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Evaluation Of Heavy Element Removal And Environmental Risk Management Of Metal Mining Industries Using Statistical And Spatial Analysis

SEYED ALIREZA SHARIFI

e-mail: sharifi.ali.r@gmail.com

Markazi Provincial Office of the Department of Environment (DOE), Markazi, Iran.

Abstract

The purpose of this research is to evaluate the amount of heavy elements removal and environmental risk management of metal mining industries around the lead and zinc processing factory of Shahin (Lakan). The statistical analysis of the data was done using d multivariate inter-subject variance analysis and independent t-test. The risk assessment was carried out using the environmental risk index of heavy metals. According to results, the amount of lead, zinc, and cadmium was 251.8, 1153.4, and 3.16 mg/kg, respectively in the plants, and in the control area, it was 44.85, 48.4, and 0.12 mg/kg, respectively, which shows a significant difference. Ecological risk assessment showed that cadmium creates the lowest risk (0.009% in the high-risk category) and zinc creates the highest risk (0.019% of the area in the high-risk category). Also, the results of the environmental risk index showed that 99% of the region is in the low risk category and 0.01% of the region is in the medium risk category. Meanwhile, for lead metal, 0.06% was in the high risk category and 92% was in the critical risk category. Heavy elements in the east of the site will create more risk. In general, the area affected by the factory's activities has caused the accumulation of cadmium, zinc and lead metals, and amount of risk created by them is related to zinc, lead and cadmium metals, respectively. Actually, the most important source of release of zinc metal in the soil of the region has been the activities of the factory.

Key words: *heavy metals, treatment plant, environmental risk index, Lakan lead and zinc processing factory*

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1. Introduction

Most developing countries try to provide the necessary financial resources for development by selling natural resources of any kind in the form of energy or raw materials in the world market to implement development programs (Litvinenko and Sergeev, 2019). In the event that these resources are used indiscriminately without compatibility with the environment, it disturbs the balance of the local and regional ecosystems and causes irreparable damage to the environment (Wassie, 2020). The quantity and quality of various types of pollution in different societies mainly depend on the degree of economic development, technology used, population distribution, environmental control methods and their general knowledge (Hsu et al., 2021). In the past decades, the introduction of pollutants of human origin such as heavy metals into ecosystems has increased to a great extent, which is considered a serious threat to the life of earth's ecosystems (Bashir et al., 2020; Alengebawy et al., 2021). Due to the nature of the accumulation of these metals and their durability and high resistance, the problems caused by them especially on the health of humans and living beings are aggravated (Mitra et al., 2022; Zaynab et al., 2022).

Extraction and processing of mineral materials as raw materials of many industries is considered as one of the most important economic activities (Xavier et al., 2021). This industry is considered as one of the polluting and destructive industries due to the creation of various pollutants, especially the production of hazardous wastes and tailings that contain pollutants, especially heavy metals (Chen et al., 2017; Zhu et al., 2018). In order to investigate the environmental problems caused by this industry, several studies have been conducted by different scientists, and some of these studies have focused on the effects of mining pollutants by examining the vegetation and soil of the affected area (Pagnanelli et al., 2004). ; Ma et al., 2015; Pan et al., 2016; Zhang and Wang, 2020; Zhao et al., 2022). In addition to soil, plant species with the abduction of toxic substances including heavy metals (accumulation process) as biological reagents are useful indicators for investigating the presence and distribution of heavy metals in the environment around the mine (Madejón et al., 2003). . As one of the methods of reducing and controlling heavy metals (remediation plants), they can also be considered in the purification of the environment around mineral extraction and processing factories (Ghosh and Maiti, 2021).

Del Rio et al. (2002) by evaluating the absorption of heavy metals and arsenic by vegetation as a result of the toxic spill of the Aznalcóllar mine in the Guadiamar river area, they concluded that many plant species, including gramineae species and dark cheese species, contain a very large amount of heavy metals. (lead, zinc, cadmium and copper). Khodadadi et al. (2009) investigated the possibility of transferring heavy metals to water sources from the tailings dam residues of the lead and zinc processing plant in Lakan. The parameters effective in the solubility of heavy metals and their transfer to the environment were used. The results show the most critical conditions in the solubility of heavy metals in the wastes of this factory and their transfer to water and soil sources, which ultimately has the greatest effect on the percent for zinc and nickel elements, and for cobalt, cadmium and lead elements, the pH factor. They had solvency.

Rodríguez et al. (2009) by investigating the distribution of heavy metals and chemical speciation in the tailings and soils around a lead and zinc mine in Spain, they concluded that the amount of heavy metals in agricultural lands and pastures around the mine is very high, that the two main reasons for the transfer of pollution, transport of particles It has been washed away by the wind and sewage of the dam. Moreno-Jiménez et al. (2011) by investigating the effect of Mediterranean shrubs for plant remediation of soil contaminated with pyrite waste in southern Spain, they concluded that the amount of absorption of metal elements is directly related to the

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acidity of the soil in the region. Deng et al. (2019) conducted a study regarding the content of heavy metals and the risk of cancer from cadmium in seven agricultural fields adjacent to pollution in Xiangtan city in southern China. Overall, the results of this study facilitated a better understanding of metal distribution characteristics and provided a scientific basis for further management of these rice fields. Gao et al. (2019) in a research focused on the accumulation and evaluation of pollutants in pipe rust and suspended sediments of drinking water distribution systems. The results showed that most of the sample sites have environmental risks. The results of the line assessment code showed that the high risk was mainly caused by cadmium in pipe rust and suspended sediments.

Examining the effects of mining pollutants by examining vegetation and soil using risk assessment methods is also considered a useful method to estimate damages caused by industrial development (Eijsackers et al., 2020). Ecological risk assessment is considered as a process to identify incompatible ecological effects that are likely to occur as a result of pressures caused by human activities (Suter, 2016). The aforementioned pressures can be of physical or chemical nature and cause incompatible negative effects of non-human ecological components at the level of organisms, populations, societies or ecosystems. Chemicals coming out of metal mining industries are an example of the pressures that enter the environment (Doležalová Weissmannová et al., 2019). In Iran, despite the high damage of heavy metal processing industries, the ecological assessment of the region, especially in terms of risk or damage estimation, has not been done correctly (Esmaeili et al., 2014; Mohammadi et al., 2020) and this research is also scientifically And it is the implementation needed by the country. Shahin lead and zinc processing factory is one of these industries that operates in the field of lead and zinc concentrate in the central province. The main process of the unit is the crushing of mineral rock and the concentration of the mentioned elements by water cycle and flotation method. During the process, the industrial effluent is produced and directed to the tailings dam site without any treatment. This tailings dam, which is a storage place for tailings, has an effective area of 10 to 15 hectares and is locally open-ended, and its surroundings are separated from the surrounding environment by earthworks. The wastes of solid materials have been piled up for 40-50 years and have formed a solid mass. After entering this part, the industrial wastewater loses its dryness and moisture with the passage of time, and its suspended particles, which probably contain metal elements and other compounds, settle down and become sediments. As the surface of the tailings dam dries with little wind, these particles are scattered in the surrounding environment, including pastures, agricultural lands, and residential areas (Sedibe et al., 2017; Du Plessis et al., 2021). Considering livestock grazing in these areas and the creation of seasonal water runoff and the possibility of contamination of these areas with heavy metal elements, it is necessary to carry out research in the field of assessing the amount of abduction and environmental management. Also, the use of environmental risk indicators and its combination with spatial information systems in the ecological risk assessment of mining industries adds to the research innovations.

2- Materials and methods

2-1- Study area

Lakan lead and zinc processing plant is located 46 kilometers southeast of Arak, and 1500 meters from Lakan village. Its location is located in a place with altitude 2190 above sea level. The area of Lakan mine is 15 hectares. The land area of the site and around the factory is 55 hectares. The total area under the control of Lakan mine is 70 hectares. Lakan factory is located in a temperate mountainous region with hot summers and cold winters. The annual temperature changes are

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very large and vary from -20 degrees in winter to +35 degrees Celsius in summer. Lakan area is located in the vicinity of Alvand protected area and due to its special topographical features, it includes a variety of habitats. The rain farming of the area is mainly grain cultivation. Besides wheat, all kinds of legumes and sugar beet are also grown in the fields with water culture. During the last years, the drilling of wells with different depths to reach underground water in a traditional and modern way has expanded a lot. The expansion of wells has expanded the area under water cultivation of agricultural products. The main environmental problem of this factory is the presence of dust from the tailings dam in the summer due to the drying of its water. The lead and zinc processing plant can cause pollution of the lands around the unit mainly through the particles coming from the tailings dam and the settling of these particles (Figure 1).

Figure 1- A view of the tailings dam and dust distribution from the tailings dam of the Lakan lead and zinc processing plant

2-2- Sampling

In order to investigate the degree of contamination of vegetation and soil in the area with heavy elements, the amount of lead, zinc and cadmium in soil and vegetation was measured from two contaminated areas (within a radius of 200 meters from the center of tailings dam) and control.

In plant sampling, three types of yellow gourd, artichoke and bulbous barley were used due to their abundance and as the dominant plants in the surrounding area according to the growing season of plants in the area in May 2020. In each region, three plant species Gunjelia tourneforti (artichoke), Hurdeum bulbosum (onion barley) and Astragalus parrowianus (yellow gorse) were sampled in three replicates. For each species in each site, plant samples were collected completely (roots and aerial parts) and transported to the laboratory with paper bags and dried at 80 degrees for testing.

The soil samples were collected at the plant sampling site and the soil samples were taken from the surface to a depth of 25 cm and after mixing with one hand, they were transferred to the laboratory in plastic bags.

2-3- Laboratory analysis

To measure the amount of heavy metals in the soil, the samples are sieved using a two millimeter sieve. Then, about two grams of the sifted soil were ground in a Chinese mortar to less than 80 microns. After being transferred to the laboratory, the plant samples were washed first with normal water and then three times with distilled water, and then placed in paper bags and completely dried in an oven at 80 degrees Celsius for 24 hours. Next, the samples were ground using an electric mill. The Daigesdal method was used to prepare the extracts of the samples. Determination of the concentration of zinc and lead elements in soil and plant samples was done

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using an atomic absorption spectrophotometric device (GBC-AWANTA) and the amount of cadmium was determined using a Varian ICP device (Karpiuk et al., 2016; Moss et al. ., 2010).

2-4- Data analysis method

In order to analyze the test data, SPSS 20.0 statistical software was used and Excel 2016 software was used to prepare graphs. The test method for the measurement of heavy metals in plants is multivariate inter-subject variance analysis (completely random) and for soil analysis, independent t-test (Nersesyan et al., 2022).

2-5- Environmental risk index of heavy metals

The environmental risk assessment should be expressed as the ratio of the concentration obtained for the desired substance in the environment to the concentration that is referred to as the risk index. The background concentration, the best concentration is used as the permissible concentration of metals In order to calculate the ecological risk index in the form of spatial zoning maps, samples were collected in four consecutive years (2016-2020), seasonally (spring, summer, autumn, winter) in two water environments (Nassar well, Makineh well and Ab Sher Lakan village) and soil (north, south, east and west of the site) were conducted and according to the description of section 2-3, the concentration values of three heavy metals cadmium, zinc and lead were determined.

Formula (1) was used to calculate the ecological risk index of each heavy metal in this study. For this purpose, the standard value considered for the heavy elements of lead, zinc and cadmium was determined based on the sources and included in the equation. Finally, the risk classification was obtained based on the cumulative risk index in Table (1) (Shi et al., 2021; Aboubakar et al., 2021):

$$I_{ERi} = \frac{A_{ci}}{R_{ci}} - 1 \quad (1)$$

A_{ci}: concentration in the environment

R_{ci}: permissible concentration of element in the environment

Classification of cumulative risk index

Risk class	Risk Index
no risk	$I_{ER} < 0$
low risk	$0 < I_{ER} \leq 1$
moderate risk	$1 < I_{ER} \leq 3$
high risk	$3 < I_{ER} \leq 5$
very high risk (critical)	$I_{ER} > 5$

3- Results

3-1- Comparison of heavy metal elements in plants

Table 2 shows the average amounts of lead, zinc and cadmium heavy metal elements in plants. Tables 3 to 5 show the amount of heavy metal elements in the plants of two areas adjacent to the factory and the control area based on multivariate inter-subject variance analysis. According to table 3 for the lead element, regarding the effect of the type of region, considering that p-value < 0.05 and F(1,24)=48.3, the effect of the type of region on the amount of lead in the plant is significant. In addition, considering that Eta squared = 0.668, the intensity of the effect of the type of area is high. Regarding the effect of the type of plant on the amount of lead absorption,

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considering that the p-value is >0.05 and F(2,24) = 0.767, the effect The type of plant is not significant on the amount of lead absorption. Regarding the type of plant organ (root and shoot), considering that p-value is <0.05 and F(1,24)=6.8, the effect of the type of plant organ on the amount of lead absorption It is meaningful. Also, since Eta = 0.22 squared, the intensity of the effect on absorption efficiency is high. Also, no significant effect was observed regarding the interaction effects, considering that the p-value is >0.05.
According to Table 4, for the zinc element, regarding the effect of the type of region, considering that p-value < 0.05 and F(1,24) = 22.3, the effect of the type of region on the amount of zinc in plants is significant. Also, since Eta = 0.48 squared, the intensity of the effect of the type of region on the amount of zinc metal in plants is high. Regarding the effect of plant type on zinc absorption rate, considering that the p-value is >0.05, the effect of plant type on zinc absorption rate is not significant. Regarding the type of plant organ (root and shoot), considering that p-value is <0.05 and F(1,24)=6.3, the effect of plant organ type on zinc metal absorption is significant. In addition, since Eta squared = 0.21, the intensity of the effect is high. Also, regarding the interactive effects (except for the interactive effect of the type of region and the type of species), considering that the p-value is <0.05, the effects are significant. .
According to Table 5, for the element cadmium, regarding the effect of the type of region, considering that p-value < 0.05 and F(1,24) = 30.4, the effect of the type of region on the amount of cadmium in plants is significant. In addition, since Eta = 5.6 squared, the intensity of the effect of the type of region on the amount of cadmium metal in plants is high. Regarding the effect of plant type on the amount of cadmium absorption, considering that the p-value is >0.05, the effect of plant type on the amount of cadmium absorption is not significant. Regarding the type of plant organ (root and shoot), considering that p-value <0.05 and F(1,24) = 10.7, the effect of plant organ type on the amount of cadmium metal absorption is significant. In addition, since Eta squared = 0.3, the intensity of the effect is high. Also, in the case of the interactive effect of the type of region and the type of plant organ and the interactive effect of the type of species and the type of plant organ, considering that the p-value is <0.05 , the effects are significant.

Table 2- Average amounts of lead, zinc and cadmium heavy metal elements in plants

Type of effect	control area ($^{Mg}/_{kg}$)	Contaminated area ($^{Mg}/_{kg}$)
Lead	44.85	251.8
Zinc	48.4	1153.4
Cadmium	0.12	3.16

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Table 3- Investigating the effects of factors on the amount of lead absorption in plants

Type of effect	Sig.	Partial Eta Squared	F	p-value
Area type effect	Yes	0.668	F(1,24)=48.3	< 0.05
Effect of plant species	No	-------	F(2,24)=0/767	> 0.05
The effect of the type of plant organ (root and shoot)	Yes	0.22	F(1,24)=6.8	< 0.05
The interactive effect of type of region and type of species	No	-------	F(2,24)=0.35	> 0.05
The interactive effect of type of region and type of plant organ	No	-------	F(1,24)=8.1	> 0.05
Interactive effect of type of region, type of species and type of plant organ	No	-------	F(2,24)=2.1	> 0.05

Table 4- Investigating the effects of factors on the amount of zinc absorption in plants

Type of effect	Sig.	Partial Eta Squared	F	p-value
Area type effect	Yes	0.48	F(1,24)=22.3	< 0.05
Effect of plant type	No	-------	------	>0.05
The effect of the type of plant organ (root and shoot)	Yes	0.21	F(1,24)=6.3	< 0.05
The interactive effect of type of region and type of species	No	------	------	>0.05
The interactive effect of type of region and type of plant organ	Yes	0.20	F(1,24)=6	< 0.05
The interactive effect of species type and plant organ type	Yes	0.29	F(1,24)=48	< 0.05
Interactive effect of type of region, type of species and type of plant organ	Yes	0.27	F(2,24)=4.6	< 0.05

Table 5- Investigating the effects of factors on the rate of cadmium absorption in plants

Type of effect	Sig.	Partial Eta Squared	F	p-value
Area type effect	Yes	0.56	F(1,24)=30.4	< 0.05
Effect of plant type	No	------	------	>0.05
The effect of the type of plant organ (root and shoot)	Yes	0.3	F(1,24)=10.7	< 0.05
The interactive effect of type of region and type of species	No	------	-------	>0.05
The interactive effect of type of region and type of plant organ	Yes	0.28	F(1,24)=9.2	< 0.05
The interactive effect of species type and plant organ type	Yes	0/23	F(2,24)=3.6	< 0.05
Interactive effect of type of region, type of species and type of plant organ	No	------	-------	>0.05

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In total, the results of the measurements indicate that the plants around the mineral unit have a much higher concentration of heavy metals than the control area. These results are consistent with the research of Del Río et al. (2002) as a result of the increase of heavy metals caused by the Azancular mine in Spain, it is similar to many plant species, including gramineous species. Also with the results of Rodríguez et al. (2009) which showed that the amount of heavy metals in the agricultural lands and pastures around the mine were very high due to two main reasons: pollution transfer by wind and tailing dam effluent.

3-2- Comparison of heavy metal elements in soil

The results of soil data analysis in the two areas near the factory and the control area are shown in Figures 2 to 4 and Table 6. It can be seen that considering that the p-value is less than 0.05, the amount of heavy elements lead, zinc and cadmium in the area near the factory is significantly higher than the control area. These results are consistent with the research of Khodadadi et al. (2009) which was conducted by examining the possibility of transferring heavy metals to water sources from tailings dam residues in the same area, is consistent.

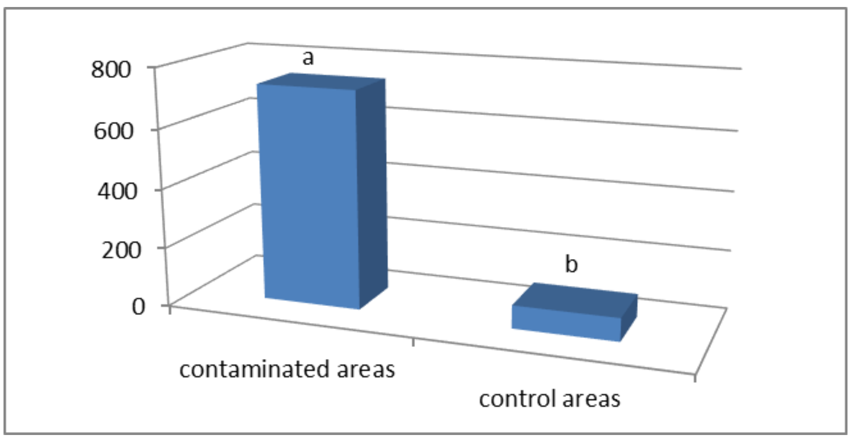

Figure 2- Average of lead in the soil of the contaminated area and the control area

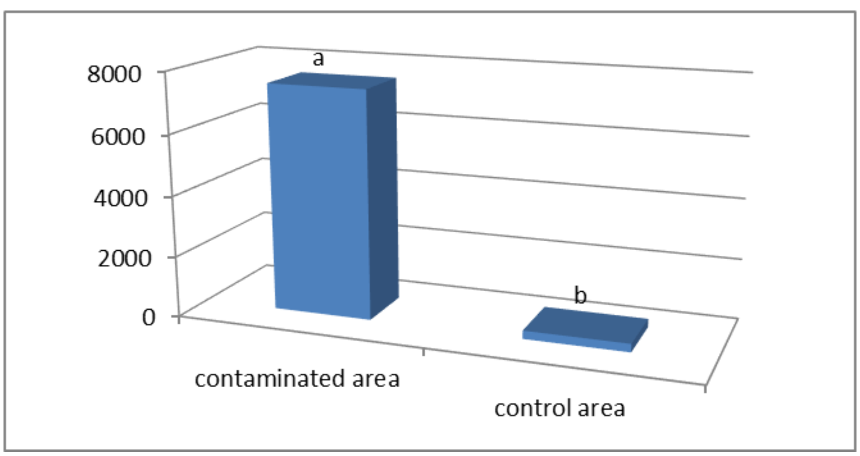

Figure 3- Average zinc in the soil of the contaminated area and the control area

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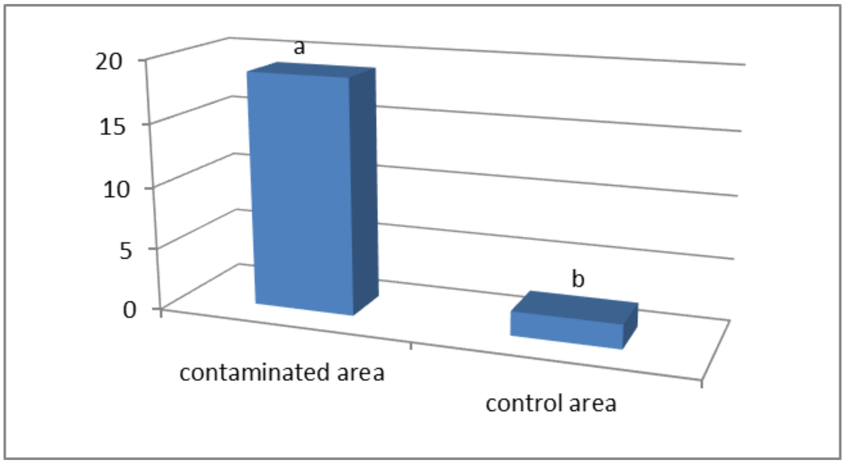


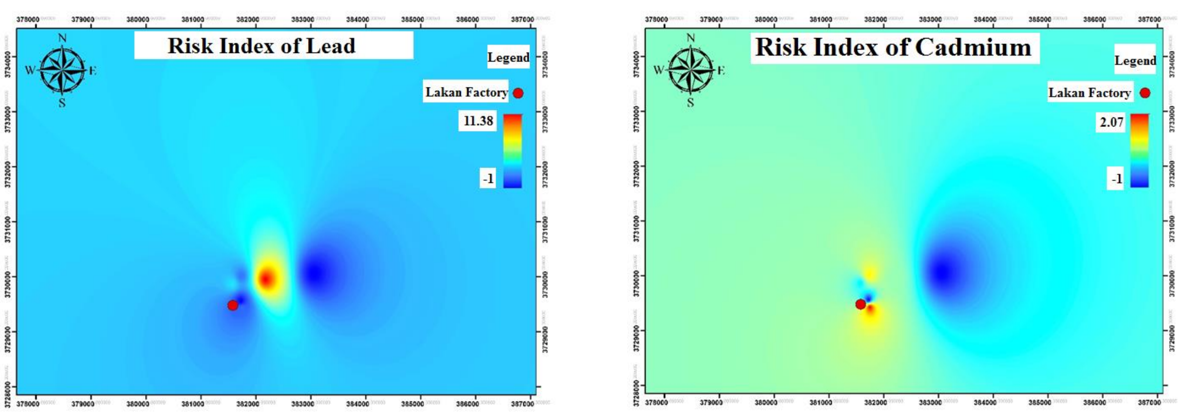
Figure 4- Average of cadmium in the soil of the contaminated area and the control area

Table 6- Investigating the effects of factors on the absorption of heavy elements in the soil

Sig.	p-value	Control area ($^{Mg}/_{kg}$)	Contaminated ($^{Mg}/_{kg}$) area	Type of effect
Yes	< 0.05	77.8	734	Lead
Yes	< 0.05	273.6	7499	Zinc
Yes	< 0.05	2.5	18.85	Cadmium

3-3- The results of the cumulative risk index of metals and its prediction

Cumulative risk index was calculated based on each of the heavy metals studied in this research using interpolated continuous images of these metals in the form of maps (Figure 5).



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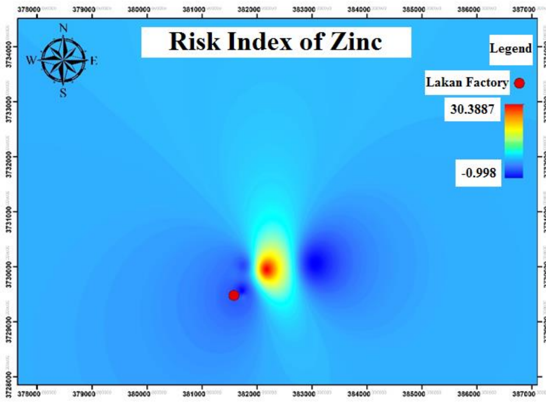

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Figure 5- Cumulative risk index map of cadmium (a), lead (b) and zinc (c) metals

According to the obtained results, 99% equivalent to 7290.72 hectares of the region are in the low risk category and 0.01% equivalent to 7.32 hectares of the region are in the medium risk category in terms of cumulative risk index of cadmium. Regarding the cumulative lead risk index, 0.13% (97.95 hectares) are in the high risk category and 0.06% (42 hectares) are in the critical risk category. Also, the results indicate that in terms of the cumulative risk index of zinc metal, 0.06% (457.39 hectares) are in the high risk category and 92% (6745.75 hectares) are in the critical risk category. It can be seen that there are high ranges of environmental risk index around the factory. Therefore, based on the existing criteria, this area has the potential of destruction and ecological vulnerability. Also, in terms of location, heavy elements in the east of the site will create more risk. According to the results, it can be acknowledged that zinc metal creates the most risk and cadmium metal creates the least risk in the region. (2020) based on the low toxicity of cadmium in industrial dust risk assessment is somewhat in agreement. Also Shojaee Barjoeea et al. (2020) stated in the ecological risk assessment of some heavy metals, zinc and lead metal respectively have the highest pollution index. According to Khodadadi et al. (2009) the presence of abandoned lead and zinc mines around the Lakan lead and zinc processing plant probably created a high background for the presence of these elements. Also, the high concentration of metals such as lead in the conditions of contact with underground water through chemical reactions can cause water pollution. Also, in the mentioned study, it is mentioned that the soil of the region is contaminated with lead, which is concentrated in the south of the tailings dam. On the other hand, the amount of cadmium compared to lead and zinc in the wells of the region is less than the permissible limit, which is why the risk created by cadmium metal is less. In general, the area affected by the factory's activities has caused the accumulation of cadmium, zinc and lead metals, and the amount of risk created by them is related to zinc, lead and cadmium metals, respectively. Actually, the most important source of release of zinc metal in the soil of the region has been the activities of the factory.

4 - Conclusion

Today, environmental pollution has become an important global problem. Since the creation of these pollutions is inevitable, methods and measures have been used to minimize their consequences. Among the important methods in the field of reducing the effects of environmental pollution is ecological risk assessment. By determining the amount of damage and risks to the environment, these methods will allow managers to organize their plans and decisions in line with the principle of sustainable development and basic preservation of the

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environment. Ecological risk assessment is a method that predicts different ecological dimensions in terms of risk by considering the environments affected by a pollutant source or a source of risk. The present study was conducted with the concern of investigating the amount of ecological damages of the lead and zinc processing plant in Lakan. In this study, the environments that receive the most effects from the factory's activity were determined and location factors and heavy metal concentration were used as influential variables in determining the vulnerability of the organized area.

The results of statistical measurements based on the amount of heavy elements abduction indicate that the plants around the mineral unit have a much higher concentration of heavy metals than the control area. The results of the ecological risk assessment showed that among the studied heavy metals, cadmium creates the least risk; Because the area of risk caused by this metal is mainly placed in the low risk category and the area that is exposed to the medium risk of this metal includes about 0.01% of the entire area. Meanwhile, for the lead element, 0.13% are in the high risk category and 0.06% are in the critical risk category. Also, for zinc metal, 0.06% (457.39 hectares) are in the high risk category and 92% (6745.75 hectares) are in the critical risk category. Considering that metal mining industries are affected and influenced by many variables of weather, land, land use, environmental data and laboratory samples, their use in order to investigate the issue more closely in future and supplementary researches. Recommended.

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