Sources and ecological risk mapping of trace elements in multi-contaminated soils of gold mine employing GIS methods - Muthe Gold Mine, Iran

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Research Article

Keywords: ecological risk assessment, heavy metal concentration, gold mine, contamination indicators, heavy metal Spatial distribution, Geographical information system (GIS)

Posted Date: October 21st, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-999830/v1>

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Abstract

The properties of solid mine wastes are essential for understanding their potential health and ecological hazards, as well as chemical composition, although there is limited empirical data, especially in developing countries. This investigation was done to evaluate the possible trace element concentrations, sources and potential ecological risks in gold mine soil by applying Hakanson risk assessment method with ArcGIS technology. In this field study, quantitative contamination indicators like geoaccumulation index, contamination factor and ecological risk index were applied to compare three different sites. A total of 34 topsoil samples were collected from three selected areas, following which the different contamination parameters as well as sources of Arsenic, Copper, Nickel, Lead and Zinc were determined. Results showed the concentration of Cu and As in soil samples of the gold mine area exceeded recommended standard values which seems to have a mix of anthropogenic and natural sources. The geochemical accumulation index results indicated clear signs that Cu with Igeo values for the three selected areas was classified as uncontaminated to moderately contaminated ($0 \leq I_{geo} < 1$). In regard to CF, the Senjedeh mine was classified as having very high contamination with Cu ($CF \geq 6$). These findings indicated that the tailing dam and concentration factory were categorized as having 'low ecological risk' ($RI \leq 150$); while Senjedeh mine was respected as having 'very high ecological risk' ($300 \leq RI < 600$). These findings emphasize the necessity for appropriate mine wastes characterization to make management decisions point towards reducing trace element pollution of soil and the related potential environmental and human health risks.

1 Introduction

Trace element contamination has become one of the environmental challenges today in both developed and developing countries all over the world (Ghafouri et al. 2021; Sun et al. 2010; Zand et al. 2019). They are regarded as a dangerous sort of anthropogenic contaminants and are a major source of concern due to their wide sources, persistence, non-biodegradable properties, toxicity and accumulative behaviors (Bhuiyan et al. 2021; Huang et al. 2012; Zhu et al. 2012).

Mining is one of the most significant sources of trace elements in the environment (Chen et al. 2017; Haddaway et al. 2019). Other sources of trace elements in the environment are: dumpsite, industries, weathering, mining and mineral processing (Adewumi 2020; Fashola et al. 2016; Kormoker et al. 2019; Laniyan and Adewumi 2019; Proshad et al. 2020). Toxic trace elements related to abandoned mining territories and minerals are released into encompassing sediments, soils and dust discharging from these activities (Emmanuel et al. 2018; Laniyan and Adewumi 2020; Lilic et al. 2018).

Accumulated heavy metals in the soil around mines have triggered widespread concern because of the serious health threat they pose to people through a variety of diseases and conditions. In recent years, many scientists have investigated trace element contamination in soils around gold mines (Basu et al. 2015; Cao et al. 2015; Chen et al. 2017; Li et al. 2014; Okang'Odumo et al. 2014).

Considering the importance of sediments and the trace elements toxicity in them, these researches have been carried out to consider the effects of trace elements on ecological systems (Guo et al. 2010; Wu et al. 2010). Most of the recently reported investigations dealing with the assessment of trace element pollution in sediments use merely the trace element content as a measure to verifying their potential effect on the environment. Nevertheless, the trace elements' total concentrations provide inadequate evidence for evaluating their toxicity or bioavailability (Sundaray et al. 2011).

When the sources of contaminants are complex and multiple, pollution zones mapping is difficult. It is also challenging to determine the pollutant's sources only using a single analytical method (Dong et al. 2019; Hu et al. 2018). From the perspective of trace element exact sources apportionment and their accumulation, the present study requires some holistic and integrated approaches. Hence, to get more reliable and precise results the ecological risk of trace elements was assessed using available tools Geoaccumulation index (Igeo), Contamination factor (CF) and potential ecological risk index (RI). These indicators are broadly used because of their capability to provide detailed evidence for chemical, and on some occasions, biological characterization of wastes such as Akoto and Anning 2021; Keshavarzi and Kumar 2019; Sulaiman et al. 2019; Tytła and Kostecki 2019. But this study applied geographic information system (GIS) for appropriate source apportionment of trace elements.

The primary goal of this research was to assess the specific sources and ecological impacts of trace elements in soils. However, the exact objectives were to (i) determine the trace elements concentration in three land-use based soils, (ii) evaluate the Geoaccumulation Index, Contamination Factor, pollution level and distribution of trace elements in soils, (iii) interpolation mapping of the ecological risk zones on the basis of observations of Arsenic, Copper, Lead, Nickle and Zinc concentrations and (iiii) providing design solutions and frameworks. The attained results from this work might reveal the overall source distribution of trace elements and ecological risk zonation in soils that would be helpful for decision-makers to articulate action-oriented contamination control measures for the industrial units, municipal and agriculture authority.

2 Material And Methods

2.1 Study area

Muteh Gold mining area is situated 270 Km southwest of Tehran, 45 Km northwest of Meimeh city and 60 Km southwest of Delijan city at the Muteh plain from Latitude 33° 22' to 33° 49' N and Longitude 51° 15' to 59° 28' E at elevation of 1983 to 2498 m above the sea level. Figure 1 shows the site of the study area presented by software Arc GIS ver. 10.3. The area is within the semi-arid zone with an average annual rainfall of almost 250 mm, maximum and minimum temperatures of 27.7°C and 0.1°C. At present, two of nine detected ore deposits are under operation; Senjedeh and Chah Khatoon deposits. An average of 150,000 tons of soil has been exploited every single year. With an extraction rate of 2-4 grams per ton for every day and a capacity of almost 500 tons of ore for each day, a relatively significant amount of

Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js ter of concentration factory and chemical

materials. The yielded waste has been damped at the tailing dams. At present, the old tailing dam (with 1.7 million tons of capacity) has been filled and the existing tailing dam (1.5 million tons of capacity) is being filled. Ore extraction using cyanide solution, and smelting are located nearby to the mining sites, where dust and polluted water affect the surrounding area.

2.2 Soil sampling and preparation

The soil samples (0-15cm) were conducted in an area of about 3km× 6 km. A total of 34 samples were taken from three chosen sampling sites (tailing dam, concentration factory and Senjedeh mine). Among the samples, S1-S8 were located in the tailing dam; S9-S12 were located in the concentration factory, S13-S16 were located in the Senjedeh mine and S17-S34 were located in the area between the other three selected locations. Samples density was comparatively lower in Senjedeh mine and higher in tailing dam and concentration factory due to accessibility. The samples were randomly collected, maintaining a distance of about 500 m from each sampling site. (Bhuiyan et al. 2021; Chaoyang et al. 2009; Zhu et al. 2012). The sampling points' location is shown in Figure 2. After air-drying and sieving via a 2 mm mesh sieve, soil samples were stored in polypropylene containers for ICP_OES analysis. Then About 20 g of soil samples were ground, and the ground materials were digested using 65 % HNO₃, 70 % HClO₄, 40 % HF. Since all of the samples were dried in the hot box, extraction and digestion of solutions from soil were revealed using inductively coupled plasma-optical emission spectrometry (PerkinElmer® - Optima™ 8300 ICP-OES) in three replicates (Afonso et al. 2019; Demarco et al. 2018; Guo et al. 2014; Langella et al. 2014; Lee et al. 2018; Nirola et al. 2015; Novo and González 2014).

2.3 Geoaccumulation index (Igeo), contamination factor (CF) and potential ecological risk index (RI):

The heavy metal contamination status in the study sites was assessed by quantitative contamination indicators and their respective characterization standards. These indicators included geoaccumulation index (Igeo), contamination factor (CF) and potential ecological risk index (RI). Igeo was used to determine the range of metal accumulation relative to the background level. Geoaccumulation index is classified into seven categories: Igeo ≥ 6 extremely contaminated; 4 ≤ Igeo < 5 strongly to extremely contaminated; 3 ≤ Igeo < 4 strongly contaminated; 2 ≤ Igeo < 3 moderately to strongly contaminated; 1 ≤ Igeo < 2 moderately contaminated; 0 ≤ Igeo < 1 uncontaminated to moderately contaminated; Igeo < 0 uncontaminated (Akoto and Anning 2021; Kusin et al. 2019).

$$I_{geo} = \ln \left(\frac{Sample}{1.5 \times Background} \right) \quad (1)$$

where Sample is the mean concentration of elements in the samples and Background is the preindustrial level of the same element as introduced by Hakanson (1980).

Contamination factor (CF) was used to determine the contamination level of each element using the formula as reported by Hakanson (1980) as follows:

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$$CF = \text{Sample} / \text{Background} \quad (2)$$

In which Sample is the mean concentration in sample relative to Background concentration (pre-industrial level). The CF was classified into four categories: $CF < 1$ low contamination; $1 < CF < 3$ moderate contamination; $3 < CF < 6$ considerable contamination; $CF > 6$ very high contamination (Haris et al. 2017; Siddiqui and Pandey 2019)

The potential ecological risk index (RI) is introduced to evaluate the ecological risk level of heavy metals in sediments or soil by Hakanson (1980) and has become one of the most generally used diagnostic and indicator tool in research domains, such as ecology, environmental chemistry and biological toxicology (Maanan et al. 2015; Zhai et al. 2014). RI is calculated by the following equation (Chen et al. 2020):

$$RI = \sum_i^n E_r^i = \sum_i^n \left(T_r^i \times \frac{C_D^i}{C_R^i} \right) \quad (3)$$

Where E_r^i is the potential ecological risk factor of each trace element, T_r^i is the toxic factor of the trace element, C_D^i is the individual concentration of trace elements in the sample and C_R^i is the reference value of trace elements which is the background concentration of trace elements in the sample. Based on the Hakanson approach, the T_r^i for Pb, Cu, Ni, Cd and Zn are 5, 5, 5, 30 and 1, respectively. Table 1 shows four categories of RI and five categories of E_r^i .

Table 1 Indices of potential ecological metals contamination (Kusin et al. 2019)

E_r^i	Ecological risk	RI value	Potential ecological risk
$E_r^i < 40$	Low risk	$RI < 150$	Low risk
$40 \leq E_r^i < 80$	Moderate risk	$150 \leq RI < 300$	Moderate risk
$80 \leq E_r^i < 160$	Considerable risk	$300 \leq RI < 600$	Considerable risk
$160 \leq E_r^i < 320$	High risk	$RI \geq 600$	Very high risk
$320 \geq E_r^i$	Very high risk		

2.4 Layer weighting and zoning

Trace element contamination maps were prepared to determine different levels of risk in the study area. The layers for each element were overlaid by the Analytic Hierarchy Process (AHP). Figure 3 demonstrates the distribution of each trace element in the study area on the basis of concentration, after which the AHP was carried out to weight the map layers (Figure 4) (Kara and Doartli 2012).

2.5 Ecological Risk Index map

After calculating the ecological risk index of the area, first, each point was given the value obtained from the calculation of the ecological risk index and then an interpolation tool was implemented to prepare an ecological risk map. In the end, the interpolated map was classified into 4 categories based on the given value.

3 Statistical Analysis

The statistical evaluations of data such as minimum, maximum, mean and standard deviation were implemented using the SPSS software package version 21.0 for windows. All maps presented in this research were generated using Geographic Information system (GIS) version 10.3.

4 Result And Discussion

4.1 Spatial distribution of heavy metals:

The metal content in soil samples is presented in Table 2 by comparing the values of the metal concentrations according to the recommended standard values of Australian Department of Environment and Conservation (2010) and Canadian Ministers of Environment (2009). The spatial distribution patterns of As, Cu, Ni, Pb and Zn are illustrated in Fig. 3. As noted in Table 2, the mean metal concentrations in all samples were observed to be in the order of Cu > Zn > Ni > As > Pb. The metal concentrations included Ni, Pb and Zn were all within the permissible regulatory standard values except for Cu and As.

The range of As is between 5.32 and 20.5 mg/kg (the highest concentration in the tailing dam) giving an average of 11.16 mg/kg. The As content in the soil samples of the Senjedeh mining area exceeds the recommended soil guideline values of the Canadian Ministry of Environment (11 mg/kg) and the tailing dam exceeds both the permissible guideline values of Canada (11 mg/kg) and Australia (20 mg/kg).

According to the results obtained from the As interpolation map (Fig. 3), it is observed that the concentration of arsenic in the Senjedeh mine and southeastern region of the tailings dam and factory has its highest concentration. The results clearly revealed that high concentrations of As in the southeastern region of the concentration factory came from the intensive activity and emissions of dust from the factory which is affected by wind direction. This was also consistent with the results of interpolation mapping of Pb, which showed that the As and Pb dispersion had a very similar distribution pattern in the tailing dam and concentration factory (Fig. 3). A greater concentration of As was detected in the tailing dam compared to that of Senjedeh mine samples in the study area. It can generally agree to take that arsenopyrite mineralization in gold-bearing rocks is one of the leading factors to the increased level of As (Ahn et al. 2005; Kusin et al. 2019).

Table 2
Descriptive statistics of different trace elements in the soil at the study area

Samples	As	Cu	Ni	Pb	Zn
1	7.8	3695.61	33.31	9	147.82
2	8	3588.53	31.58	10.8	146
3	7.3	3713.67	37.23	8	150.15
4	8.1	3764.4	35.1	6.57	153.4
5	12.4	3641.07	33	10.26	143.66
6	20.5	3628	34.7	12	145
7	10.82	3701.08	32.3	6.89	149.16
8	14.8	3721.11	31.61	9.11	147
9	12.49	900	7	5	45.03
10	12.1	956.4	6.52	4.5	43
11	12.35	886.23	7.5	5.5	47.09
12	13.18	934.71	7.88	6.6	38.04
13	11.9	895.11	6.83	4.2	51.6
14	12.52	922.78	5	5.22	51.38
15	12.83	890.54	9.1	6.34	39.33
16	11.59	878.47	10.5	3.37	42
17	12.81	915.15	4.51	3.5	48.09
18	12.69	940.34	6.8	6.51	45.07
19	12.64	887.36	8.2	4.98	40.75
20	12.22	927.08	5.8	5.58	48.1
21	12.65	893.6	12.53	4.5	49.78
22	12.9	918.18	3.91	4.34	39.33
23	12.16	955.98	6.16	6.5	44.8
24	13.13	844	7.92	4.72	46.91
25	11.17	3300.47	29.15	8.5	140
26	8.44	3246.5	27.6	8.1	142.6
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Samples	As	Cu	Ni	Pb	Zn
28	5.32	3165.76	26.33	8.5	127.15
29	11.38	3468.56	6.51	8.72	116.01
30	7.26	3125.08	34.3	7.53	140.07
31	12.5	3503.84	35.1	9.5	153.63
32	8.22	3318.07	36.75	10.52	139.94
33	5.86	3325.76	24.22	6.58	132.08
34	10.9	3425	26.83	7.45	134.7
Standard deviation	2.91	1304.97	12.70	2.22	49.28
Min	5.32	844	3.91	3.37	38.04
Max	20.5	3764.4	37.23	12	153.63
Mean	11.16	2261.14	19.32	6.97	95.91
Reference values (mg/kg)					
Canadian Ministry of Environment (2009)	11	63	37	45	290
Australian Dep. Of Environment and Conservation (2010)	20	100	60	600	200
Pre-industrial level ^a	15	50	80	70	175
^a Hakanson (1980).					

The range of Cu in this study was observed between 844 (tailing dam) and 3764.4 mg/kg (Senjedeh mine) with an average of 2261.14 mg/kg. The concentration of Cu element in all of the three sampling areas exceeded the permissible limits of the Canadian Ministry of Environment (63 mg/kg) and Australian Department of Environment and Conservation (100 mg/kg). The fact that the highest concentration of Cu was observed in the Senjedeh mining area because the mining area is the parent materials of soils. The findings in the current work are also consistent with those derived by Bhuiyan et al. (2021), who revealed that As indicated natural weathering from parent materials and its concentration varied significantly with land use changes.

The mean soil concentrations of Ni, Pb and Zn (19.3, 6.97, 95.91 mg/kg) were below the recommended limits set by presented reference values, with the tailing dam being the most contaminated (with Ni, Pb and Zn). Notably, Ni and Zn were also observed to have a similar distribution pattern in the tailing dam and concentration factory which might largely derive from Ni and Zn in the smoke discharged from smelters, like the cases of Pb and As.

Figure 4 indicates overlaid map layers using the Analytic Hierarchy Process (AHP). Concentrations of the five metal elements in three sampling sites indicated significant variations which are mainly due to the spatial differences such as functional properties of concentration factory, tailing dam and mining activities. According to the results obtained from overlaying, as expected, the tailings dam and concentration factory have more pollutants than other places. As the distance from these areas increases, the concentration of elements and the level of pollutants decrease. The only exception in the area is the Cu concentration in the Senjadedeh mine area, which is extremely high. Also, compared to the standard concentration of elements in the soil, none of the studied elements, except Cu, have a toxic concentration, only the tailing dam and factory have a higher concentration of elements than other areas which is not toxic.

This is consistent with the result obtained by Chaoyang et al. (2009), who discovered that the heavy metals concentration in Shuikoushan is the result of volatile particulates of the chimneys, airborne emissions of aerosols, leaching and chemical weathering of tailings and level off with distance from the source of pollution. Due to the possibility of spreading pollutants to pristine pastures adjacent to creating a buffer zone at the edge of the tailings dam is recommended. On the other hand, because one of the ways of spreading these pollutants is the prevailing seasonal winds, so the construction of windbreak trees suitable for the region also seems appropriate.

In the tailings dam, due to the bare soil and the release of contaminants by wind and water erosion, it is recommended to plant accumulator and stabilizer species that are resistant to harsh environmental conditions. It is also suggested to cultivate species with significant aerial parts and root systems to create porosity in the soil for absorbing runoff caused by cross-sectional rainfall.

4.2 Geo-accumulation index and contamination factor

Geochemical indices of the research area including contamination factor and geo-accumulation index (Igeo) are presented in Table 3. Igeo was calculated to evaluate the accumulation status of many toxic metals in various sediments and soils (Mushtaha et al. 2017). The presence of metals in the soil of the tailing dam, Senjadedeh mine and around the concentration factory such as As, Cu, Ni, Pb and Zn had been assessed for their Igeo. All samples were observed to be uncontaminated except for Cu. All the metals except for Cu have geo-accumulation index values below 0, demonstrating that the samples were uncontaminated. However, concerning Cu, the Igeo values for the tailing dam, Senjadedeh Mine and the concentration factory were classified as uncontaminated to moderately contaminated ($0 \leq I_{geo} < 1$).

In regard to CF, it was noticed that all samples were considered as having low contamination of all the metals Ni, Pb and Zn except for As and Cu. Tailing dam and concentration factory are categorized as having moderate contamination of As with CFs 1.153 and 1.313 and Cu with CFs 1.76 and 1.92, respectively ($1 \leq CF < 3$); Senjadedeh mine was classified as having very high contamination with Cu (CF ≥ 6). As a result, the geochemical indices have revealed a generally low level of contamination with all the presented metals, except for Cu. This is in line with the earlier discussion that most of the presented

metals in the samples were in concentrations less than the permissible regulatory guidelines, however, that of Cu has surpassed most of the suggested guideline values.

Table 3
Geo-accumulation (*I*_{geo}), contamination factor (CF) of each trace element in observed sites

Geochemical indices	location	As	Cu	Ni	Pb	Zn
<i>I</i> _{geo}	Factory	-0.057	0.107	-0.499	-0.313	-0.817
	Tailing dam	-0.114	0.069	-0.560	-1.066	-0.446
	Senjedeh mine	-0.221	0.802	-0.756	-1.243	-0.648
<i>CF</i>	Factory	1.313	1.92	0.475	0.728	0.228
	Tailing dam	1.153	1.76	0.412	0.128	0.537
	Senjedeh mine	0.9	9.52	0.262	0.085	0.337

4.3 Ecological risk assessment

The metals' presence in the concentration factory, tailing dam and Senjedeh mine such as As, Cu, Ni, Pb and Zn were assessed for their potential ecological risk. Table 4 reveals the contributions of each element (*E*_{*r*}^{*i*}) to the potential ecological risk index (RI). Regardless of the types of samples, compared to other heavy metals in the samples, the contribution of Cu to the total RI was noticeable. The results revealed that all samples were dominated by Cu, particularly in the Senjedeh mine. The value of RI was the highest for the Senjedeh mine (380.94) and was the lowest in soils of the concentration factory (24.65). The *E*_{*r*}^{*i*} values for Cu, based on the risk index classification of metals introduced by Hakanson (1980), were considered as; considerable potential ecological risk for tailing dam (80≤*E*_{*r*}^{*i*}< 160) and very high ecological risk for Senjedeh mine (*E*_{*r*}^{*i*}>320). For RI, tailing dam and concentration factory were categorized as having 'low ecological risk' (RI≤150); while Senjedeh mine was respected as having 'very high ecological risk' (300≤RI<600). Notably, the influence of Cu on the total RI was very apparent, recommending the appropriate control treatment for studied metal elements in the mining area.

Table 4
ecological risk index (RI)

Location	<i>E</i> _{<i>r</i>} ^{<i>i</i>} (ppm)					RI	Contamination degree
	As	Cu	Ni	Pb	Zn		
Tailing dam	5.75	91.5	0.7	0.9	0.225	99.075	Considerable risk
Factory	9.85	9.6	3.8	1.2	0.2	24.65	Low risk
Senjede Mine	6.3	369.6	3.4	0.9	0.74	380.94	Very high risk

Figure 5 illustrates the interpolation mapping of the potential ecological risk index in the sampled areas. According to the results, it seems that the Senjedeh mine with a risk index of 380.94 has the highest probability of risk in the region. While comparing the results of the analysis with the standard limit of elements in the soil, all elements in the region except Cu have low pollution. Therefore, it can be concluded that the Cu in this region is the only hazardous pollutant that caused to high ecological risk index of the Senjedeh mine.

5 Conclusion

Abandoned mine waste contains certain amounts of potentially hazardous elements for the environment. Human interventions in the mining area and neighboring areas have severely affected the landscape and natural environment. This study was carried out to evaluate the possible trace element concentrations, sources and potential ecological risks in Muthe gold mine soil. About one-sixth of the study area is affected by mine tailings, with effects such as changes in land surface topography, immature infertile soil, and poor grass and shrub structure. Findings show that human impact related to mining activities is evident in the studied soils. Gold mining activities of the Muthe mining area have caused the study area to become seriously polluted with trace elements. This was especially true for As and Cu which their observed concentrations were higher than the recommended standard values. The geochemical accumulation index showed serious Cu contamination ($0 \leq I_{geo} < 1$), arsenic (with CFs 1.153 and 1.313 for both tailing dam and concentration factory) and to some extent zinc and nickel with a clear dispersion. The overall pollution degrees of trace elements are in the order of $Cu > As > Zn > Ni > Pb$. Sources of trace elements in the studied area are mostly mining, mineral processes (chimneys, airborne emissions of aerosols, leaching and chemical weathering of tailings) and other sources such as natural sources (parent materials of soils) also influence their accumulation in the environment. It is recommended to create a buffer zone at the edge of the tailing dam to prevent pollutants spread to pristine pastures adjacent, construction of windbreak trees to reduce contaminant release by wind and water and planting accumulator and stabilizer species that are resistant to harsh environmental conditions. It is also suggested to cultivate species with significant aerial parts and root systems to create porosity in the soil for absorbing runoff caused by cross-sectional rainfall.

Declarations

Funding No funding was received for conducting this study.

Financial interests The authors declare they have no financial interests.

Conflicts of interest Authors have no conflict of interest to declare that are relevant to the content of this article.

Availability of data and material All data analysed during this study are included in this manuscript.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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Figures

Figure 1

Muthe Gold Mine Location

Figure 2

Sampling points (Satellite map: Arc Bru Tile 2017)

Figure 3

Interpolation mapping of heavy metals in Muthe gold mine area

Figure 4

Weighted overlay mapping of trace elements

Figure 5

Ecological Risk Index Map