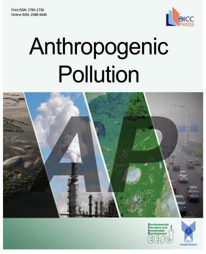

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Assessment and prioritization of different land use effect on surface soils contamination with some trace elements in Rey City, Tehran Province, Iran

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Abstract:

Assessment of different land use effects on surface soil contamination is necessary for sustainable management of urban-industrial ecosystem. For this purpose in Rey city of Tehran province, soil sampling was conducted across industrial and other land-use areas, collecting 52 composite surface samples ($0-20$ cm depth) to assess trace metal contamination. Samples were analyzed for metals (As, Cd, Pb, Zn, Cu, Ni) using atomic absorption spectrophotometry (AAS) and inductively coupled plasma (ICP-OES). Physical and chemical properties (texture, pH, organic matter, calcium carbonate) were measured via standardized methods. Pollution levels were evaluated using indices like the geoaccumulation index (Igeo), contamination factor (CF), Nemerow pollution index (NIPI), and potential ecological risk index (PERI), which incorporated toxicity factors and background values. Spatial hot/cold spots of contamination were identified via Getis-Ord analysis, highlighting clusters of high/low metal concentrations. These methods aimed to distinguish natural versus anthropogenic contamination and assess ecological risks. The study emphasized integrating geochemical, statistical, and spatial tools to map pollution patterns and prioritize mitigation efforts in Rey City's industrially impacted soils. The Getis-Ord analysis revealed minimal pollution for Al (12% cold spots), localized As ($< 5\%$) and Cd hot spots, and elevated contamination for Cu (13%), Hg ($> 50\%$ in west/north), and Mn. Mercury and manganese exhibited the most widespread pollution, highlighting critical environmental risks in Ray City, while aluminum showed negligible contamination. The results provide valuable guidance for policymakers, urban planners, and environmental managers to design targeted remediation efforts and preventive measures to reduce soil pollution risks.

Keywords: Soil pollution; Trace metals; Geoaccumulation index; Environmental risk; Land use impact

1. Introduction

Today, one of the most important global environmental problems is pollution caused by terace metals. Because these elements, due to their properties such as chemical stability, poor degradability,and having the power of bioaccumulation at different levels of the food chain, cause many damages and ecological risks to living organisms.

Providing healthy food security for the world's growing population is one of the most important issues, considering the limited resources of the earth, in a way that causes the least damage to its environment. The increase in industrial activities along with the production of pollutants, including terace metals, is one of the serious and expanding problems facing modern mankind (Abdi et al., 2017). Soil contamination with terace metals is one of the most important environmental problems around the world. Since these metals are absorbed by plants and fruits and transferred to humans body, this issue is more serious in the case of agricultural and garden soils (Chen et al., 2016; Cui et al., 2020; Mirzaei et al., 2023). Therefore, considering the possibility of accumulation in the food chain and endangering the health of living organisms, it is necessary to investigate the concentration and dispersion of these metals in different soils, including agricultural soil (Deng et al., 2016). Terace metals in the agricultural sector are introduced into these soils by the use of polluted sewage sludge and the excessive consumption of pesticides, agricultural fertilizers (Cadelis et al., 2014). Therefore, it is important to study the contamination of terace metals in agricultural products and agricultural soils of these products. The behavior of terace metals in soil is important in the sense that they can cause the pollution of underground and surface water and can also enter the food chain (Cai et al., 2019). Terace metals are of particular importance due to their indestructibility and physiological effects on living organisms. These metals enter the cycle of nature through water, air and soil through various natural and artificial sources and create dangerous short-term and long-term effects on them (Boudia et al., 2019). The key to effective assessment of soil pollution with terace metals is the use of appropriate pollution indicators, which can be considered as a tool and guide for a comprehensive assessment of the soil environment. Measurement and determination of pollution indicators allow for quick assessment of soil quality and the source of pollution and help to diagnose and manage pollution (Boudia et al., 2019; Dayani and Mohammadi, 2010; El Azhari et al., 2017). In addition, the indicators help to determine whether the accumulation of terace metals is due to natural processes or human activities; As a result, pollution indicators can monitor human activities (Esmaeili et al., 2014; Mirzaei et al., 2023). Over the past few decades, various indicators have been presented to evaluate the accumulation of terace metals. In most cases, the amount of geochemical background (GB) is needed to evaluate the amount of terace metal pollution using pollution indicators (Worlanyo and Jiangfeng, 2021a; Yu et al., 2021). This term was introduced to distinguish natural concentrations of terace metals in soil from abnormal concentrations. (Kowalska et al., 2021) have distinguished two types of GB: Reference and local (natural). The reference geochemical background can be considered as the average concentration of terace metals in scientific sources, which varies due to differences in location and soil type. The local geochemical context is the concentration of terace metals under the influence of natural processes characteristic of a particular region. Terace metals are considered as local geochemical background when they are not affected by human activities. Different geochemical contexts (reference and local) can be used in order to more accurately investigate the pollution index values. Many of the geochemical questions that arise are related to the use of reference and local context. In general, the reference field is the average concentration of terace metals in the earth's crust, shale and global soil, which is related to the geological reference level (Abeer et al., 2020; Sun et al., 2020). Some articles with the aim of evaluating the concentration of terace metals have used reference values for pollution index calculations (El Azhari et al., 2017; Gabarrón et al., 2017). The reference context allows soil quality information to be considered at a global scale and allows for comparisons beyond the local scale. The local geochemical background includes the concentration of terace metals in the most pristine locations, the C horizon of the soil profile, and the composition of terace metals in rocks (Li et al., 2021) The local geochemical context may vary significantly in different geological settings and its surface should be investigated in geologically similar areas. Choosing the appropriate geochemical background plays an important role in the assessment of pollution. To avoid confusion in the choice of geochemical context, Kowalska et al. (2021) suggest the use of both GB contexts (reference and local) for comprehensive assessment of soil contamination. On the other hand, regardless of the context used and the level of terace metal pollution, indicators may not always accurately reflect environmental threats, because the threshold level of toxicity to human health is still not clear and is completely personal (Cepa, 2007; Dang et al., 2022). Pollution indicators are generally divided into two categories: the first group are single indicators that are used to evaluate the pollution of one element, and the second group are integrated indicators that examine the pollution of more than one element (Table 1). Also, pollution indicators can be divided into six groups based on different goals: 1: Evaluation of the level of pollution based on one element, including the index of the geoaccumulation index (Igeo), pollution index (Kumar et al., 2023) and contamination factor (Cf). 2: The overall pollution scale includes the sum of the pollution index (PIsum), the number pollution index (PINemerow), the pollution load index (PLI), the average pollution index (PIavg), the modified pollution degree (mcd), the vector coefficient of the pollution index (PIVector), Degree of Contamination (Cdeg), Context Enrichment Factor (Kumar et al., 2023) and Contamination Security Index (CSI). 3: Source of terace metals including enrichment factor and multi-element pollution (MEC). 4: Environmental risk including environmental risk potential index (RI) and toxicity probability index (MERMQ), 5: The highest possible risk areas of terace metal accumulation including the exposure factor (ExF), 6: The ability of the surface horizon to accumulate terace metals, including the biogeochemical index (BGI). To calculate each of the mentioned indicators, the total concentration of analyzed terace metals is used. Although total concentration cannot accurately reflect the mobility and bioavailability of metals in soil, total concentration is still the most common measure of terace metal concentration in soil (Afshari et al., 2016; Al-Saleh, 2020; Gabarrón et al., 2017)

After evaluating the strengths and weaknesses of various pollution indicators, and based on previous studies and a review of scientific literature, it can be concluded that the Geoaccumulation Index (Igeo) and the Enrichment Factor (EF) are among the most useful. The Igeo provides information on the degree of pollution, while the EF helps identify whether trace metals originate from natural or anthropogenic sources.

Among the integrated indicators, the environmental risk potential index (RI) and the pollution security index (CSI) are the most useful and universal indicators (Doabi et al., 2018; Gabarrón et al., 2017; Wang et al., 2018). Chen et al. (2016) by examining the assessment of concentration and identification of resources in the city of Xi'an, China concluded that natural resources, transportation, industrial activities and complex resources are 25.04%, 24.71%, 25.26% and

Table 1. Individual and integrated pollution indicators.

Pollution indicators	
Individual pollution indicators	Integrated pollution indicators
The geoaccumulation index (Igeo)	Pollution Index (PIsum)
Pollution Index	Pinemerow pollution index
Enrichment Factor	Pollution Load Index (PLI)
Contamination Factor (Cf)	Average Pollution Index (PIavg)
Biogeochemical Index (BGI)	Pollution Index Vector Coefficient (PIVector)
	Context Enrichment Factor
	Multi-Element Pollution (MEC)
	Contamination Security Index (CSI)
	Toxicity Likelihood Index (MERMQ).
	Degree of pollution (Cdeg)
	Environmental Risk Potential Index (RI)
	Exposure Factor (ExF)

Based on an evaluation of the strengths and weaknesses of various pollution indicators, it can be concluded that the Geoaccumulation Index (Igeo) and the Enrichment Factor (EF) are among the most effective tools for assessing trace metal contamination. The Igeo provides insight into the degree of pollution, whereas the EF helps determine whether trace metals originate from natural or anthropogenic sources.

24.99% of the total share of polluting sources respectively. Comparing the paper with the literarature review it is obvious that,the paper contributes to the existing literature by investigating the recognition and prioritization of different land use effects on surface soil contamination with terace metals in Rey City, Tehran Province. It provides insights into the behavior of terace metals in soil, their potential risks to human health and ecosystems, and the need for effective pollution indicators for assessing and managing terace metal pollution .The paper discusses the strengths and weaknesses of pollution indicators and identifies the earth accumulation index (Igeo) and enrichment factor as the most useful indicators for assessing pollution levels and determining the origin of terace metals. Environmental pollution, particularly soil contamination by trace metals, has become one of the most pressing challenges in the context of rapid urbanization and industrial development worldwide. Trace metals, such as lead (Pb), cadmium (Cd), arsenic (As), copper (Cu), nickel (Ni), and zinc (Zn), pose significant environmental and public health risks due to their persistence in the environment, poor degradability, and potential for bioaccumulation through the food chain. These metals are not only harmful to plant and animal life but also affect human health, particularly when present in agricultural soils, as they can enter the food chain and cause chronic toxicity. With the growing concern over food security and public health, the study of soil pollution is critical in understanding and mitigating risks to ecosystems and human populations. In regions with intensive urban and industrial activities, like Rey city in Tehran, soil contamination by trace metals is an emerging environmental concern that requires immediate attention. Previous research has highlighted the pervasive issue of trace metal pollution across various regions globally, particularly in industrial and urban areas. For instance, studies have identified the sources and distribution of heavy metals in soils from industrial zones and urban areas (Cai et al., 2019; Mirzaei et al., 2023). Research conducted by Dang et al. (2022) and Doabi et al. (2018) provides insight into the risks associated with metals such as arsenic, cadmium, and lead, especially in agricultural lands, where these pollutants can accumulate and enter the food chain. Additionally, several studies have focused on the use of pollution indicators—such as the geoaccumulation index, contamination factor, and pollution load index-to assess the degree of soil contamination and the ecological risks posed by these pollutants (Hajjabbari and Fataei, 2016; Kowalska et al., 2021; Kumar et al., 2023).

The existing body of research has extensively analyzed the presence and toxicity of trace metals in different regions, but much of this research tends to focus on either individual metals or specific geographical areas, with limited comprehensive studies that evaluate multiple trace metals and land uses in the same region. While significant strides have been made in the study of trace metal contamination in soils, several gaps remain in the literature. Firstly, the interaction of various land uses (urban, industrial, agricultural, etc.) in relation to soil contamination by multiple trace metals has not been sufficiently explored, especially in regions undergoing rapid urbanization and industrialization, like Rey city. Although previous studies have examined the distribution of trace metals in agricultural soils, few have focused on how different land uses impact trace metal concentrations across urban and industrial environments. Secondly, the methods used to assess contamination, while robust, have not been consistently applied across different regions or land use types, limiting the comparability of results. Additionally, there is a lack of studies that combine spatial and pollution indicator-based assessments to pinpoint hotspots of contamination, which are crucial for targeted remediation efforts.This study aims to fill the existing gaps by providing a comprehensive analysis of soil pollution in Rey city, Tehran, with a focus on how various land uses contribute to the accumulation of trace metals. The specific objectives of this study are to assess the concentration and distribution of key trace metals (Pb, Cd, As, Cu, Ni, and Zn) in surface soils from different land uses in Rey city,to apply a range of pollution indicators, such as the geoaccumulation index, contamination factor, and potential ecological risk index, to evaluate the degree of contamination and associated risks,to identify spatial hotspots of trace metal pollution using advanced geostatistical methods, providing insights into areas that require urgent remediation, to compare the effects of different land uses on the concentration of trace metals, particularly focusing on industrial, agricultural, and urban zones. By addressing these objectives, this study aims to contribute to the understanding of how industrial and urban development impacts soil quality and public health in rapidly growing cities, while also offering guidance for effective pollution management strategies in similar regions.

2. Materials and methods

2.1 Study area

Rey city with area of 2293 square kilometers located between the geographical coordinates of 36°35′ altitude, and 26°51′ longitude. The avergae elevation of this city is 1062 meters above sea level. The climate is moderate and dry. The maximum temperature in summer is 42 °C and the minimum in winter is −9 °C. The annual rainfall of Ray city is 250 mm on average. Several famous and important rivers of Iran that flow into Alborz basin in central Iran, such as Karaj, Shur Feshapoyeh, Jajrud rivers (in the eastern border area of Ray city) flow in Ray city and then to Karaj and Jajrud rivers join (figure 1).

2.2 Field studies

At first, with the help of ArcMap 10.3 software, the locations of observation points were randomly classified according to the existence of different industries and land uses, and then soil points were determined and soil samples were taken with recoding UTM geographical coordinate. Then, according to the size of the study area, 52 composite surface soil samples (each sample is a mixture of 5 samples) were collected from 0 to 20 cm soil depth and the samples were transferred to the laboratory to analyze terace metals and analyze the necessary physical and chemical characteristics (Iranian Soil Survey Staff, 2001). The samples taken in May to Jun 2023, during wet season. Composite Samples are a mixture of individual samples, or subsamples, generally collected from multiple locations and mixed together to form a single composite sample. By combining multiple subsamples into a single composite sample, we can minimize the effects of soil variability by averaging the soil properties over larger areas. Based on FAO classification method, Fine-loamy-Calcareous-mesic-calcaric cambisols could be seen in average in the sampling area previously

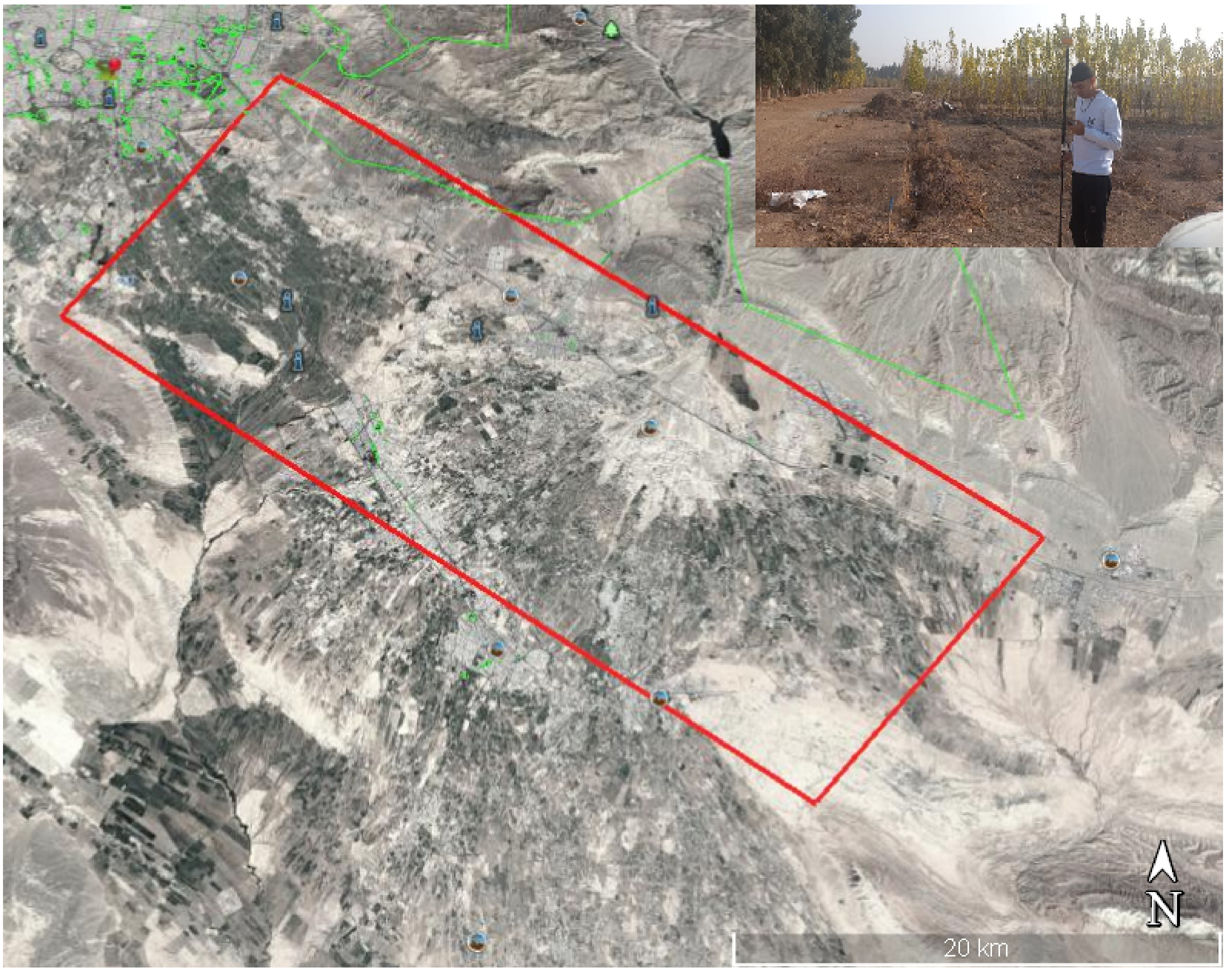

Figure 1. The location of sampling in the south of Ray city and part of the steps of recording the location of sampling points.

determined by Iranian Soil Survey Staff (2001).

2.3 Laboratory analyses

After air-drying the collected samples and passing them through a two-millimeter sieve, necessary laboratory analyzes were performed on them. For this purpose, soil texture by hydrometric method (Bauder and Brock, 2001), calcium carbonate equivalent (CCE) by Bernard method (Moret-Fernández and Herrero, 2015; Fataei, 2016), organic matter by more oxidation method (Abril and Bucher, 1999), soil reaction (Worlanyo and Jiangfeng, 2021b) and electrical conductivity (Smith and Doran, 1997) were measured in a 2:1 water-to-soil suspension using pH meters and EC meters, respectively. To determine the total concentration of metals As, Cd, Pb, Zn, Cu and Ni in the soil, extraction was done by acid digestion method using 4N nitric acid. After preparing the samples, the total concentration of Cd, Pb, Zn, Cu and Ni was read with an atomic absorption spectrophotometer (AAS Model GBC 932AB Plus (Bortoli et al., 1996). The total concentration of As was read with an inductively coupled plasma measuring device (ICP OES GBC Integra XL (Bortoli et al., 1996). Changes in the concentration of elements in each type of land use were investigated by comparing the averages and soil pollution indices (Kumar et al., 2023). Table 2 explains laboratory reagents and equipment specifications used in this study.

To ensure reliable results, strict Quality Control (QC) procedures were followed, including calibration of instruments, the use of blanks and replicates, and analysis of Standard Reference Materials (SRMs). Quality Assurance (QA) practices involved adherence to Standard Operating Procedures (SOPs), thorough documentation for traceability, and inter-laboratory comparisons. Routine equipment maintenance, statistical data analysis, and field sample handling were also part of the QA process to ensure accuracy and prevent contamination. These practices maintained the integrity of the analysis, ensuring the reliability of the study's findings

2.4 Indicators

Due to the destructive effects of terace metals on humans and the environment, the evaluation of terace metal contamination is of particular importance. In order to control the potential risks of metals, various tools such as the land accumulation index, enrichment factor, pollution degree, contamination factor (Cf), potential ecological risk index and pollution load index are used to evaluate the level of terace metal pollution.

Table 2. Laboratory reagents and equipment specifications used in this study.

Category	Item	Details	Protocol/Reference
Reagents	Nitric Acid (HNO_3)	Purity: ≥99%, Manufacturer: Merck, Darmstadt, Germany	EPA Method 3051A for digestion of soil samples
	Hydrochloric Acid (HCl)	Purity: ≥37%, Manufacturer: Sigma-Aldrich, St. Louis, MO, USA	Used in sequential extraction; Tessier et al. (1979)
	Hydrofluoric Acid (HF)	Purity: ≥40%, Manufacturer: Fisher Scientific, Waltham, MA, USA	ISO 11466:1995 for total metal digestion
	Deionized Water	Milli-Q Purification System, Millipore, Bedford, MA, USA	Used for sample preparation (ISO 3696:1987)
Instruments	Atomic Absorption Spectrophotometer (AAS)	Model: PerkinElmer AAnalyst 400, Manufacturer: PerkinElmer, Waltham, MA, USA	EPA Method 7000B for metals analysis
	Inductively Coupled Plasma Mass Spectrometer (ICP-MS)	Model: Agilent 7900, Manufacturer: Agilent Technologies, Santa Clara, CA, USA	EPA Method 6020B for trace metal determination
	pH Meter	Model: Metrohm 827 pH Lab, Manufacturer: Metrohm, Herisau, Switzerland	ISO 10390:2005 for soil pH measurement
	Centrifuge	Model: Eppendorf 5810R, Manufacturer: Eppendorf, Hamburg, Germany	Standardized for sample extraction (Tessier et al., 1979)
	Oven (Drying Samples)	Model: Memmert UN110, Manufacturer: Memmert GmbH, Schwabach, Germany	ASTM D2974-14 for drying soil samples
	Balance (Weighing Samples)	Model: Sartorius Entris II, Manufacturer: Sartorius AG, Göttingen, Germany	Used for precise sample weighing (ISO 11277:2009

2.4.1 The geoaccumulation index (Igeo)

The basis of the geo accumulation index is the comparison of the metal concentration with its amount in the geochemical field of the region, which is calculated using equation (1).

$$I_{geo} = \log_2 \frac{C_i}{1.5B_i} \tag{1}$$

In this equation: I_{geo}: index of accumulation of land, C_i: amount of elements in the studied soil or sediment samples and B_i: background value. A factor of 1.5 has been used to correct the parent material of soil effects, natural fluctuations and very small changes caused by human activities. Based on the amount of the index, 7 pollution classes are shown in Table 2: $\mathrm{PI}_i \leq 0$ (not polluted), $0 < \mathrm{PI}_i \leq 1$ (not polluted to slightly polluted), $1 < \mathrm{PI}_i \leq 2$ (slightly polluted), $2 < \mathrm{PI}_i \leq 3$ (slightly polluted to very polluted), $3 < \mathrm{PI}_i \leq 4$ (very polluted), $4 < \mathrm{PI}_i \leq 5$ (very polluted to heavily polluted), and $5 < \mathrm{PI}_i$ (severe pollution) (Kumar et al., 2023).

2.4.2 Pollution index

The PI index was introduced in 1980 by Hakanson (Chen et al., 2021a) and in which the average concentration of the measured element is compared with the amount of the same element in the reference area and is calculated based on equation (2):

$$\mathrm{PI}_i = \frac{C_i}{B_i} \tag{2}$$

In this equation: C_i: the concentration of the i^{th} pollutant, B_i: the base line concentration caused by the parent rock of the pollutant and PI_i: the pollution index related to the i^{th} pollutant. Based on the PI_i index, 4 pollution classes are defined as follows: $\mathrm{PI}_i < 1$(allowable), $1 \leq \mathrm{PI}_i < 2$ (moderate), $3 \leq \mathrm{PI}_i < 6$ (high) and $6 \leq \mathrm{PI}_i$ (too many).

2.4.3 Contamination factor (Cf)

Equation (3) is used to determine the risk of soil contamination using the contamination factor. Pollution levels can be divided between 1 and 6 based on the intensity of pollution (Table 3).

$$\mathrm{CF}_{\text{metal}} = \frac{[C]_{\text{terace metal}}}{[C]_{\text{background}}} \tag{3}$$

In this equation: $\mathrm{CF}_{\text{metal}}$: The pollution factor of any desired metal, $[C]_{\text{background}}$ and $[C]_{\text{terace metal}}$ are the concentration of the desired metal in the surface soil and in the background soil, respectively (Golia et al., 2021; Yari et al., 2021).

2.4.4 The Nemerow pollution index

In order to evaluate the quantity of pollution risk and awareness of pollution potential in the area, The Nemerow pollution index (NIPI) was used. It emphasizes the most polluting factor while also taking into account the contribution of other factors in the assessment system, and determines the water quality category through the comprehensive pollution index. NIPI is calculated based on equation (4) and for each sampling station (Wei et al., 2023; Yari et al., 2021):

$$\mathrm{NIPI} = \sqrt{\frac{(P_{i\text{ave}})^2 + (P_{i\max})^2}{2}} \tag{4}$$

In this equation: NIPI: Nemerow pollution index, $P_{i\text{ave}}$: the average pollution index of element i and $P_{i\max}$: the maximum amount of pollution index of element i. The amount of pollution is also based on the index value calculated in 5 classes of pollution as follows:

$\mathrm{PI}_i < 0.7$ (unpolluted), $0.7 \leq \mathrm{PI}_i < 1$ (relatively unpolluted), $1 \leq \mathrm{PI}_i < 2$ (slightly polluted), $2 \leq \mathrm{PI}_i < 3$ (moderately polluted) and $3 \leq \mathrm{PI}_i$ (severe pollution).

The advantage of this index compared to other indices is that in this index, the contamination risk of all the metals studied in the region is determined . This index is a reflection of the status of metal pollutants and identifies the biggest pollutants in the environment.

2.4.5 The potential ecological risk index (RI)

PERI is defined to evaluate the degree of metal contamination based on the toxicity of metals and the organism's response to the environment and is calculated based on relations (5) and (6):

$$E_r^i = T_r^i \times C_f^i = T_r^i \times (C_s^i / C_n^i) \tag{5}$$

$$\mathrm{RI} = \sum_{i=1}^{n} E_r^i \tag{6}$$

where: C_s^i is the amount of the element in the sample, C_n^i is the background value of the element, C_f^i is the pollution factor of a single element, T_r^i is the "toxic-response" factor for the given substance i and E_r^i is the potential ecological risk factor for the given substance i. The Tri factor of the investigated elements is Zn = 1, Cu = Pb = 5, As = 10, Cd = 30, Hg = 40 (Hakanson, 1980), Mo = 15 and Sb = 10 (Zhou et al., 2012). ERI is the total ecological risk index, which is the sum of E_r^i and shows the sensitivity of connection with toxic substances. The proposed classification based on E_r^i and RI is given in Table 4 (Wei et al., 2023; Yari et al., 2021; Hakanson, 1980). The background values used in the study are derived from two sources: The reference geochemical background, which reflects global averages in the earth's crust and soils, and the local geochemical background, which represents the natural metal concentrations specific to the study area. These values help distinguish between natural metal levels and potential contamination from human activities. They are essential for accurate pollution assessments.

Table 3. Classification of contamination factor values (Bhuiyana et al., 2010).

Degree of pollution	No pollution	No pollution to moderat pollution	Moderate pollution	Moderate to strong pollution	Strong pollution	Strong to very strong pollution	Very strong pollution
Rate	0	1	2	3	4	5	6

Table 4. Classification of PERI factor (Ei) and PERI index (ERI).

Ei		ERI	
Ei < 40	Low potential ecological risk	RI < 150	Low potential ecological risk
40 ≤ Ei < 80	Moderate potential ecological risk	150 ≤ RI < 300	Moderate potential ecological risk
80 ≤ Ei < 160	Considerable potential ecological risk	300 ≤ RI < 600	Considerable potential ecological risk
160 ≤ Ei < 320	High potential ecological risk	600 ≤ RI	Very high ecological risk
320 ≤ Ei	Very high ecological risk		

2.5 Hot spot analysis (Getis-Ord G_i^*)

The Getis-Ord statistic, or simply the z-test statistic, is used to test the detection of spatial clusters. Like local Moran's I, it enables us to identify clusters that may not be represented when using global spatial statistics. It is calculated as follows for feature i:

$$G_i^* = \frac{\sum_{j-1}^{n} w_{jj}(d)x_j - \bar{x}\sum_{j-1}^{n} w_{jj}(d)}{\sqrt[5]{\{n\sum_{j-1}^{n}[w_{ij}(d)]^2 - [\sum_{j-1}^{n} w_j(d)]^2\}/(n-1)}} \qquad (7)$$

where w_{ij} is a spatial 1 or 0 symmetric weight matrix with 1s for all features within d distance from feature i, including feature i itself, and 0s for all other features, x_j is the feature value associated with feature j and s. The mean and standard deviation of attribute values are respectively (Rogerson, 2024). In this method, it is determined whether the feature i and its adjacent features have higher or lower values than the average feature or variable. A positive value greater than the critical z-value at the specific significance level indicates that the feature is part of a spatial cluster with very high values, while a negative value less than minus the critical z-value indicates that the feature is in a spatial cluster with very high values. Thus, given a set of features, it can be used to identify those features with values of a particular variable in magnitude higher or lower than what would be expected to be found by chance. The clusters of high values are called hot spots and the clusters of low values are called cold spots. In this research, after drawing the zoning maps of the concentration of terace elements in the region with the Getis-Ord method, the analysis of hot and cold spots in the region and corresponding map carried out (Joseph et al., 2010).

3. Results and discustion

3.1 Statistical description of data

3.1.1 Statistical description of physical and chemical characteristics of soil

The statistical summary of the physical and chemical characteristics of the soils of the region is presented in Table 5, 6 while the ANOVA data presented in figure 2. Normality (Shapiro-Wilk, Kolmogorov-Smirnov) and homogeneity of variance (Levene's, Bartlett's) tests used to ensure the validity of ANOVA and Duncan's test. Clay values in the samples varies between 88.88 and 52.88%, values of silt between 14% and 64% and values of sand between 8.56% and 76.56% and according to the textural classes, the soils of the region are divided into 8 textural classes, including clay loam, Loam, clay, sandy clay loam, silty loam, silty clay, sandy loam and silty clay loam are placed (figure 1). The average value of electrical conductivity in the samples is 0.4 decisiemens/meter (dS/m) and by converting it to saturated extract, it is classified as non-saline (Iranian Soil Survey Staff, 2001). The pH of the soil varies between 7 and 8, which is in the range of low-alkaline soils based on the classification of Ikem and Campbell (Ira-

Table 5. Soil physical and chemical characteristics based on the statistical data.

Element	Mean Concentration (mg/kg)	Range (Min-Max)	Standard Deviation	Spatial Variation
Pb (Lead)	19.8	9.17 - 36.6	7.09	Moderate
Cd (Cadmium)	0.28	0.13 - 0.58	0.11	Low
Cu (Copper)	9.35	4.62 - 22.8	3.5	Moderate
Ni (Nickel)	56.1	23.47 - 98.8	24.2	High
Zn (Zinc)	73.9	30.4 - 130	32.3	High
As (Arsenic)	98.7	40.06 - 175	43.6	High
Hg (Mercury)	0.16	0.1 - 0.19	0.03	Low
Al (Aluminum)	3991	3684 - 4503	213	Low
Fe (Iron)	1229	1015- 1832	181	Moderate
Mn (Manganese)	672	486 - 854	95.9	Moderate
Mg (Magnesium)	28.1	12 - 36	7	Moderate

Table 6. Correlation between studied elements in the region of rey city.

	Pb	Cd	Cu	Ni	Zn	As
Pb	1	0.474	0.302	0.411	0.433	0.306
Cd	0.474	1	0.454	0.706	0.462	0.450
Cu	0.302	0.454	1	0.066	-0.193	-0.089
Ni	0.411	0.706	0.066	1	0.842	0.799
Zn	0.433	0.462	-0.193	0.842	1	0.899
As	0.306	0.450	-0.089	0.799	0.899	1

nian Soil Survey Staff, 2001). The average amount of organic matter and equivalent calcium carbonate was 1.29 and 27.71%, respectively. Among the studied physical and chemical characteristics, EC shows the highest coefficient of variation (59.29%) and pH shows the lowest coefficient of variation (2.17%).

3.1.2 Statistical description of terace metal concentration in soil samples

Descriptive statistics of total concentration of terace metals in soil samples are shown in Table 4, 5. The concentration range of terace metals in the soil ranges from 6.75 to 255 mg/kg for Pb, 0.1 to 3.65 mg/kg for Cd, 55.7 to 357 mg/kg for As, It was 5.05 to 34.05 mg/kg for Cu, 26.65 to 171 mg/kg for Ni, and 13.15 to 858 mg/kg for Zn. The average concentration of Pb, Cd, As, Cu, Ni and Zn was 27.88, 1.03, 132.78, 11.48, 84.98 and 98.04 mg/kg respectively. Therefore, the concentration trend of terace metals based on the average is as follows: As > Zn > Ni > Pb > Cu > Cd. About 90% and 100% of the soil samples have higher concentrations of Cd and As, respectively, than the global soil average, which is a threat to human health and a serious risk to the surrounding ecosystems. According to the soil quality standard, the concentration of Ni and As is higher than the standard (Table 7). The coefficient of variation is used to show the degree of variability of soil terace metals. 20% ≥ CV (low variability), 50% ≥ CV >21% (moderate variability), 100% ≥ CV >50% (high variability) and 100% < CV (very high variability) (Siu et al., 2015). The basis of this classification is the percentage of metal change coefficient as follows: (26%) Cu > (29%) As > (35%) Ni > (60%) Cd > (111%) > Pb > (125%) Zn. The percentage of coefficient of variation of Zn and Pb is very high and Cd is high, which are more variable compared to other elements, and therefore it is possible that these metals are affected by external factors such as human activities (Table 8-9).

3.1.3 Comparison of the average concentration of elements in different land uses

Based on the field observation and land use information, seven groups of land use were studied. In each group, sampling was done depending on the conditions of environmental changes. The studied land use groups included agricultural lands in the region, rural and urban residential contexts, oil and gas companies, cemeteries and tombs in the region, integrated industrial settlements, scattered industrial workshops and existing greenhouses (Fig. 3). A

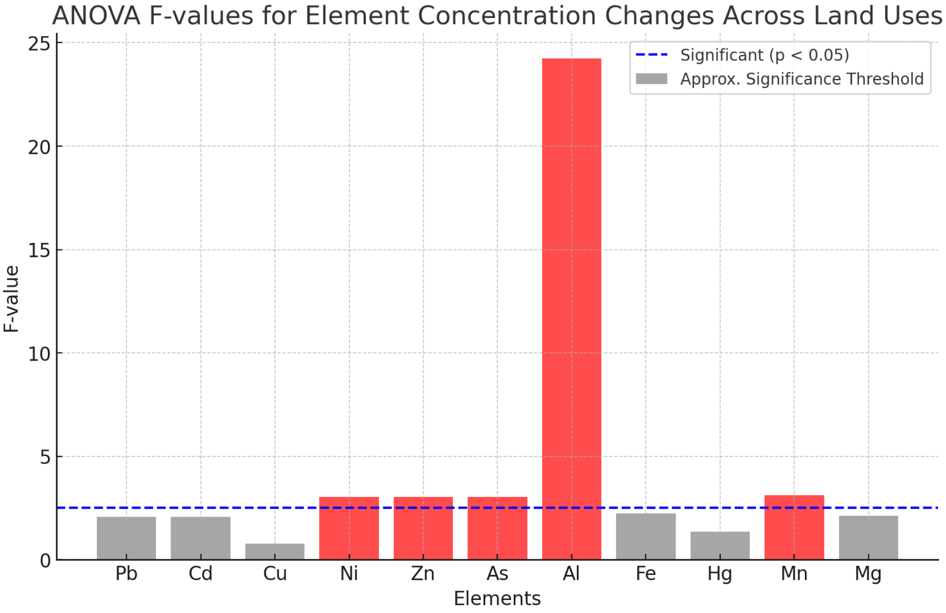

Figure 2. Anova F values of element concentarion changes Across Landuses.

Table 7. Values of Geoaccumulation indices and enrichment factor in the study area.

Terace element		Geoaccumulation index (Igeo)		Enrichment factor
Parameter/Index	cn	Igeo	Degree of pollution	
Pb	27.8	0.95	No pollution to moderate pollution	0.24
Cd	1.03	0.89	No pollution to moderate pollution	0.49
Cu	11.4	1.1	Moderate pollution	2.1
Ni	84.9	0.82	No pollution to moderate pollution	0.9
Zn	98.04	1.05	Moderate pollution	2.6
As	132	0.64	No pollution to moderate pollution	0.79

comparative statistical analysis of the mean concentrations of trace metals across the land uses was conducted at a 0.05 significance level (figures 3–4). According to the available charts and tables, the amount of lead has been observed from 16.05 units in the studied agricultural lands to 24.28 units in the studied cemeteries and tombs. It is observed that the values of copper varied in urban and rural areas with the maximum values of (9.8 units) and the minimum values in agricultural lands (6.4). Among the other studied elements, Ni has the highest amount scattered in industrial workshops and the lowest amount in agricultural lands (77.5 units and 41.3 units). The highest amount of zinc (Zn) in agricultural lands is 100.31 units and the lowest amount is 63.9 units. Values of Mg was the highest amount in oil and gas companies and lowest in cemeteries and tombs. The highest amount of Fe was observed in greenhouse land uses and the lowest amount was observed in industrial towns. Mg also has higher values in agricultural and urban and rural lands than in other uses. The amount of As was the highest in the lause of greenhouses, and the least amount of this element was observed in urban and rural areas. The lowest amount of mercury was observed in landuse of greenhouses and the highest amount was observed in cemeteries, tombs, oil and gas companies landuses.

3.1.4 Homogeneous land use groups based on ANOVA and Duncan test

In order to test the assumptions in the discussion of changes in the concentration of elements in the studied land uses, the results of ANOVA and comparison of averages using Duncan's method (**u47**) show that two homogeneous groups of land uses are observed in the case of Ni, Zn, As and Mg. The first group includes agricultural, urban and rural lands, oil and gas companies, industrial towns, cemeteries and tombs. In the second group, the land use of agricultural land is excluded, but the other two landuses of scattered

Table 8. Values of potential environmental risk index (RI) in the study area.

Parameter/ Index	Tr	Cf	Terace metal	Background	Er	Pollution level	RI	Environmental risk level	NIPI
Pb	5	1.99	27.8	14.00	9.96	Low	208.46	Moderate	unpolluted
Cd	30	5.15	1.03	0.20	154	Considerable	208.46	Moderate	unpolluted
Cu	5	5.15	11.4	2.23	25.7	Low	208.46	Moderate	unpolluted
Ni	5	1.06	84.9	80.0	5.31	Low	208.46	Moderate	unpolluted
Zn	1	1.18	98	83.3	1.18	Low	208.46	Moderate	unpolluted
As	10	1.18	132	112	11.7	Low	208.46	Moderate	unpolluted
Pb	5	1.99	27.8	14.00	9.96	Low	208.46	Moderate	unpolluted

Table 9. The Contamination Security Index (CSI) values in the study area.

Element	ERM	ERL	CSI	Intensity of pollution
Pb	255	41.2	0.4	No pollution
Cd	12.3	3.3	1.2	Low
Cu	270	42	0.9	Very Low
Ni	62.3	18.5	0.85	Very Low
Zn	385	36.3	0.83	Very Low
As	68.3	12.3	2.3	Moderate

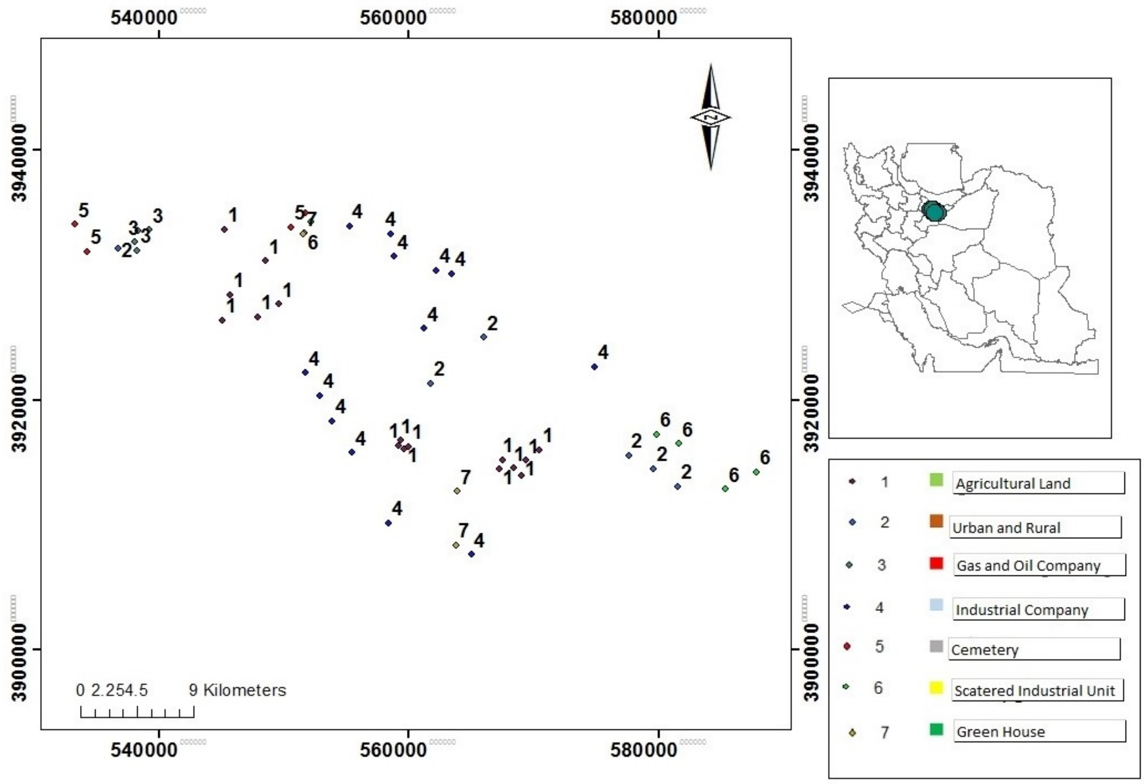

Figure 3. Distribution of sampled land use in study area.

industrial workshops and greenhouses are included. Metals Fe, Hg, Cu and Pb have similar behavior so that there is no significant difference between different land uses in terms of these three elements. Regarding the element Cd, the behavior of the landuse was very different, so that the greenhouse land use was not included in the first group, and in the second group, industrial companies, scattered industrial workshops, and agricultural land use were excluded. Regarding Mg, three groups can be observed. In the first group, there are no greenhouse land use and oil and gas companies. In the second group, there are no, cemeteries, and oil and gas companies land use, and in the third group there are urban and rural areas, greenhouses, and oil and gas companies landuses. In the case of Al, the behavior of the studied land uses has been somewhat different, so it can be said that the first group includes oil and gas companies, urban and rural areas, and industrial companies. The second group includes agricultural lands and oil and gas companies. In the third group there are greenhouses, scattered industrial workshops and cemeteries and tombs.

3.2 Hot spot analysis (Getis-Ord G_i^*)

Based on zoning maps of the hot and cold spot and Getis ord method (figures 5-6), it revealed that in case of AL, there is a small strip band of cold spot in the region (12% of total area) which means there is no evidence of pollution to this element in the studied area.in case of arsenic (As) and Cadmium (Cd) it could be observed a small hot spot covering the northern part with area less than 5% and central part respectively. For Cu hot spot area increased to 13% ,for Hg more than 50% area covering west and northern part of studied area showing hot spots and for Mn also it is considerable parts showing hot spots using Getis ord method. Gan et al. (2023), in study of metal pollution in agricultural soils, discuses that he relatively high values of the geo-accumulation index (Igeo) and the enrichment factor (EF) suggested that Sr, V, and Zn had cumulative trends in the soils. The average pollution load index (PLI) values of the industrial towns (1.19 and 0.99) were higher than those of the agricultural towns (0.92, 0.53, and 0.43), demonstrating the contribution of industrial activities to soil metal enrichment (Patra et al., 2023) also in remediation of lead toxicity using phosphorus in lead-contaminated agricultural soils. The results indicate that Pb × P interactions significantly decrease bioavailable soil-Pb concentrations by $38.9 - 43.9\%$. Likewise, interactions of Pb × day and P × day significantly reduce soil-Pb concentrations by $33.1 - 35.1$ and $31.8 - 33.6\%$ at different levels of Pb and P spiking, respectively. In this study, values of Geoaccumulation indices and enrichment factor indicate no pollution sign for the elements Pb, Cd, Ni and moderate pollution for Cu and Zn and allitle pollution sign for the As. values of potential environmental risk index (RI) in the study area shows the moderate environmental risk for the elements considered in the Table 7 and unpolluted condition based on Nemerow pollution index. Contamination Security Index (CSI) values in the study area (Table 8) present values of 2.3 for the As element which means moderate intensity of pollution and $0.4 - 0.85$ to other elements of the Table 8, which means no pollution to very low pollution sign in the study area .Results of assessment of soil trace metal pollution in the Xuejiping mine area, Yunan, China (Chen et al., 2021b)

Figure 4. Percentage changes in the concentration of Pb, Al, Cd, As, Ni and Zn metals in different land uses in study area.

indicate that the surface soil of the Xuejiping mining area is moderately polluted by trace metal elements. Therefore, effective measures can be taken to control the trace metals pollution in the mining area (especially for Pb and Cu) (Neeraj et al., 2023) in study of current status of agricultural soil pollution by trace metals in Raebareli india .their study employed various pollutant indices and geographical information system (GIS) echniques. This research work evaluated the physiochemical properties, the pollution load index (PLI), contamination factor (CF) and the degree of contamination and geoaccumulation (Igeo) in sodic soils of the Raebareli District, Uttar Pradesh, India. The PLI values indicate that most of the study subSites come under a slightly polluted class, except US1 where the PLl was >3 indicating severe 'potentially toxic elements' pollution at this site. All the pollution indices have then been utilized for building maps using the IDW method of interpolation. The spatial projection of PLI and ecological risk index (Er) values suggest that the northern part of Raebareli has a high pollution load and ecological risk in terms of potentially toxic elements metal pollution. This study assessed trace metal contamination in surface soils of Rey City, Tehran, under different land uses, including agricultural, industrial, and urban zones. The results revealed significant variations in trace metal concentrations, with arsenic (As) and cadmium (Cd) exceeding global soil averages in more than 90% of the samples. The contamination factor (Cf) and potential ecological risk index (RI) classified Ni and As as major environmental threats, with industrial zones showing the highest levels of Zn, Ni, and Pb. The Getis-Ord hot spot analysis identified contamination clusters, particularly in industrial and urban areas, highlighting anthropogenic contributions to soil pollution. The application of pollution indices provided a comprehensive assessment of contamination levels. The geoaccumulation index (Igeo) and enrichment factor (EF) classified Zn and Cu as moderately enriched, whereas Pb and Ni showed no significant accumulation. This supports findings from Chen et al. (2021b), who noted that while some metals accumulate in soil, others remain within natural variability. The potential ecological risk index (RI) confirmed that Cd and As pose considerable ecological risks, similar to the results of Doabi et al. (2018) in Kermanshah Province, Iran. This study reinforces the anthropogenic influence theory (Cai et al., 2019), which states that industrial activities, traffic emissions, and urban development significantly alter soil metal concentrations. The spatial distribution of metals, particularly in industrial areas, supports the land use contamination model, which predicts

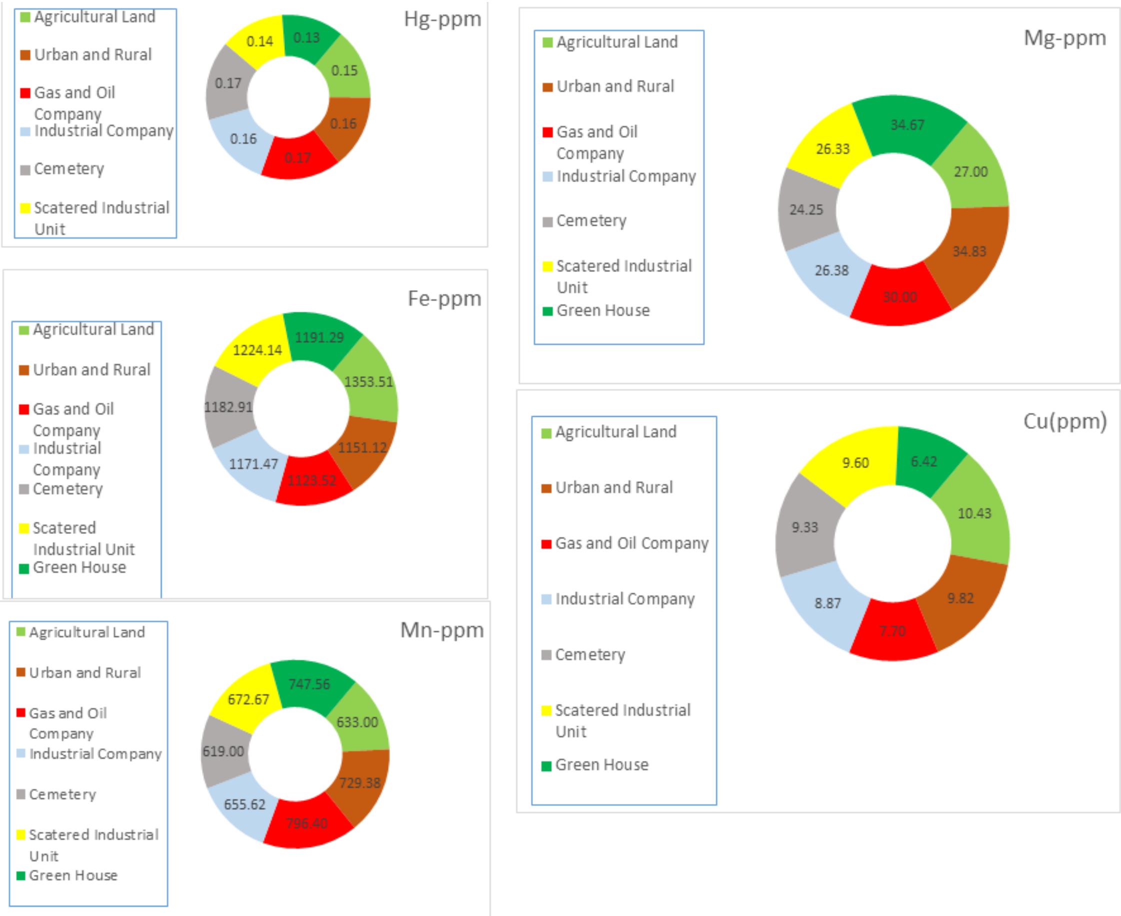

Figure 5. Percentage changes in the concentration of Hg,Mg, Fe, Mn and Cu metals in different land uses in study area.

that high human activity zones correspond to elevated pollution levels (Kowalska et al., 2021). Our results validate the effectiveness of multi-indicator approaches in assessing soil contamination. While Igeo and EF provided insights into metal accumulation, RI and Nemerow's pollution index offered a broader ecological risk assessment. This aligns with Wei et al. (2023), who argued that combining multiple indices enhances pollution evaluation accuracy.

4. Conclusion

Along with the increasing growth of industry and technology, the entry of environmental pollutants, especially terace metals into the soil, has caused the growing concerns of the world community about the possible dangers of soil resource pollution. Due to the multiplicity of sources of polluting terace metals entering the soil, these dangerous elements are often found together in the soil environment, and as a result, the correct assessment of the risk of environmental pollution requires simultaneous attention to all existing pollutants. Soil contamination with terace metals is one of the most important environmental problems around the world. Since these metals are absorbed by plants and fruits and transferred to humans, this issue is more serious in the case of agricultural and garden soils. Therefore, considering the possibility of accumulation in the food chain and endangering the health of living organisms, it is necessary to investigate the concentration and dispersion of these metals in different soils, including agricultural soil. Descriptive statistics of total concentration of terace metals in soil samples are shown in Table 2-4. The concentration range of terace metals in the soil ranges from 6.75 to 255.9 mg/kg for Pb, 0.1 to 3.65 mg/kg for Cd, 55.7 to 357.15 mg/kg for As, It was 5.05 to 34.05 mg/kg for Cu, 26.65 to 171.95 mg/kg for Ni, and 13.15 to 858 mg/kg for Zn. The average concentration of Pb, Cd, As, Cu, Ni and Zn was 27.88, 1.03, 132.78, 11.48, 84.98 and 98.04 mg/kg respectively. Therefore, the concentration trend of terace metals based on the average is as follows: As > Zn > Ni > Pb > Cu > Cd. About 90% and 100% of the soil samples have higher concentrations of Cd and As, respectively, than the global soil average, which is a threat to human health and a serious risk to the surrounding ecosystems. According to the soil quality standard the concentration of Ni and As is higher than the standard . The coefficient of variation is used to show the degree of variability of soil terace metals.in witch values of 20% $\geq$ CV (low variability), 50% $\geq$ CV > 21% (moderate variability), 100% $\geq$ CV >50% (high variability) and 100% < CV (very high variability) (Siu et al., 2015). The basis of this classification is the percentage of coefficient of variation of terace metal that calculated as follow in the region: (26%) Cu > (29%) As > (35%) Ni > (60%) Cd > (111%) > Pb > (125%) Zn. The percentage of coefficient of variation of Zn and Pb is very high and which means it is

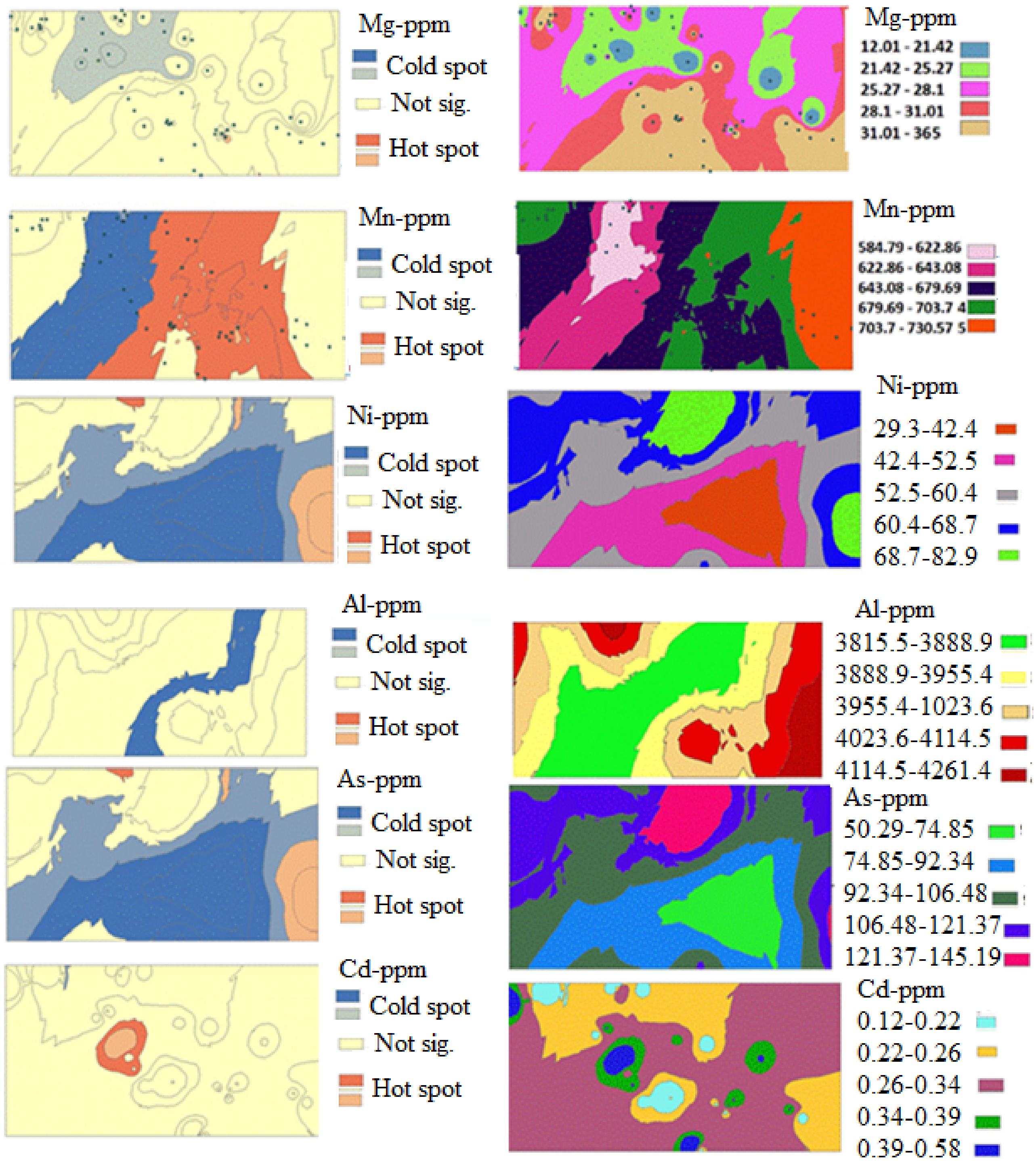

Figure 6. Distribution map of spatial changes and hot and cold spots of Mg, Mn, Ni, Al, As, Cd concentration in the study area based on the Getis-Ord method.

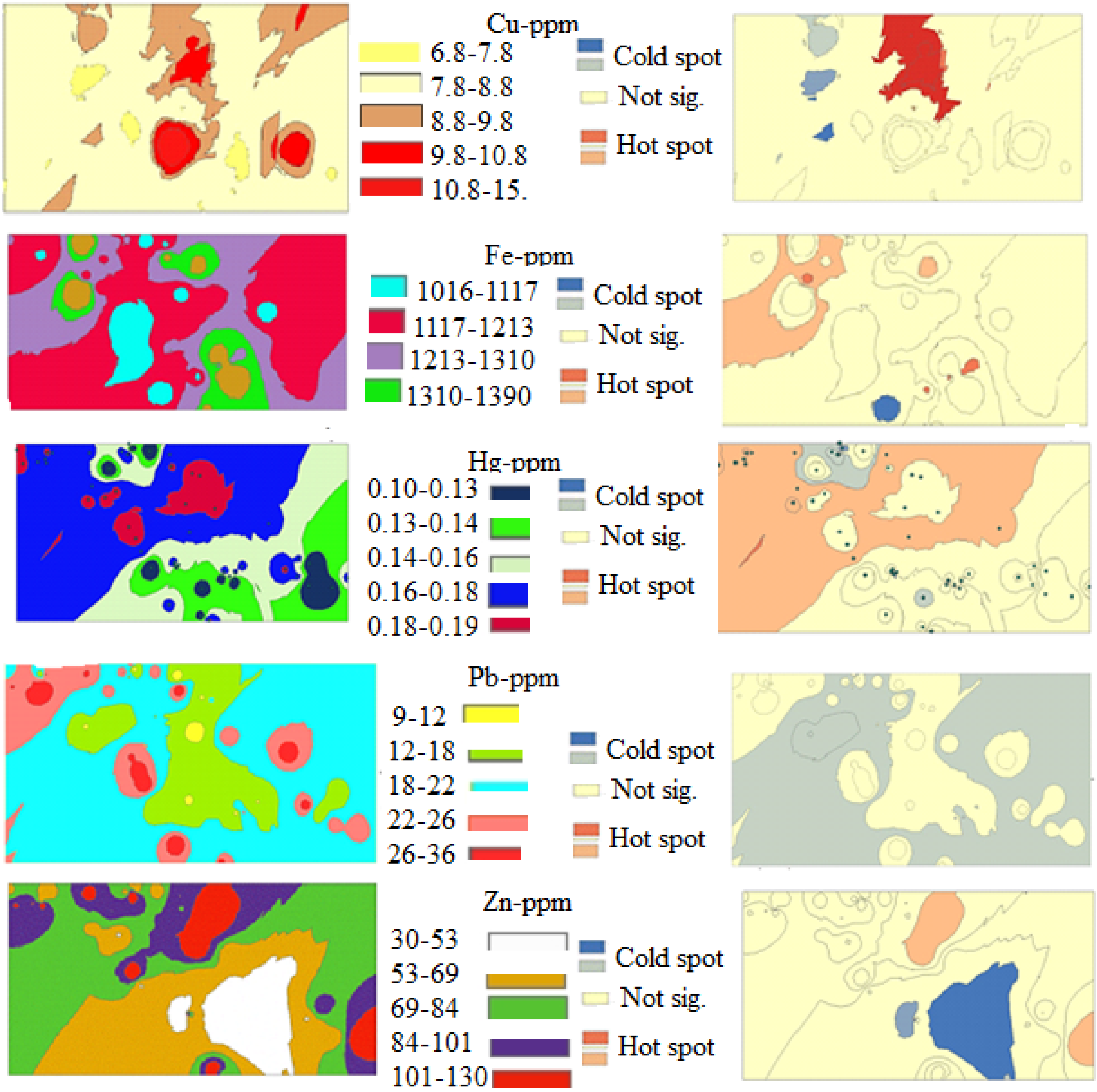

Figure 7. Distribution map of spatial changes and hot and cold spots of Cu, Fe, Hg, Pb, Zn concentration in the study area based on the Getis-Ord method.

possible that these metals are affected by external factors such as human activities.The southern area of Tehran city, especially Ray city, is currently prone to environmental pollution due to the increasing development of urbanization, the expansion of industries and industrial factories, and the high use of water and soil resources in the region. The executive bodies of the government are heavily involved with the challenge of environmental pollution of water and soil resources, and therefore, investigating the impact of different land uses on surface soil pollution in the region can be used in macro-decisions and government policies and urban planning and the municipality effectively. In this research, the basic hypotheses were considered as follows, which will be evaluated according to the results of this research. The first hypothesis that was considered is "the sameness of the effect of different land uses on surface soil pollution". To test the mentioned assumption, the results of analysis of variance and comparison of averages using Duncan's method show that in the case of Ni, Zn, As and Mg, two homogeneous groups of land uses are observed. The first group includes agricultural, urban and rural lands, oil and gas companies, industrial towns, cemeteries and tombs. In the second group, the land use of agricultural land is excluded, but the other two uses of scattered industrial workshops and greenhouses are included. Metals Fe, Hg, Cu and Pb have similar behavior so that there is no significant difference between different uses in terms of these three elements. Regarding the element Cd, the behavior of the users was very different, so that the greenhouse use was not included in the first group, and in the second group, industrial companies, scattered industrial workshops, and agricultural lands were excluded. Regarding Mg, three groups can be observed. In the first group, there are no greenhouse lands and oil and gas companies. In the second group, there are no aramgas, cemeteries, and oil and gas companies, and in the third group are urban and rural areas, greenhouses, and oil and gas companies. In the case of Al, the behavior of the studied land uses has been somewhat different, so it can be said that the first group includes oil and gas companies, urban and rural areas, and industrial companies. The second group includes agricultural lands and oil and gas companies. In the third group there are greenhouses, scattered industrial workshops and cemeteries and tombs. In general the study found that different land uses have varying effects on surface soil pollution with terace metals, with some land uses showing higher concentrations of certain metals than others. The concentration trend of terace metals based on the average concentration is as follows: As > Zn > Ni > Pb > Cu > Cd. The soil samples in the study area had higher concentrations of Cd and As compared to the global soil average, posing a threat to human health and surrounding ecosystems. The concentration of Ni and As in the soil exceeded the soil quality standard of Canada, indicating potential risks to the environment and human health. The behavior of land uses in relation to terace metal pollution varied, and the impact of land use on pollution levels differed depending on the specific element being studied. The accumulation of terace metals in the soil was influenced by the type of land use, rejecting the assumption that accumulation is independent of land use. comparing the paper with the literarature review it is obvious that, the paper contributes to the existing literature by investigating the recognition and prioritization of different land use effects on surface soil contamination with terace metals in Rey City, Tehran Province .It provides insights into the behavior of terace metals in soil, their potential risks to human health and ecosystems, and the need for effective pollution indicators for assessing and managing terace metal pollution. Continuous monitoring of soil properties in urban and industrial environments is one of the necessities of today's society. Therefore, based on the results of this research, it is suggested to continuously monitor the quality of soil elements in urban environments. Temporal changes, especially seasonal changes, and examining the amount of changes in the time scale are among the needs of future research in this field. Preparation of zoning maps of soil properties and their periodic updating in similar areas is one of the necessities of urban management. This study contributes to the growing body of research on soil contamination by trace metals, particularly in urban and industrial settings. By investigating the effects of different land uses on surface soil pollution in Rey City, Tehran, the research provides a comprehensive assessment of contamination sources, risk levels, and spatial distribution patterns of key trace metals. One of the main contributions of this study is the application of multiple pollution indicators (Igeo, EF, RI, NIPI, CSI) to assess both contamination levels and ecological risks. The findings validate the effectiveness of these indicators in identifying pollution trends, reinforcing previous research (Kowalska et al., 2021; Wei et al., 2023). Furthermore, the integration of hot spot analysis (Getis-Ord Gi)*demonstrates a spatial approach to pollution assessment, providing new insights into contamination clustering patterns.This study deepens our understanding of how different land uses impact trace metal accumulation in soils. The research confirms that industrial zones contribute the most to Zn, Ni, and Pb pollution, while agricultural lands are more affected by Cd and As contamination, which has serious implications for food safety and human health. These findings align with global research (Gan et al., 2023; Neeraj et al., 2023) and highlight the importance of site-specific pollution management strategies. From a policy perspective, this study underscores the urgent need for soil monitoring programs, stricter industrial regulations, and land-use planning that integrates contamination data. The results provide valuable guidance for policymakers, urban planners, and environmental managers to design targeted remediation efforts and preventive measures to reduce soil pollution risks.

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Authors contributions
Authors have contributed equally in preparing and writing the manuscript.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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

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