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Distribution and risk assessment of toxic metal pollution in the soil and sediment around the copper mine

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Abstract

Background: Industrial pollution of metals is a serious environmental concern. The presence of Sarcheshmeh copper (Cu) mine and the possibility of soil pollution, were the primary motivations for evaluating heavy metals in this area.

Methods: A total of 171 soil and 10 sediment samples were collected randomly from the study area for Cu, aluminum (Al), molybdenum (Mo), lead (Pb), and cadmium (Cd) determination. The USEPA method was used to acid digest soil samples, and metals present in the samples were detected using atomic absorption spectroscopy.

Results: By measuring metal concentrations and calculating the geo-accumulation index (I_{geo}), enrichment factor (EF), and contamination factor (CF), the level of soil pollution by metals was assessed. It was found that soil and sediment samples were contaminated with Cu and the pollution decreased from the mine to Rafsanjan city, indicating that the pollution was anthropogenic. The soil has not been poisoned by Al or non-natural states because it was alkaline. Sediment samples were less than moderately polluted by Mo and Pb, but Cd and Cu were more problematic.

Conclusion: Increasing the distance from the Cu mine resulted in a decrease in toxic metal concentration. The study concludes that by monitoring and filtering wastewater from the Cu mine, pollution caused by trace elements in the soil can be greatly reduced.

Keywords: Copper mine, Heavy metal pollution, Risk assessment, Sediments

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Introduction

In the environment, heavy metals originate both from natural and anthropogenic sources. Considering their toxicity, bioaccumulation, and persistence, they have captured significant attention in recent years. Polluting media such as air (1), soil, water (2,3), and sediments (4) with excess emissions and accumulations of heavy metals may affect ecological protection and human health (4). Because most heavy metals are not degradable, they do not undergo microbial or chemical degradation, and as a result, their total concentrations persist for a long period after they are discharged into the environment. Heavy metals in soils are a severe problem because they accumulate in food chains, damaging the entire ecosystem. Heavy metals pose threats to humans, animals, plants, and ecosystems in general in a variety of ways (5). Soil has always been important to humans and their health, and it is an integral part of both urban and non-urban ecosystems (6). It is subjected to both natural and anthropogenic metal deposition, which includes particles from soil erosion, road building, industrial pollutants, and mining (7,8). Metal poisoning of soil has received a lot of attention in recent decades as a way to prevent additional environmental degradation. Trace metals in soil are regarded as an important indicator of the effects of human activity (9,10). Information about the distribution of metals in the soil is essential because it affects environment (11,12) and human health. As the effect of sources on the pollution of river sediments depends on the morphology of riverbeds and hydrological conditions, the particles and pollutant material are moved far away from the source of pollution (13). The source of trace metal in surface soils can be studied by multivariate geostatistical models (14). Among all various types of metal contaminants, heavy metals are dangerous for their ubiquity, toxicity, and persistence (15), and many researchers have studied this subject around the world. Some of the newest researches have been done in India

(16), Australia (17), and Vietnam (18). The low density of trace metals is necessary for the normal growth of living organisms, but high concentrations of these metals may cause toxicity. For example, copper (Cu) is a vital element, but it becomes toxic at elevated levels; thus, the level of Cu in natural environments is important. Cu is freed into waterways as a result of natural weathering of soils and rocks, anthropogenic sources, or soil disturbances. Trace elements are different in chemical properties. They are used extensively in high technology usages. As a result, they are released to the natural environment from human resources and natural geochemical activities (19-22)

In acidic habitats, aluminum (Al) toxicity is a significant factor impacting plant and aquatic biota growth (23). As pH drops, the oxide surfaces, particularly iron and manganese, Al oxides, carbonate surfaces, and insoluble organic materials may generate large positive charges (24). If pH decreases in soil, the density of soluble Al, which is toxic, increases (25). Total Al, as a direct measure of Al toxicity, is often measured in the soil as it provides useful information on soil property with respect to the origin of parent materials and weathering. It is also used as a basis for calculating the mineralogical composition of samples (26). The emission of gases containing sulfur compounds in industrial areas can be caused by acidic rains. Oxidation of sulfur compounds in the soil can also cause the release of Al from soil particles. Also, industrial wastewater causes increased contamination of Al in soil (27).

This research follows the previous studies conducted by this author on contamination of soil by cadmium (Cd), molybdenum (Mo), and lead (Pb) in this area (28). Therefore, to continue and complete this study, the present research aimed to determine the characteristics of the pollution caused by Al and Cu in the catchment area soil affected by the Sarcheshmeh Cu mine. In addition, Cd, Mo, and Pb, that were tested in the previous study in soil, were also measured in sediment samples from the Shoor River in this study.

Material and Methods

Study area

Sarcheshmeh is a large open-pit Cu mine in Kerman, Iran, and the second-largest Cu deposit in the world. The Sarcheshmeh Cu complex is placed 65 km southwest of Kerman and 50 km south of Rafsanjan. The average height of the region is 2600 m, the highest point is around 3000 m. The Sarcheshmeh ore bodies, located in the central part of the Zagros mountain ranges, are composed of folded and discarded Early Tertiary volcanic sedimentary rocks (29). The statistics and all information pertaining to the watershed of the upstream river that flows into the tailing dam of Cu factory in Sarcheshmeh as well as its shallow section were gathered from statistics and information resources of soil, water, geology, topography, hydrology, lithology, operation of soil and water resources, waterways network, physiography, weather, and climate. The statistics and data pertaining to the watershed of the two branches of Shoor river that join each other in the tailing dam, and those belonging to the shallow section of the dam were gathered through monitoring the desert, preparing maps as well as collecting descriptive and basic data, especially those related to statistics and information of weather and climate, soil survey, geology, lithology, geology geomorphology, topography, physiography, topography, soil survey, exploitation of lands, hydrology, the quality of surface groundwater and surface water.

Basic maps for determining the sampling area

In this section, the unit works map shown in Figure 1 was provided by slope and lithology maps; the homogeneity of working units was also determined through not only collecting the maps, but also, incorporating differences and similarities of the above-mentioned details in downstream and upstream parts of the tailing dam of Sarcheshmeh Cu factory. The maps of work units were prepared by integrating slope into lithology maps, and then, similar units were sampled from different points of the field under study.

In this study, the geographic information system (GIS) analysis with ArcGIS software ILWIS 2.1 (Esri, Redlands, CA, the USA) was used to process and prepare soil pollution zone maps. The Kriging method and the Spherical model were used to create continuous data layers and estimate residential exposure to pollution. Kriging is an advanced geo-statistical technique that produces surfaces estimated from a series of distributed values, enabling the interactive study of spatial behavior in the case of trace metal soil pollution.

Sampling and analysis

A total of 171 soil (3 depths) and 10 sediment samples were collected from the study area. In the study area, rock outcrops confined to thin soil were observed. The soil samples were comprised of three units of 57 sample sites and were collected from three depths, 0-10, 10-20, and 20-40 cm from Sarcheshmeh area work units, as shown in Figure 2.

The soil samples were prepared by mixing 4-10 subsamples from each work unit. To determine the level of trace elements in river sediments, for each kilometer of the length of the river as far as possible, a sample of sediments was prepared to a maximum depth of 40 cm. In the case of sediment sampling, due to the droughts of recent years, a large length of the river had dried up. About 1 kg of each soil and sediment sample was collected by a stainless-steel spade and stored in a clean polyethylene bag. Each bag was marked for sample identification, and then, the samples were sent to the laboratory. The spade was washed with distilled water and wiped dry with paper towels between each sampling. The geographical coordinates of sampling locations were recorded at each sampling point by a global positioning system (GPS).

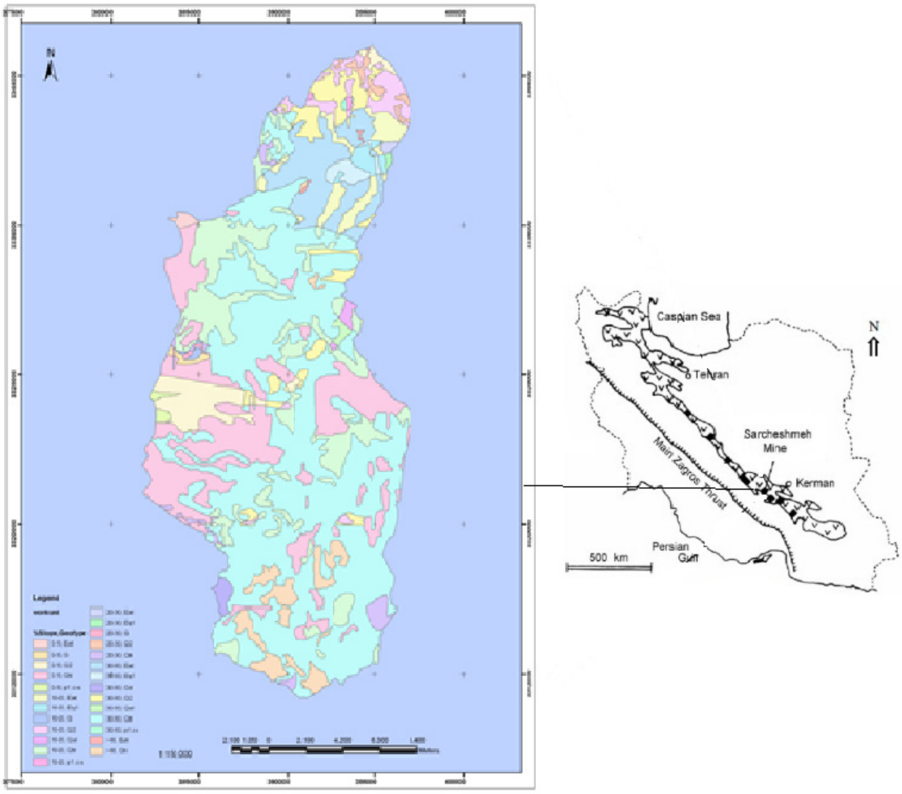

Figure 1. The map of unit works in the study area.

Chemical analytic method

All soil and sediment samples were lightly dried at room temperature, ground, and sieved through a 2 mm polyethylene sieve. All processing was performed without any metal contact to avoid the possibility of cross-contamination of the sample. Soil texture and particle size were determined using the hydrometer method (30), and organic matter extent was determined by the Walkley-Black method (31). Soil pH and electrical conductivity (EC) were obtained in saturation paste extract. For metals determination, 1 g of the powdered and dry soil was placed in a distillation flask, coated with 10 mL of concentrated HNO_3, and heated to 95°C for 30 minutes to determine metals. Afterward, another 10 mL of HNO_3 was added, and the mixture was then boiled under reflux until the sample became bright. The mixture was heated again after adding 10 mL of 6N HCl. Then, it was diluted with 20 mL of water and filtered into a 50 ml volumetric flask to volume (32). After the preparation of the sample, Al and Cu in the soil samples, Cd, Mo, and Pb in sediments were measured by atomic absorption spectroscopy (AA Seri Termoelemental, UK). Standard reference materials from Merck Company were used as standard solutions for calibration and quality control.

Statistical analysis

In this study, all statistical analyses were performed using MSTAT-C software by Duncan's multiple range tests at a 1% level of probability. A randomized complete block design was used in the variance analysis. The geochemical maps of metals were obtained using the geo-statistical analysis of the geographical information with ArcGIS software ILWIS 2.1.

Methods for pollutant effect assessment

There are various methods and indicators used to comprehensively assess the extent of heavy metal contamination and ecological risks in soil and sediment, such as the geo-accumulation index (I_{geo}), enrichment factor (EF), and contamination factor (CF). The geo-accumulation index that has been defined by Muller is calculated using the following equation (33):

$$I(geo) = \log_2\left(\frac{Cn}{1.5Bn}\right) \quad (1)$$

Where C_n is the average metal concentration in the soil and B_n is the background metal concentration, a value of 1.5 has been defined to minimize the effect of feasible variations in the background value attributable to lithological variations in soils. Müller proposed the classes for increasing I_{geo} values that are shown in Table 1.

An EF was used for investigation of soil contamination. It is a method for determining how much of a possibly contaminant-derived element has accumulated in an environmental sample in comparison to a user-defined background composition. Assessment of EF is a common way to examine anthropogenic influences on soils and sediments. It can also help figure out how to tell the difference between man-made and natural metals. It has been defined in some papers as Eq. (2):

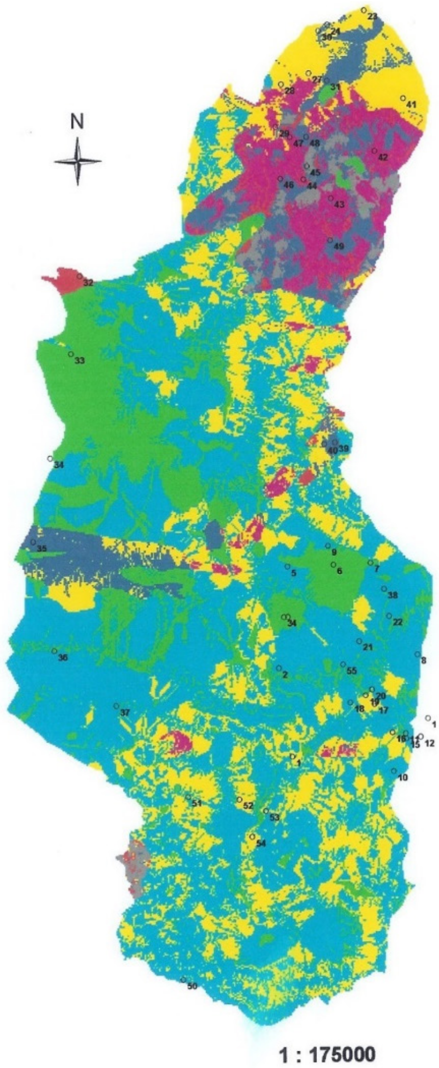

Figure 2. Study area and location of sample sites.

$$EF= (C_n/C_{ref})/(B_n/B_{ref}) \quad (2)$$

Where, C_n is the content of the element to be investigated in the soil, C_{ref} is the content of the element to be investigated in the crust, B_n is the content of the reference element in the soil, and B_{ref} is the content of the reference element in the crust. An EF value <10 indicates a natural background metal source. The soil sample EF is calculated by comparing an immobilized metal as a reference element. Reference elements that are most commonly used, like zirconium (Zr), titanium (Ti), iron (Fe), and scandium (Sc), are indicated by researchers. Since Deely and Fergusson concluded that the distribution of Fe had nothing to do with the distribution of other heavy metals, they offered Fe as a valid normalizing element for computing the EF (35). Because Fe occurs naturally in the upper continental crust, it was utilized as the reference element in this study. It is crucial to investigate heavy metal enrichment and accumulation variables in order to find human activities that have an impact on the environment in the study area.

The CF determines the level of pollution in the soil. The CF is calculated by dividing the heavy metal content in soil or sediment by the background quantity (Eq. 3).

$$CF=C_{sample}/C_{background} \quad (3)$$

Where *C* is the concentration of metals, which can be graded on a scale of 1 to 6, from low to very high potency, as illustrated in Table 1 (36,37).

Results

Concentration of metals

Concentration of Al and Cu in the soil around Sarcheshmeh area is presented in Table 2.

The mean concentration of Al increased at a depth of 10-20 cm, but there was no statistical significant difference between the depths for Cu and Al. Moreover, comparative evaluation of calculated Cu element median in different depths showed intense contamination in topsoil. It appears that Cu deposited from smelter plant emissions

Table 1. The level of metal contamination according to seven enrichment classes

Class	Value (I_{geo})	CF (34)	
0	<0	0	Not polluted
1	0-1	1<	Not polluted to rather polluted
2	1-2	1<3	Rather polluted
3	2-3	-	Rather to highly polluted
4	3-4	-	Highly polluted
5	4-5	3<6	Seriously polluted
6	5<	<6	Exceedingly polluted

Table 2. Concentration of Al and Cu (mg/kg) in the soil of Sarcheshmeh area

Depth (cm)	Metal	Min	Max	Mean	SD	CV
0-10	Al	2368.70	69352.00	17717.83	10740.38	0.61
10-20	Al	6015.65	126727.60	18344.80	16515.75	0.90
20-40	Al	1687.85	71833	17462.59	11358.73	0.65
0-10	Cu	0.30	5000.19	553.21	1246.64	2.25
10-20	Cu	2.00	4993.50	345.89	912.49	2.64
20-40	Cu	4.50	4154.01	180.49	586.84	3.25

Abbreviations: CV, coefficient of variation
Confidence limits 99%.

has relatively little mobility within the soil from mine to city. In this study, sampling points were used as replicates, and sampling depths were used as a treatment for variance analysis. Table 3 shows the mean square of soil samples. The results of variance analysis showed that there was no significant difference in all elements in sampling points at a confidence level of 99%.

A normal soil sample was collected and compared to other work (38) in the study area to show the background or reference values of the unmineralized and unpolluted zones. For Cu, Pb, Mo, Cd, and Al, the average background concentrations were 41.2, 12.65, 1.8, 0.22, and 15052.50 mg/kg, respectively. Then, I_{geo}, EF, and CF were calculated for these metals in the soil and sediment results. Their mean results for Al and Cu in soil samples are shown in Table 4.

The distribution maps of metals in the soil around the Sarcheshmeh Cu mine were drawn to display pollution in this area more clearly. As shown in Figure 3, Sarcheshmeh Cu mine did not have a special effect on soil pollution by Al. The comparison of the means of Cu level in the three sampling depths shows that they are located in the “a” and “b” classes. Also, as shown in Figure 3, the concentration of Cu reduces, as expected, with greater distance from the mine and Sarcheshmeh town to the city of Rafsanjan. There was also no significant difference for Cu in the two depths, 10-20 and 20-40 cm, and the highest Cu concentration was found at a depth of 10-20 cm.

In Table 5, the physicochemical parameters of soil samples and statistical data on their main characteristics, such as pH and EC values, and soil texture are displayed. That shows all soil samples have a slightly alkaline pH ranging from 7.6 to 8.4 in general.

The physical properties of soil samples were determined based on their texture, as shown in Table 5, indicating the sandy loam of this area mostly.

Due to drought and the seasonal nature of the Shoor River, a section of the river has been exhausted to the point of becoming a passage for vehicles, so the number of sediment samples obtained from the river was restricted, as shown in Table 6. The minimum and maximum values of Al in the sediment samples were 10381 and 13518 mg/kg, and for Cu, 120 and 141 mg/kg, respectively. In addition, the accuracy and precision of the metal analysis were over 90%, except that for Al, it was 84% and 81%,

Table 3. The mean square of soil samples

Resources of variation	Degree of freedom	Mean of squares	
		Al	Cu
Replicate (sampling points)	55	2395.36	537.27
Treatment (sampling depths)	2	437.77n.s	243.94
Total	110	1006.071	10.86

All elements and amounts are in 99% confidence level.

Table 4. The results of I_{geo}, EF, and CF for Al and Cu in the soil samples

	I_{geo} (Al)	EF (Al)	CF (Al)	I_{geo} (Cu)	EF(Cu)	CF (Cu)
Max	1.18	3.55	3.41	6.34	100.29	121.18
Min	-1.52	0.54	0.52	-3.42	0.12	0.14
Average	-0.49	1.23	1.18	1.07	8.14	9.84
SD	0.63	0.68	0.66	1.83	20.14	28.07
CV	-1.27	0.56	0.56	1.71	2.47	2.85

Abbreviations: EF, enrichment factor, CF, contamination factor; SD, standard deviation; CV,coefficient of variation

Table 5. Statistical data on the main characteristics of the soil in the study area

Soil sample	Sand (%)	Silt (%)	Clay (%)	pH of Paste	Organic C (%)	EC (mS/cm)
Mean	77.85	11.78	10	7.94	0.09	0.78
SD	9.54	6.73	4.7	0.16	0.07	0.37
Min	52	2	4	7.6	0.01	0.44
Max	92	28	20	8.4	0.32	1.90

Abbreviations: SD, standard deviation; EC, electrical conductivity.

Table 6. Concentration of heavy metals in the river sediments

Metal	Sample										Mean	SD	CV
	1	2	3	4	5	6	7	8	9	10			
Al (mg/kg)	12510	11381	12412	13518	12810	12518	10381	11591	11861	10591	11957.30	989.756	970.712
Cu (mg/kg)	131.980	129.030	138.990	140.980	138.050	132.990	120.020	127.970	130.060	127.040	131.711	6.352	0.048
Pb (mg/kg)	33.000	30.900	29.500	34.500	33.900	32.900	35.500	37.900	36.900	38.300	34.330	2.898	0.080
Mo (mg/kg)	5.000	4.910	5.300	5.900	5.500	5.300	4.300	4.700	5.100	5.500	5.151	0.454	0.088
Cd (mg/kg)	0.800	0.780	0.890	0.910	0.830	0.790	0.610	0.680	0.710	0.630	0.760	0.103	0.134

Abbreviations: SD, standard deviation; CV, coefficient of variation .

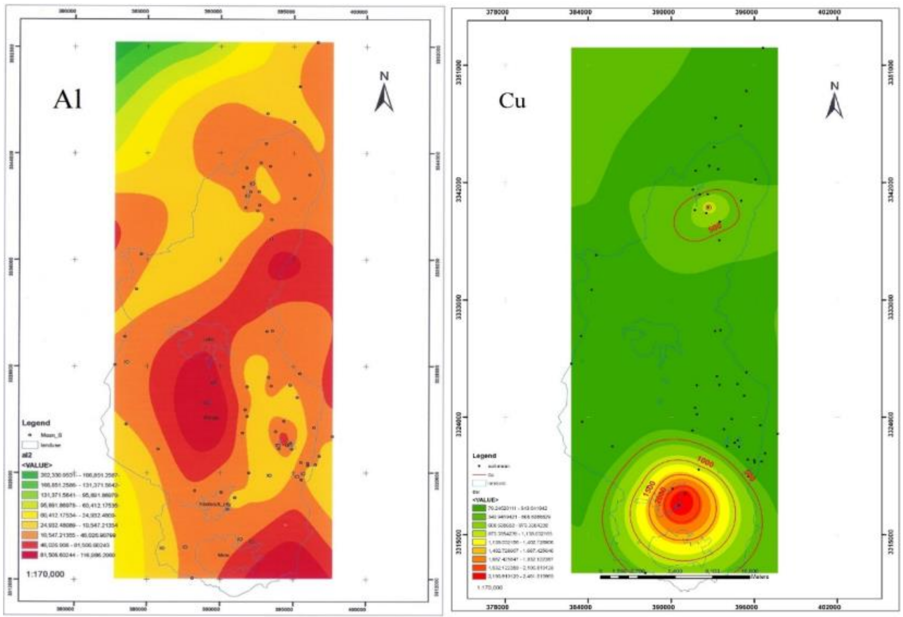

Figure 3. Distribution maps of Al and Cu in soil around Sarcheshmeh copper mine for the means of 3 depths.

respectively.

The evaluation of heavy metal contamination in sediment was accomplished by EF, CF, and geo-accumulation index calculations (Table 7).

Discussion

According to Table 2, the mean values of Al and Cu existing in three depths of 0-10, 10-20, and 20-40 cm, were 17717.83 and 553.21, 18344.80 and 345.89, and 17462.59 and 180.49 mg/kg, respectively. The mean concentration of Cu in the soil of the area surrounding Sarcheshmeh Cu mine decreased in the order of 0-10 > 10-20 > 20-40 cm depths. It shows that the concentration of Cu reduced with distance from the mine in deep levels of the soil, which could indicate the role of the mine in Cu contamination of the region's soils.

The comparison of the means of sampling points in the soil of working units through Duncan's method demonstrated that the mean concentration of Al does not change with the farther distance from the Cu mine to Rafsanjan city. Also, there was no significant difference for Al in the three depths. Since Al is dependent on the geology of the region, there was no specific trend of pollution dispersion. According to sources, contamination of Al was at the permitted limit. However, the mean concentration of Cu decreased, as expected, by taking a greater distance from the Cu mine to Rafsanjan city.

Table 7. The results of I_{geo}, EF, and CF for trace metals in the sediment samples

	Cd	Mo	Pb	Cu	Al
I_{geo}	1.23	0.92	0.85	1.09	-0.92
EF	0.41	1.4	1.71	2.66	0.83
CF	3.89	2.7	2.70	3.21	0.79

Abbreviations: EF, enrichment factor, CF, contamination factor

According to the mean value of I_{geo} compared to Table 1, the mean of soil samples has been contaminated by Cu and has decreased from mine to Rafsanjan. They have no Al contamination and do not follow a specific pattern by farther distance from the Cu mine to the city. Values of EF near to 1 demonstrate natural origin, while EF more than 10 arrive mainly from anthropogenic sources. Therefore, the average EF for Al that was slightly higher than 1 indicates a deviation from the natural state, and the mean Cu EF (EF =8.14) shows anthropogenic and non-natural states.

The mean values of CF for Cu and Al in the soil samples were obtained at 9.84 and 1.18, respectively. The maximum amounts were 121.18 and 3.41, and the minimum values were 0.14 and 0.52, respectively. According to Table 2, the soil samples pollution for Cu were very high and moderate for Al. But in in the minimum concentration, both Cu and Al had low contamination, and for maximum concentration, Cu had very high contamination and considerable for Al. Therefore, Al is mainly created from the earth, whereas Cu has also a man-made and unnatural origin and is mainly due to Cu mining and industrial emissions.

Due to the formation of calcium carbonate and evapotranspiration, soil pH values in dry and semi-arid areas generally range from 7 to 9. According to Table 5, since soil EC lower than 0.4 mS/cm is not considered saline and a value greater than 0.8 mS/cm is considered highly saline (39), the soil samples in the study area are moderately salty to severely salty. This can be effective in reducing the level of trace metals. The organic matter content was mainly about 0.9% and contained a low concentration of carbonates, indicating that the soil of its area is not calcareous. The amount of organic matter in any particular soil is the result of a wide variety of environments, some of which, such as climate and soil texture, are naturally occurring.

According to the environmental quality standards, soil with a Cu concentration lower than 125 mg/kg is appropriate for agricultural land. While the mean level of Cu in the soil of the Sarcheshmeh area was obtained at a level higher than the permissible level. The toxicity of Al is a potentially limiting factor for the growth of plants growing on acidic soils. The total Al concentration in the soil depends on Al species, pH, and the chemistry of the soil (40).

According to Table 7 and 1, and when compared to I_{geo}, it was observed that sediment samples have no Al contamination, near moderate pollution by Mo and Pb, and moderate pollution by cd and Cu. Comparing the CF shows that there was no pollution with Al, medium pollution by Mo and Pb. There was serious pollution by Cd and Cu. EFs for investigated metals show that contamination of them is not by anthropogenic sources.

The results of this investigation are definitely comparable to those of previous research. The highest quantities were found in samples obtained in the region of the pollution source in northern England. Increased distance from the pollution source resulted in a decrease in metal concentration (41). Researchers in Saudi Arabia discovered that all metals were concentrated on the surface of the soil and reduced in the lower layers (42). The highest concentration of heavy metals was found in topsoil near Dashkason's gold mine in Hamadan, Iran. As the distance from the mine was increased, the concentration of heavy metals gradually decreased (43). Heavy metals were seen in soil around the Imcheon gold-silver mine in Korea, as well. They also concluded that metal concentrations reduced exponentially as the distance from the mine increased (44). The results of heavy metal analysis of soil samples in Omdurman industrial area in Sudan showed that Pb, Cu, and Ni are the most important released trace metals in industrial areas (45). In Rudňany in Slovakia, soil and water pollution by heavy metals in an old mining area and their effect on soil properties were determined. They reported a significant positive correlation between zinc, Pb, and Cu ranges in soils. The most elevated and above-limit values of metals were detected in a downstream direction at a village (46). Rong et al. studied the contamination of heavy metals in water and soil from College Town in the Pearl River Delta. The concentration of some heavy metals, such as Cu, in their study was very low in comparison with the soil around Sarcheshmeh Cu mine (47).

Comparing the mean concentrations of toxic metals determined in this study with other research is shown in Table 8. As shown in this table, the average concentration of Cd was measured, and it was seen mostly in topsoil. Also, Sarcheshmeh has the highest pollution. Aluminium has not been studied in most research, but it exists in surface water, soil, and sediment of the Sarcheshmeh area. The comparative evaluation of the average concentrations of determining metals showed that the Sarcheshmeh area has the highest levels of these elements (Table 8). Also, this zone is seriously contaminated with Cu, Pb, Cd, and Mo more than other cities.

Conclusion

In the present research, the concentration of Cu decreased with increasing distance from the Cu mine and Sarcheshmeh town to the city of Rafsanjan. This, however, is not true for Al, therefore, Sarcheshmeh Cu mine did not have a specific effect on soil pollution by Al. The concentration of the other examined elements in sediment also decreased from the mine to the city. This finding was important to prevent metal pollution from spreading to industrial regions. Also, the results indicate that Sarcheshmeh and its surrounding areas are among the most polluted cities not only in Iran, but also, in many other countries. Therefore, the hypothetical approach in this study is useful in determining the overall ecological risk of the soil. Further studies are needed to identify unidentified potential hazards in the contaminated environmental areas of this region. Management strategies should be adopted to reduce pollution from industrial

Table 8. Comparison of toxic metal mean concentrations (mg/kg) with the results from some research

Study zone	Type of sample	Cu	Al	Cd	Mo	Pb	Reference
Sarcheshmeh/ Kerman/Iran	Sediment sewage	1373.500	-	-	21.210	62.660	(48)
Sarcheshmeh/ Kerman/Iran	soil	8430.000	-	17.200	61.00	331.000	(38)
Sarcheshmeh/ Kerman/Iran	Surface water	0.771	0.466	0.026	-	0.116	(49)
Rafsanjan/Kerman/Iran	Road dust	791.400	-	3.100	-	123.100	(50)
Zrand/Kerman/Iran	Air dust	0.805	-	0.006	-	2.490	(1)
Bu-Ali Hamedan/Iran	Groundwater	0.461	-	0.026	-	4.965	(11)
Babol/ Mazandaran/Iran	Agricultural soil	-	-	0.570	-	29.900	(12)
18 provinces/China	Surface soil	28.60	-	0.24	-	28.86	(51)
Delhi city/India	Road dust	168.7	-	-	-	128.7	(52)
Sarcheshmeh/ Kerman/Iran	Soil and sediment	553.21	17717.83	0.76	5.151	34.330	This study

towns. Therefore, future investigations need to consider the water sources, plant uptake, and, consequently, human health in the area.

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Ethical issues
No life science threat was practiced in this research.

Competing interests
The authors declare that they have no conflict of interests.

Authors' contributions
All authors were equally involved in the data collection, analysis, and interpretation. All authors critically reviewed, refined, and approved the manuscript.

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