial / Potential of Acid Leakage	35° 45′ 50″	51° 16′ 50″
S6	Kan Gas Station	Transport Infrastructure / Fueling	35° 45′ 16″	51° 16′ 48″
S7	Paint Workshop	Industrial / Chemical Solvents	35° 45′ 24″	51° 16′ 45″
S8	Nikan Hospital	Sensitive Receptor / Medical Service	35° 45′ 19″	51° 16′ 12″

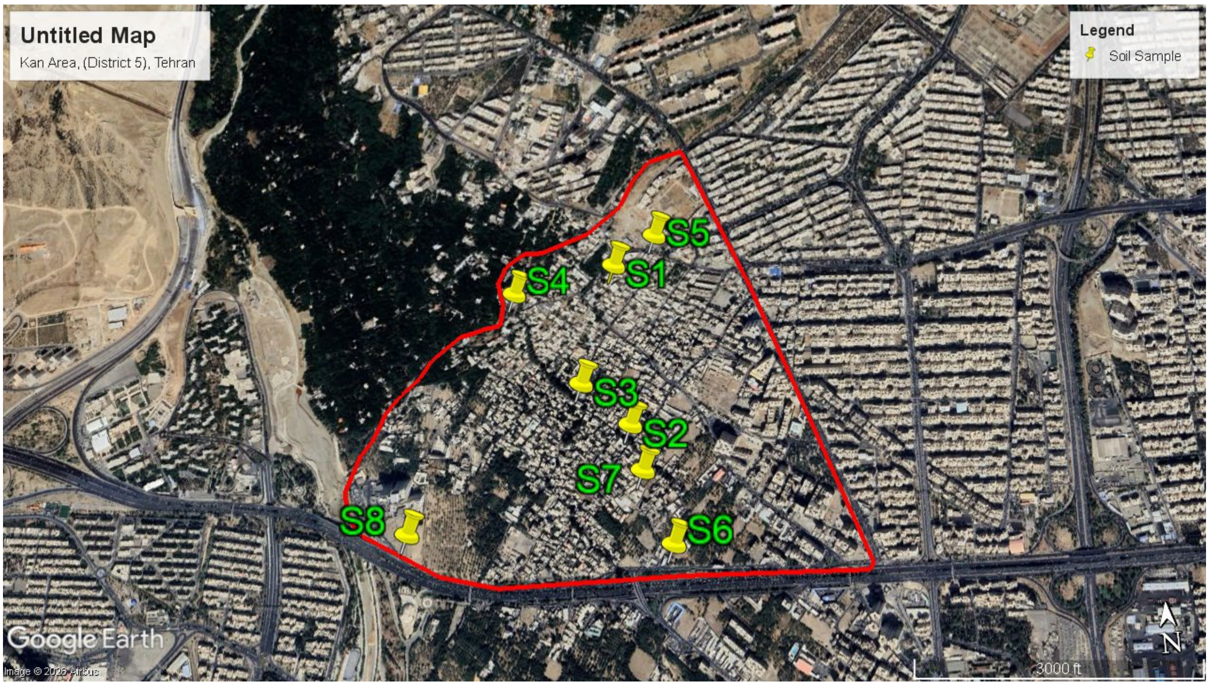

Fig. 1. Location of samples in Kan area (Tehran)

Heavy metal measurement

After air drying, soil samples were oven-dried at 105 °C for 24 h, homogenized, and passed through a 10-mesh sieve. Approximately 1 g of dried soil was weighed into Teflon beakers and subjected to a four-acid total digestion using HCl, HNO_3, HF, and $HClO_4$ to ensure dissolution of silicate lattices (Hossner, 1996; Hseu et al., 2002). The digestion was carried out on a hot plate at high temperature to near dryness to volatilize silicon, after which the residue was re-dissolved in dilute HCl. After cooling to room temperature, the digest was filtered through a 0.45 µm membrane filter, transferred to volumetric flasks, and brought to volume with deionized water. The concentrations of Fe, Mn, Zn, Cu, Cr, Ni, Pb, Cd, As, and Co were quantified using inductively coupled plasma mass spectrometry (ICP-MS, Agilent 736, USA) (EPA 3052) (Shariati et al., 2019; Karimian et al., 2021). Quality assurance and quality control (QA/QC) procedures were applied throughout the analytical process to ensure data reliability. Analytical accuracy was checked using reagent blanks and certified reference materials (CRMs). Instrument calibration was performed using multi-element standard solutions. Recovery rates for the target metals were within an acceptable range.

Heavy metal contamination indexes

Contamination Factor (CF)

The contamination factor (CF) was used to evaluate the contamination level of each heavy metal in the studied soils by comparing the measured concentration in each sample ((C_m)) with the corresponding background/reference concentration (C_b) (Martin & Meybeck, 1979):

$$CF = \frac{C_m}{C_b} \tag{1}$$

Modified degree of contamination (mCd)

To quantify the integrated contamination level at each sampling station considering all analyzed metals, the modified degree of contamination (mCd) was calculated (Abrahim & Parker, 2008).

$$mCd = \left(\sum C_f^i\right) / n \tag{2}$$

Table 2. Description of Contamination Factor (CF) (Hakanson, 1980)

CF	Description
< 1	Low contamination
1–3	Moderate contamination
3–6	Considerable contamination
> 6	Very high contamination

Table 3. Description of modified contamination degree (mCd) (Abrahim & Parker, 2008)

mCd	Description
< 1.5	Zero to very low degree of contamination
1.5–2	Low degree of contamination
2–4	Moderate degree of contamination
4–8	High degree of contamination
8–16	Very high degree of contamination
16–32	Extremely high degree of contamination
≥ 32	Ultra-high degree of contamination

Table 4. Group and description of Geo-accumulation (Igeo)

Class	Igeo	Description
0	<0	Unpolluted
1	0-1	Unpolluted to moderately polluted
2	1-2	Moderately polluted
3	2-3	Moderately to strongly polluted
4	3-4	Strongly polluted
5	4-5	strongly to extremely polluted
6	>6	Extremely

Table 5. Classification of ecological risk (E) and overall potential ecological risk (PER)

Category	E (single metal)	PER (overall)	Description
1	< 40	< 150	Low risk
2	40–<80	150–<300	Medium risk
3	80–<160	300–<600	Significant risk
4	160–<320	≥ 600	High risk
5	≥ 320	—	Very high risk (single-metal)

Geo-accumulation Index (Igeo)

The geo-accumulation index (Igeo) was used to assess metal enrichment relative to background concentrations (Müller, 1969) (Table 4).

$$Igeo = log_2\left[C_n / \left(1.5B_n\right)\right] \quad (3)$$

Pollution Load Index (PLI)

The pollution load index (PLI) was applied to provide an integrated assessment of overall heavy metal pollution at each sampling station. PLI was calculated from the contamination factor (CF) values of the analyzed metals using the geometric mean (Tomlinson et al., 1980):

$$PLI = (CF_1 \times CF_2 \times \ldots \times CF_n)^{\wedge}(1/n) \quad (4)$$

where (n) is the number of analyzed metals and (CF_i) is the contamination factor of metal (i). PLI values were interpreted according to Table 4, where values < 1 indicate unpolluted conditions and values > 1 indicate pollution by heavy metals (Harikumar et al., 2009).

Potential Ecological Risk (PER)

The potential ecological risk (PER) (Table 5) index was used to evaluate the ecological risk posed by heavy metals by integrating contamination levels with metal-specific toxicity (Hakanson, 1980). First, the contamination factor for each metal was computed as:

$$CF = Ca / Cb \quad (5)$$

$$\left[E = T \times C\right] \quad (6)$$

$$\left[PER = \sum Ei\right] \quad (7)$$

where (T) is the toxic-response factor for each metal. T values were adopted from Hakanson (1980) and as applied by Wei et al. (2020): Zn=1, Cr=2, Cu=5, Ni=5, Pb=5, Co=5, Mn=1, As=10, and Cd=30.

Mean ERM quotient index

Because contaminants may occur as complex mixtures, the mean effects range–median quotient (mean-ERM-Q) was applied as a screening metric for potential combined biological effects. Although ERM benchmarks were originally developed for marine/estuarine sediments (Long et al., 1995; Long et al., 2000), mean-ERM-Q has also been used in soil risk assessments as a screening indicator (Huang et al., 2022; Moon et al., 2024). The mean-ERM-Q was calculated as (Long et al., 2000):

Mean-ERM-Q = (1/n) × Σ (Ci / ERMi) (8)

where (C_i) is the measured concentration of metal (i), (ERM_i) is the Effect Range Median guideline value for the same metal, and (n) is the number of metals included in the calculation.

Carcinogenic risk assessment (ILCR)

Screening carcinogenic risk associated with Pb in soil was quantified as incremental lifetime cancer risk (ILCR) following the USEPA human health risk assessment (HHRA) framework (USEPA, 1989; USEPA, 2004) Three exposure pathways were considered: soil ingestion (ing), dermal contact (derm), and inhalation of resuspended soil particulates (inh). For ingestion and dermal contact, the lifetime average daily dose (LADD, mg/kg-day) was calculated as follows:

$$LADD_{(ing)} = \left(C \times IngR \times EF \times ED \times 10^{(-6)}\right) / \left(BW \times AT\right) \quad (9)$$

$$LADD_{(derm)} = \left(C \times SA \times AF \times ABS_d \times EF \times ED \times 10^{(-6)}\right) / \left(BW \times AT\right) \quad (10)$$

where *C* is the Pb concentration in soil (mg/kg), *IngR* is the soil ingestion rate (mg/day), *EF* is the exposure frequency (days/year), *ED* is the exposure duration (years), *BW* is body weight (kg), *AT* is the averaging time for carcinogenic effects (days; 70 years × 365 days), *SA* is exposed skin surface area (cm^2), *AF* is the soil adherence factor (mg/cm^2-event), and *ABS_d* is the dermal absorption fraction (unitless). Inhalation exposure concentration (EC, $\mu g/m^3$) associated with particulate emissions from soil was estimated using the particle emission factor (PEF) as:

$$EC_{(inh)} = \left(C / PEF\right) \times \left(EF \times ED / AT\right) \times 1000 \quad (11)$$

where *PEF* is the particle emission factor (m^3/kg). Carcinogenic risk for each pathway and total cancer risk (TCR) was then calculated as:

$$CR_{(ing)} = LADD_{(ing)} \times SF_o \quad (12)$$

$$CR_{(derm)} = LADD_{(derm)} \times SF_o \quad (13)$$

$$CR_{(inh)} = EC_{(inh)} \times IUR \quad (14)$$

$$TCR = CR_{(ing)} + CR_{(derm)} + CR_{(inh)} \quad (15)$$

Age-specific exposure parameters were adopted for residential receptors (child: 0–6 years; adult: 6–30 years), and risks were summed across life stages to obtain the lifetime risk. The default inputs used were EF=350 days/year, ED=6 and 24 years, BW=15 and 70 kg, IngR=200 and 100 mg/day, SA=2800 and 5700 cm^2, and AF=0.2 and 0.07 mg/cm^2-event (USEPA, 2004; USEPA, 2024). Toxicity values were obtained from the USEPA Regional Screening Levels (RSLs) Resident Soil Table (November 2024) for Pb, using lead acetate as a screening surrogate for inorganic lead in soil (SFo=2.1E-01 (mg/kg-day)^-1; IUR=8.0E-05 (μg/m3)^-1; ABSd=0.1) (USEPA, 2024).

RESULTS AND DISCUSSION

Heavy metal concentrations

Measured concentrations of heavy metals in surface soils (0–20 cm) are summarized in Table 6. Across all stations, the mean concentration pattern was: Fe > Mn > Zn > Cr > Cu > Pb > Ni > As > Co > Cd. The coefficient of variation revealed considerable spatial variability for some metals, particularly Pb (63.18%), Cd (59.23%), Cu (35.71%), As (31.85%), and Zn (30.37%). In contrast, Mn (5.39%) and Fe (8.41%) showed relatively low variability, suggesting a more uniform distribution across the sampling stations. This order is typical for urban soils where Fe and Mn are largely lithogenic, whereas Pb, Cu, Zn, As, and Cd may show stronger anthropogenic influence from traffic and urban activities (Saeedi et al., 2012; Taghavi et al., 2019; Mahmoudabadi et al., 2015; Khan et al., 2021). Across the eight stations, concentrations (mg/kg) ranged as follows: As 7.8–19.6 (mean 12.85), Cd <0.1–0.40 (mean 0.19), Co 7.4–12.5 (mean 10.65), Cr 58–100 (mean 76.0), Cu 43–104 (mean 67.0), Ni 25–39 (mean 29.9), Pb 26–129 (mean 60.9), Zn 111–225 (mean 167), Fe 21905–29374 (mean 27270), and Mn 942–1117 (mean 1048) (Table 5). Compared with the soil threshold (screening) values compiled by Tóth et al. (2016) (Table 5), As (5 mg/kg) exceeded the threshold at all stations; Pb (60 mg/kg) exceeded at S2 and S3; Zn (200 mg/kg) exceeded at S2, S4, and S7; and Cu (100 mg/kg) exceeded at S4 and equaled the threshold at S7. Cr reached the threshold (100 mg/kg) at S2 but did not exceed it, while Cd (1 mg/kg), Ni (50 mg/kg), and Co (20 mg/kg) remained below threshold values at all stations. For element Mn, comparison to world surface rock averages (Martin & Meybeck, 1979) indicates Mn exceeded 750 mg/kg at all stations.

Inter-element correlation analysis

Table 7 presents the correlation matrix for the analyzed heavy metals. The results indicate a strong positive correlation between Cu and Zn (r = 0.88), Co and Fe (r=0.83), Cr and Ni (0.88), suggesting that these elements may share a common source or similar geochemical behavior. A moderately strong positive correlation was also observed between Cr and Zn (r = 0.65), while Cd showed moderate correlations with Pb (r = 0.46) and Zn (r = 0.33). In addition, As

Table 6. Summary statistics and concentration (mg/kg) of Heavy metals in soils

Station/Metal	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	19.6	0.2	11.1	75	43	27593	1018	31	37	122
2	17.6	0.2	11.6	100	77	29374	1003	39	129	225
3	12.2	0.3	10.3	67	52	28043	1117	25	112	116
4	12.7	0.2	7.4	89	104	21905	942	29	48	225
5	7.8	0.1	12.5	81	61	27158	1067	31	45	188
6	10.9	0.1	11.4	75	49	28908	1085	31	26	136
7	13.5	0.4	10	63	100	27608	1080	26	59	213
8	8.5	<0.1	10.9	58	50	27569	1074	27	31	111
Minimum	7.8	0.1	7.4	58	43	21905	942	25	26	111
Maximum	19.6	0.4	12.5	100	104	29374	1117	39	129	225
Mean	12.85	0.19	10.65	0.76	67	27269	1048	29.88	60.88	167
CV (%)	31.85	59.23	14.31	18.25	35.71	8.41	5.39	14.69	63.18	30.37
World surface rock average	13	0.2	13	71	32	35900	750	49	16	127
Threshold values (Toth et al., 2016)	5	1	20	100	100	-	-	50	60	200

Table 7. Correlation matrix for heavy metal concentrations in soil samples from the studied stations

	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
As	1	0.27	-0.09	0.40	0.07	0.13	-0.44	0.45	0.37	0.15
Cd	0.27	1	-0.40	-0.51	0.46	0.00	0.21	-0.52	0.37	0.14
Co	-0.09	-0.40	1	-0.03	-0.65	0.83	0.52	0.39	0.04	-0.30
Cr	0.40	-0.51	-0.03	1	0.32	-0.17	-0.71	0.84	0.41	0.65
Cu	0.07	0.46	-0.65	0.32	1	-0.57	-0.51	0.00	0.18	0.88
Fe	0.13	0.00	0.83	-0.17	-0.57	1	0.66	0.28	0.29	-0.37
Mn	-0.44	0.52	0.39	-0.71	-0.51	0.66	1	-0.47	0.01	-0.58
Ni	0.45	-0.52	0.39	0.84	0.00	0.28	-0.47	1	0.33	0.42
Pb	0.37	0.37	0.04	0.41	0.18	0.29	0.01	0.33	1	0.29
Zn	0.15	0.14	-0.30	0.65	0.88	-0.37	-0.58	0.42	0.29	1

Table 8. CF, mCd, and PLI indexes by stations

Station	Zn	Pb	Ni	Mn	Fe	Cu	Cr	Co	Cd	As	mCd	PLI
1	0.96	2.31	0.63	1.36	0.77	1.34	1.06	0.85	1.00	1.51	1.18	1.10
2	1.77	8.06	0.80	1.34	0.82	2.41	1.41	0.89	1.00	1.35	1.98	1.48
3	0.91	7.00	0.51	1.49	0.78	1.62	0.94	0.79	1.50	0.94	1.65	1.21
4	1.77	3.00	0.59	1.26	0.61	3.25	1.25	0.57	1.00	0.98	1.43	1.199
5	1.48	2.81	0.63	1.42	0.76	1.91	1.144	0.96	0.50	0.60	1.22	1.06
6	1.07	1.62	0.63	1.45	0.81	1.53	1.06	0.88	0.50	0.84	1.04	0.97
7	1.68	3.69	0.53	1.44	0.77	3.12	0.89	0.77	2.00	1.04	1.59	1.32
8	0.87	1.94	0.55	1.43	0.77	1.56	0.82	0.84	0.25	0.65	0.97	0.84

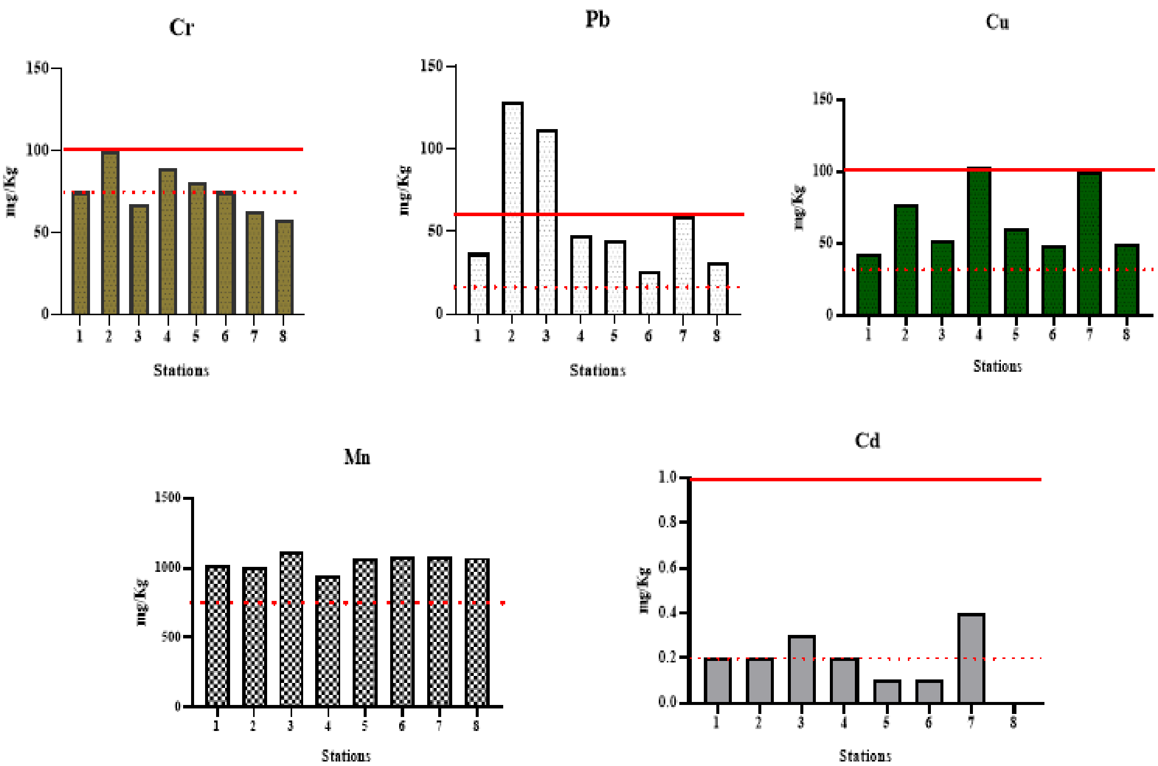

Fig. 2. Heavy metals concentration across stations with threshold (screening) value (Tóth et al., 2016) and background reference (world surface rock average) (Martin & Meybeck, 1979)

was moderately correlated with Pb (r = 0.37), and Ni showed a weak to moderate correlation with Pb (r = 0.33). Overall, these relationships suggest that some of the metals may originate from common anthropogenic inputs, whereas others are more likely controlled by natural background or site-specific factors. Pb, Cu, and Zn showed relatively elevated concentrations, which are commonly associated with vehicular emissions, brake and tire wear, atmospheric deposition, and urban activities (Chabukdhara & Nema, 2013; Dehghani et al., 2017). Similar findings have been reported in urban soils and street dust from Tehran and other metropolitan regions (Dehghani et al., 2017). The strong positive correlation between Cu and Zn further suggests a common anthropogenic source, particularly traffic-related activities (Han et al., 2023). In contrast, Cr and Ni exhibited relatively more stable distributions, implying a greater contribution from natural geological materials (Fei et al., 2023). Compared with previous studies conducted in Iranian urban environments, the concentrations of Pb and Cu in the Kan area were relatively high, whereas Cd levels remained comparatively low (Mohammadi et al., 2023). These differences may be related to local land use, traffic density, industrial influence, and environmental conditions.

Contamination factor (CF), and integrated indices (PLI and mCd)

Contamination factor (CF) values are presented in Table 8. Overall, CF outcomes indicate that Pb and Cu dominate enrichment intensity in the study area. Pb shows very high contamination (CF>6) at S2 (CF=8.06) and S3 (CF=7.00), while Cu reaches considerable contamination at S4 and S7 (Fig. 3). These findings are consistent with traffic and mixed urban micro-sources reported for Tehran soils and dust (Saeedi et al., 2012; Taghavi et al., 2019; Mahmoudabadi et al., 2015). PLI ranged from 0.84 (S8) to 1.48 (S2); thus, S6 and S8 were classified as unpolluted (PLI<1), whereas the remaining stations were polluted (PLI>1), with the highest overall loading at S2. mCd varied from 0.97 (S8) to 1.98 (S2), placing most stations in the "zero to very low" class (mCd<1.5) and indicating a "low degree of contamination" at S2, S3, and S7 (mCd=1.98, 1.65, and 1.59, respectively) (Abrahim & Parker, 2008; Tomlinson et al., 1980).

Geo-accumulation index (Igeo)

Geo-accumulation index (Igeo) values (Table 9) confirm that Pb is the most critical pollutant, reaching Igeo=2.43 at S2 and Igeo=2.22 at S3 (Fig. 4) ("moderately to strongly polluted"), while Cu is moderately polluted at S4 and S7 (Müller, 1969).

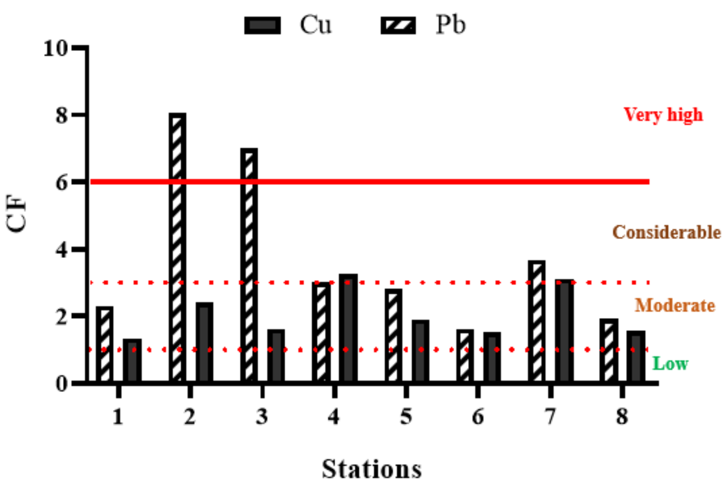

Fig. 3. Contamination factor (CF) for Pb and Cu across stations

Potential ecological risk (E and PER)

Ecological risk results (Table 10) show that overall PER remains below 150 at all stations, corresponding to the low-risk class (Hakanson, 1980; Wei et al., 2020). Moderate single-metal risk is observed for Pb at S2 (E=40.31) and for Cd at S3 (E=45) and S7 (E=60). This highlights that Cd (and locally Pb) can dominate risk even at relatively low mg/kg concentrations due to high toxicity weights (Hakanson, 1980; Wei et al., 2020).

Mean ERM quotient and mixture toxicity screening

Mean-ERM-Q values range from 0.200 to 0.389, placing all stations in the 0.11–<0.5 category corresponding to an estimated ~21% probability of toxicity (Long et al., 2000) and used here as a screening estimate for soils (Huang et al., 2022; Moon et al., 2024). The highest mean-ERM-Q is observed at S2, consistent with elevated Pb and co-enrichment of Cu and Zn (Fig. 5) (Long et al., 1995; Long et al., 2000).

Table 9. Geo-accumulation index (Igeo) values by station

Station	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	0.01	-0.58	-0.81	-0.51	-0.16	-0.96	-0.14	-1.25	0.62	-0.64
2	-0.15	-0.58	-0.75	-0.09	0.68	-0.87	-0.17	-0.91	2.43	0.24
3	-0.68	-0.00	-0.92	-0.67	0.12	-0.94	-0.01	-1.56	2.22	-0.72
4	-0.62	-0.58	-1.40	-0.26	1.12	-1.30	-0.26	-1.34	1.00	0.24
5	-1.32	-1.58	-0.64	-0.39	0.35	-0.99	-0.08	-1.25	0.91	-0.02
6	-0.84	-1.58	-0.77	-0.51	0.03	-0.90	-0.05	-1.25	0.12	-0.49
7	-0.53	0.42	-0.96	-0.76	1.06	-0.96	-0.06	-1.50	1.30	0.16
8	-1.20	-2.58	-0.84	-0.88	0.06	-0.97	-0.07	-1.44	0.37	-0.78

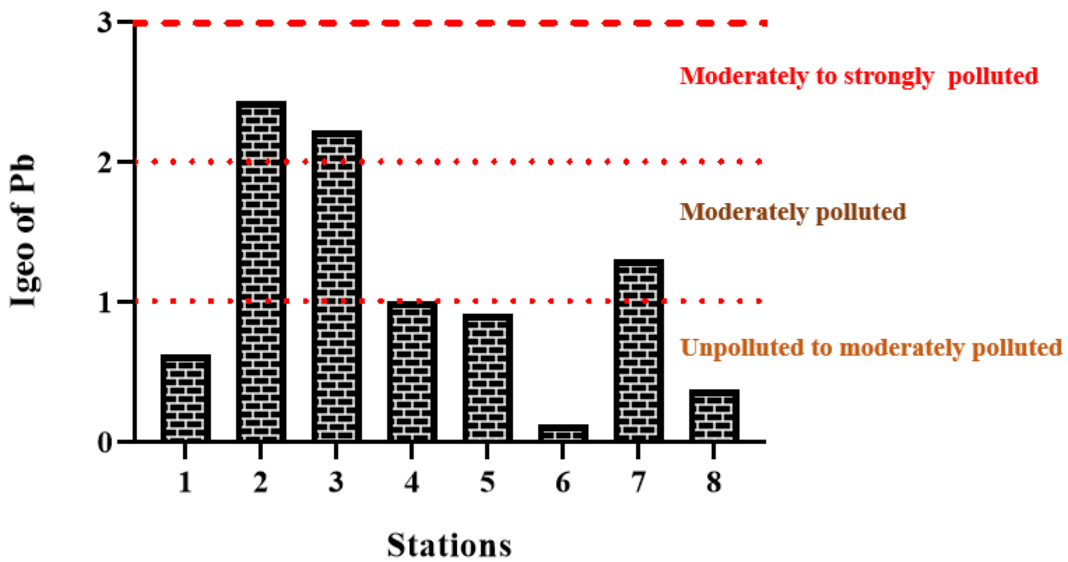

Fig. 4. Geo-accumulation index (Igeo) for Pb across stations

Carcinogenic risk assessment (ILCR)

Estimated carcinogenic risk results are summarized in Table 11. Screening ILCR for Pb ranged from 1.12E-05 at S6 to 5.58E-05 at S2. Spatially, higher ILCR values occur at the traffic intersection (S2) and Saraasiab Hosseiniyeh (S3), reflecting elevated Pb concentrations; similar hotspot patterns near high-traffic/urban activity zones have been reported for Tehran soils and street dust (Saeedi et al., 2012; Taghavi et al., 2019; Rahmati et al., 2025). All stations fall within the commonly used risk-management range of 1E-06 to 1E-04 used in USEPA-based soil HHRA (USEPA, 1989; Karimian et al., 2021; Soltani-Gerdefaramarzi et al., 2021). Compared with heavily impacted sites such as Tehran landfill soils (reported ILCR values on the order of 1E-04), the estimated cancer risk level in Kan soils is lower by roughly one order of magnitude (Karimian et al., 2021).

Table 10. Single-metal ecological risk factor (E) and PER by stations

Station	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	PER
1	15.08	30	4.27	2.11	6.72	1.36	3.16	11.56	0.96	75.22
2	13.54	30	4.46	2.82	12.03	1.34	3.98	40.31	1.77	110.25
3	9.38	45	3.96	1.89	8.13	1.49	2.55	35	0.91	108.31
4	9.77	30	2.85	2.51	16.25	1.26	2.96	15	1.77	82.36
5	6.00	15	4.81	2.28	9.53	1.42	3.16	14.06	1.48	57.75
6	8.38	15	4.38	2.11	7.66	1.45	3.16	8.13	1.07	51.34
7	10.38	60	3.85	1.77	15.63	1.44	2.65	18.44	1.68	115.84
8	6.54	7.50	4.19	1.63	7.81	1.43	2.76	9.69	0.87	42.43

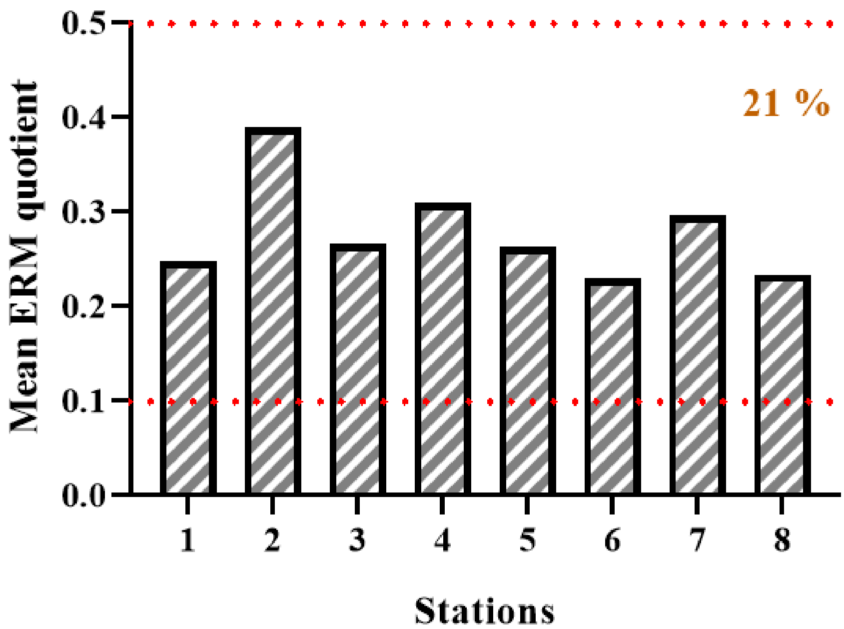

Fig. 5. Mean ERM quotient (mean-ERM-Q) across stations

Table 11. Screening carcinogenic risk for Pb (dimensionless)

Station	ILCR (Pb)	Risk range
S1	1.60E-05	1E-06–1E-04
S2	5.58E-05	1E-06–1E-04
S3	4.84E-05	1E-06–1E-04
S4	2.08E-05	1E-06–1E-04
S5	1.95E-05	1E-06–1E-04
S6	1.12E-05	1E-06–1E-04
S7	2.55E-05	1E-06–1E-04
S8	1.34E-05	1E-06–1E-04

Table 12. Summary classification of key indices by station

Station	PLI	PLI class	mCd	mCd class	PER	PER class	Mean ERM quotient	Toxicity probability
1	1.10	Polluted	1.18	Zero to the very low degree of contamination	75.22	Low risk	0.247	21%
2	1.48	Polluted	1.98	Low degree of contamination	110.25	Low risk	0.389	21%
3	1.21	Polluted	1.65	Low degree of contamination	108.31	Low risk	0.266	21%
4	1.19	Polluted	1.43	Zero to the very low degree of contamination	82.36	Low risk	0.308	21%
5	1.06	Polluted	1.22	Zero to the very low degree of contamination	57.75	Low risk	0.262	21%
6	0.97	Unpolluted	1.04	Zero to the very low degree of contamination	51.34	Low risk	0.229	21%
7	1.32	Polluted	1.59	Low degree of contamination	115.84	Low risk	0.296	21%
8	0.84	Unpolluted	0.97	Zero to the very low degree of contamination	42.43	Low risk	0.200	21%

Summary classification and interpretation

Table 12 provides a consolidated classification of the principal indices (PLI, mCd, PER, and mean-ERM-Q) by station, translating numerical outputs into their corresponding qualitative classes and the associated toxicity probability to enable rapid cross-station comparison. Overall, results indicate hotspot-driven enrichment in the Kan area: Pb is the dominant pollutant at S2–S3, while Cu and Cd contributions are most prominent at S4 and S7. Ecological risk remains low overall (PER<150), but moderate single-metal risk is indicated for Pb at S2 and for Cd at S3 and S7, highlighting the need for targeted monitoring and management at these hotspots (Saeedi et al., 2012; Taghavi et al., 2019; Faraji et al., 2023). Screening carcinogenic risk assessment for Pb indicates ILCR values on the order of 10^-5 (Table 12), remaining within the commonly used acceptable range (1E-06–1E-04) but warranting continued monitoring of Pb at the higher-risk stations (USEPA, 1989; USEPA, 2024).

CONCLUSION

Surface soils (0–20 cm) in the Kan area (District 5, Tehran) exhibit hotspot-driven enrichment of potentially toxic elements, with Pb as the dominant contaminant at traffic-influenced stations and localized contributions of Cu and Cd near workshop/service activities. The results of the CD and Igeo indices for lead (Pb) showed that the Intersection of Ghaem & Rahim St.

and Saraasiab Hosseiniyeh were classified as "very high contamination" and "moderately to strongly polluted," respectively. The coefficient of variation (CV) indicated substantial spatial heterogeneity for several metals, notably Pb, Cd, Cu, As, and Zn, reflecting uneven distribution patterns and the potential impact of localized anthropogenic activities. Conversely, Mn and Fe exhibited low variability, implying a relatively homogeneous distribution across the sampling sites. Exploratory correlations showed a strong positive correlation between Cu and Zn (r = 0.88), Co and Fe (r=0.83), Cr and Ni (0.88), suggesting that these elements may share a common source or similar geochemical behavior. Pb, Cu, and Zn showed relatively elevated concentrations, which are commonly associated with vehicular emissions, brake and tire wear, atmospheric deposition, and urban activities. Integrated indices indicate overall low-to-moderate contamination with clear spatial concentration, while ecological risk remains low at the area scale. Mixture-toxicity screening places all stations in the category associated with an estimated ~21% probability of effects, supporting the interpretation that risk is not uniform but concentrated at specific urban nodes. Screening ILCR for Pb ranged from 1.12E-05 to 5.58E-05, within the commonly used management range (10^{-6}–10^{-4}). These results provide a quantitative baseline for urban soil quality in a rapidly urbanizing district and support targeted mitigation and monitoring focused on high-traffic intersections and localized industrial/service hotspots. Because Pb carcinogenic parameters rely on screening surrogates, refined risk estimates should incorporate more site-specific exposure and toxicity information to reduce uncertainty and improve source-risk attribution.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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