

Research Article

The concentration of heavy metals and pollution indices in a selected abandoned mine in the State of Pahang, Malaysia

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Abstract

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Abandoned iron ore mining soil was analyzed for its metal contamination. Pollution indices were calculated and used to examine the potential of the area to be polluted by the metals. The samples were collected in triplicate from ten sampling points spread throughout the mining area. The energy dispersive X-ray fluorescence (EDXRF) analytical method was used to determine the concentrations of Cd, Cu, Co, Pb, Zn, Fe, Cr, Ni, and Mn. The order of the mean metal concentrations (mg/kg) in soil samples taken at random from ten locations near the chosen iron ore mines is Fe, Mn, Cr, Pb, Cu, Zn, Co, Ni, and Cd. The Geoaccumulation Index (Igeo) results showed that the area was moderately contaminated, especially with Fe, whereas the results of the Enrichment Factor (EF) and the Quantification of Contamination (QoC) showed that metal enrichment was strongly related to anthropogenic origins. EF and Quantification of Contamination (QoC) results revealed that metal enrichment was strongly related to anthropogenic origins. The ecological risk based on individual metals followed the following order: Cd > Pb > Co > Cu > Cr > Fe > Ni > Mn > Zn, and the average Potential Ecological Risk Index (PERI) was recorded at the severely high-risk level. The findings clearly showed that the study area might pose a serious threat to environmental health.

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Introduction

Prospecting, exploring, building, running, maintaining, expanding, closing, shutting down, and reusing a mine are all mining activities that can have direct or indirect effects on social and environmental systems. Similarly, mining can alter environments, but remediation and mitigation can restore them. Mining work alters the surface topography, resulting in excessive erosion of the area (Sun et al., 2014; Liu, 2016). The major sources of metal pollution in mining industries are waste rock and the exposed rock walls from which it is removed (Fashola et al., 2016). Iron is found in nature primarily as oxides (Bernát, 1983). The most common iron ores were

haematite (Fe₂O₃), magnetite (Fe₃O₄), and goethite (Fe(OH)O). In comparison to other metals, mining for iron ore has more significant environmental consequences worldwide (Maus, 2020).

Mining activities harm the environment by causing air pollution, water pollution, and other environmental issues. Other environmental problems caused by mining include large amounts of solid waste in huge tailings piles, the destruction and degradation of forests and farmland, and the release of mine wastewater into nearby bodies of water. Also, mining activities are known to pollute the area around the mines with heavy metals because they release heavy metals into the surface soil (Li et al., 2018). Abandoned mines are places where mining stopped

because the clean-up was not done right or the mine was not closed properly. These things could happen for a number of reasons, such as the operators not following or not having enough Environmental Protection Agency compliance policies. High metal concentrations in abandoned mining sites have a significant impact on the degradation of ecosystems and the increase of phytotoxicity in sediments (Chen et al., 2022). Numerous variables significantly influence and vary the effects of these metal pollutants (Iordache et al., 2022). Depending on the size of the metal fractions and the chemical form of the metals, hazardous metals can travel over long distances by wind, runoff, and rain in either gaseous form or as particles (Yan et al., 2020).

Mining for iron ore generates solid, liquid, and gaseous waste (Shahba et al., 2017). Acid mine drainage (AMD) is produced by the exposure of sulphide minerals (pyrite and arsenopyrite) to air and water, resulting in an elevation of metal concentrations in the area (Dold, 2014; Tomiyama, et al., 2019). Finely ground mine tailings or pulverised by-products of mining operations are rich in metal-bearing minerals like arsenopyrite, pyrite, and chalcopyrite (Obasi, 2021). The pH of the water at active or abandoned mine sites will drop as a result of the chemical reactions that can turn sulfuric acid from sulphide minerals. Such water will increase the concentrations of toxic metals like Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn, posing an additional danger to the environment (Obasi, 2021).

Previous related studies in Malaysia have shown that mining is one of the sources of heavy metal pollution in some ponds and rivers. Mining has also been linked to higher levels of heavy metals in Malaysian waterways and sediment (Ashraf et al., 2010; Ahmad et al., 2014). Elements with a high atomic weight and densities at least five times greater than those of water are considered heavy metals. They are parts of the earth's crust that occur naturally and are often used in industrial processes and products. Heavy metals are toxic to living organisms and can cause a range of health problems if ingested or inhaled. They can also contaminate water and soil, making it difficult for plants and animals to survive. Ingesting or inhaling heavy metals can harm living things. The amount of heavy metals released into the environment must be limited because they can have serious consequences for human, animal, and environmental health.

To keep the environment safe, it is important to know what risks heavy metals might pose. A comprehensive study was performed to evaluate the heavy metal concentration in an abandoned mining site, as well as the associated ecological concerns and potential heavy metal sources in the chosen abandoned mining area. The environmental effects of the heavy metals prevalent in the region were evaluated utilizing multiple contamination indices.

Materials and Methods

Study area

An abandoned iron ore mine located in Kampung Besul, Kuala Tembeling, Jerantut, Pahang, Malaysia (latitude 4° 00' 27" N, longitude 102° 18' 32" E) was selected as the study area. This mine is a significant source of income for the local community by providing jobs. Traditional mining techniques were used to extract the ore from the ground, which is then processed and sold to steel mills throughout the region. The mine was once an important part of the local economy, and its continued operation is critical to the well-being of the people of Kampung Besul. There are no other industries operating in the vicinity of the mine's compound. It consists primarily of a mining area and residential houses.

Sample collection

The surface soil was sampled at ten different points around the mine site at random. The Global Positioning System (GPS) was used to ensure that the points corresponded to the coordinates marked for each sampling point. Soils with a nominal mass of 1 kg per sample (approximate dry weights) were collected at each sampling point using plastic tools (soil hoes) and then packed in well-secured polythene bags to prevent contamination before being transported to the laboratory for further treatment and analysis.

Sample treatment and analysis

Stones, organic material, and foreign bodies (any impurities) discovered in the samples were manually removed. After fourteen days of air drying, all samples were ground into fine particles with paste and mortar and sieved through a 2 mm mesh. A thorough drying process was required to reduce errors in the spectral analysis. The concentrations of the specified elements in the samples were determined using a Panalytical Epsilon3-XL EDXRF spectrometer. The method is widely regarded as one of the most efficient and effective non-destructive multi-element analyses of a wide variety of environmental samples, including soils (Min et al., 2015). Furthermore, because this technique is portable and requires little sample preparation, it is ideal for on-site analysis (Maame et al., 2020).

Contamination Factor (CF)

The level of pollution in a specific sample is determined by the Contamination Factor, or CF. It is calculated by dividing the amount of contamination in the sample by the amount of contamination that is considered acceptable. The CF is an important indicator of the quality of a sample, as it allows us to determine if the sample has been contaminated beyond acceptable levels. A CF of 1 indicates that the sample is within acceptable contamination levels,

while a CF of greater than 1 indicates that the sample has been contaminated beyond acceptable levels. Knowing the CF of a sample can help us identify potential sources of contamination and take steps to reduce or eliminate it. According to Hakanson (1980), the following equation was used to determine the CF:

$$CF = CM/CB \quad (1)$$

where CF is the Contamination Factor, CM is the mean concentration of each heavy metal in the soil, and CB is the background concentration of the metal.

Quantification of Contamination (QoC)

Quantification of Contamination (QoC) refers to the process of measuring the amount of contamination present in a given environment. This procedure is essential for recognizing the level of pollution and any potential health risks. It can involve measuring the concentration of contaminants in the air, water, soil, or other materials, as well as determining the amount of contamination in a particular area. Quantification of Contamination is important for identifying and monitoring sources of contamination, as well as for helping to determine the best methods for reducing contamination levels. The concentration of background metals is used to indicate the geogenic metal in the index of QoC, which quantifies the anthropogenic metal concentration (Asaah et al., 2006). This index was calculated based on Equation 2:

$$QoC (\%) = [(X - X_c)/X] \times 100 \quad (2)$$

The average concentration of the metal in the sample is denoted by X, and the average concentration of the metal in the background is represented by Xc. This index's values were primarily expressed as percentages and demonstrated the extent of geogenic and anthropogenic influences.

Index of Geoaccumulation (Igeo)

The Index of Geoaccumulation (Igeo) is a technique used to determine the degree of contamination in a particular area. It is based on the accumulation of pollutants in the environment and is calculated by taking the ratio of the concentration of a given pollutant and the background concentration of that pollutant in a specific area. The Index of Geoaccumulation is an important tool for environmental monitoring and management, as it provides a quick and effective way to identify areas of potential risk. This index was calculated using the formula suggested by Muller (1969):

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

Where Bn denotes the pre-industrial, undisturbed, or crustal soil levels and Cn signifies the element's measured concentration in the soil or sediment. The

background matrix correction factor due to lithological variations is represented by the constant value 1.5. Muller proposed the following Igeo value descriptive classes: Igeo=0 (uncontaminated), 0-1 (moderately contaminated to uncontaminated), 1-2 (moderately to heavily contaminated), 3-4 (heavily contaminated), 4-5 (heavily to extremely contaminated), and Igeo >5 (extremely contaminated).

Enrichment Factor (EF)

The soil contamination rate can be calculated using the Enrichment Factor (EF). This index can be used to determine whether or not anthropogenic contaminants have been deposited on topsoil (Barbieri, 2016). The enrichment factor is calculated by comparing the abundance of species in the parent material to the abundance of species in the Earth's crust. Fe was selected as the reference element in this study because it occurs naturally in most soils and sediments and is not associated with other heavy metals (Reimann and Caritat, 2005). Equation 4 was used to calculate the EFs:

$$EF = \left[\frac{C_i}{C_{ref}} \right]_{\text{sample}} \div \left[\frac{B_n}{B_{ref}} \right]_{\text{background}} \quad (4)$$

Heavy metal concentration (Ci), reference heavy metal concentration (Cref), background heavy metal concentration (Bn), and reference heavy metal background concentration (Bref) are all shown in the equation. The index (EF) can be classified as follows: deficient to minimal (<2), moderate (2-5), substantial (5-20), very high (20-40), and extremely high (>40).

Potential Ecological Risk Index (PERI)

The Potential Ecological Risk Index (PERI) assesses site ecological risk. It is based on a series of factors, including the presence of hazardous substances, the potential for exposure, and the sensitivity of the local environment. The PERI is used to identify areas of potential risk, allowing for the development of strategies to reduce or mitigate the risk. PERI has also been used to describe human sensitivity to heavy metals as well as the high environmental risk posed by total contamination. The method was shown in Equation 5 (Hakanson, 1980):

$$PERI = \sum CF \times Trf \quad (5)$$

where CF is the contamination factor of heavy metal, Trf is the toxic-response factor for heavy metal contamination and PERI is the potential risk for heavy metal. Toxic response factor for metals were; Zn = 1, Mn = 1, Cr = 2, Co = Cu = Pb = 5, Ni = 5 and Cd = 30. Potential ecological risk can be divided into several categories: PERI <40 indicates a low ecological risk; 40 to 80 is a moderate ecological risk; 80 to 160 is a considerable ecological risk; 160 to 320 is a high ecological risk, and >320 is a very high ecological risk (Tomlinson et al., 1980).

Results and Discussion

Metal concentrations and relative comparison

The heavy metal concentrations were discovered to be unevenly distributed across the mines studied. In this study, earlier investigations conducted at the Kuala Lipis Iron Mine (KLIOM) (Diami et al., 2016) and the Bukit Ibam Abandoned Mine (BIAM) (Wan Zuhairi et al., 2009) were compared. Table 1

elucidates a summary of the metal concentrations discovered in this study and the two reference mines. The MSC (mean continental shale value) (Wedepohl, 1971) and the WA (world normal average) were also included in the table as benchmarks (Chen et al., 2018). The Cr, Mn, Co, Ni, Cu, Zn, Cd, Pb, and Fe (mg/kg) concentration ranges in the studied area are 66-753, 2,124-3,905, 98-130, 62-101, 140-190, 94-179, 0.1-27, 212-378, and 24.8-35.01, respectively.

Table 1. Metal concentrations (averages) in soil samples (mg/kg) from ten sampling sites scattered around the iron ore extraction compound as compared with the other reference data.

Sample	Fe (%)	Cr	Mn	Co	Ni	Cu	Zn	Cd	Pb
					(mg/kg)				
This study	29.2	597.2	3059.9	119.5	82.9	146.2	125.6	0.7	298.4
Std Dev	3.5	212.4	659.3	15.5	14.4	17.9	27.5	0.1	54.9
KLIOM	128.5	97.0	21277	-	1.4	7.9	106	0.3	63.5
BIAM	134.1	1798	4478	-	4.3	11.1	1512	0.1	289.5
MCS	29.4	90.1	850.3	19.3	56.3	27.4	36.6	0.2	19.4
WA	-	70.9	571	8.0	23	28.2	67.8	0.4	28.4

BIAM: Bukit Ibam Abandoned Mine, KLIOM: Kuala Lipis Iron Mine, MCS: mean continental shale value; WA: world normal average.

Fe was found to have the highest average concentration at 29000 mg/kg, followed by Mn at 3059.9 mg/kg, Cr at 597.2 mg/kg, Pb at 298.4 mg/kg, Cu at 146.2 mg/kg, Zn at 125.6 mg/kg, Co at 119.5 mg/kg, Ni at 82.9 mg/kg, and Cd with the lowest concentration at 0.7 mg/kg. The order of the average metal concentrations obtained in this study, Fe > Mn > Cr > Pb > Cu > Zn > Co > Ni > Cd, is nearly identical to the results obtained in a previous study conducted at an abandoned iron mining site in the same state of Pahang, where the average concentrations followed the order Fe > Mn > Zn > Cu > Co > Pb > Cr > As > Ni > Cd (Diami et al., 2016).

As expected, the first two elements, Fe and Mn, were found in higher concentrations in the region, as they were considered to be the principal soil constituents (Iqbal and Shah, 2014). Soil iron concentrations typically range from 0.2% to 55% (20,000 to 550,000 mg/kg) (Mahender et al., 2019), with concentrations varying significantly depending on soil type and other factors. Cu and Zn were two of the most abundant elements found in the iron ore soil of Pahang. These two elements were found in large amounts, which showed that they were important parts of the soil. This is not surprising given that Cu and Zn are both trace elements required by plant and animal life. In addition, they are important for the production of steel, which is a key component of many industries in the region (Taylor, 1971). Covellite (CuS), chalcotite (Cu₂S), and native Cu were believed to be associated with Cu distributions in the Earth's crust. Covellite is a mineral composed of copper and sulfur, chalcotite is a mineral composed of copper and sulfur in a 2:1 ratio, and native Cu is a mineral composed of elemental copper. These minerals are thought to be related with the

distribution of copper in the Earth's crust, and are often found in areas with high concentrations of copper. In contrast, zinc acts as an iron molecular replacement in chlorite, which develops from weathered limonite. Despite the fact that the metal Cd is one of the most common elements associated with mine tailings, the Cd concentration in the soil sample studied was the lowest, at 0.7 mg/kg. However, the mean Cd concentration observed is higher when compared to the other reference sites used in this study.

The findings of this study were compared to those of the Kuala Lipis iron ore mine (KLIOM) and the abandoned Bukit Ibam mine (BIAM). The findings were also compared to other guideline values, such as the continental shale value (MSC) and global world normal concentration (GWNC) (WA). The results of this study show that with the exception of Fe, the average concentrations of all elements were found to be higher than the average concentrations suggested by the continental shale value (MCS) and the average concentrations suggested by the mean global normal concentration (WNA) in the soil. When compared to the average global normal concentration, Co showed the greatest increase, followed by Pb, Cr, Mn, Cu, Ni, Cd, and Zn.

The concentrations of Fe, Cr, Mn, and Zn measured in the study site were lower compared to the abandoned iron-ore mining of Bukit Ibam (BIAM), but higher for Ni, Cu, Cd, and Pb. Fe and Mn had lower concentrations when compared to the active mining site (KLIOM), while the other elements had higher concentrations. Metal concentration trends at active and abandoned mining sites are influenced by the mining site hydrogeology and soil chemistry (Zin et al., 2015).

Correlation analysis

This study assessed the degree of correlation between the logarithms of the heavy metals data using Pearson's correlation coefficient. The strong relationship between heavy metals in soil suggest that they are likely originated from the same sources of pollution. Typically, heavy metal contamination in soils are obtained from two sources: natural (soil parent materials) and diverse human-made sources (transportation, industrial activities, and agricultural activities). Based on Table 2, Cd had a weak relationship with all the other metals and a negative relationship with Ni, Cu, and Zn. Six pairs of metals showed strong or very strong positive correlations: Mn/Cu ($r = 0.74$), Fe/Co ($r = 0.99$), Fe/Pb ($r = 0.94$), Pb/Co ($r = 0.91$), Ni/Zn ($r = 0.89$), and Cu/Zn ($r = 0.81$). With a correlation coefficient of over 0.9, Fe, Pb, and Co were found to be the most related metals. The high positive correlation suggests that these metals are related to the same parent materials. The strong relationship between Fe and Co suggests that sulphide is the most common source of the elements. The strong bond between iron (Fe) and cobalt (Co) suggests that sulphide is the most common source of

these two elements. This is because sulphide is the only mineral that contains both elements in large enough concentrations to be mined commercially. Furthermore, the presence of both elements in sulphide deposits is usually in the same proportions, indicating that they are likely to have been formed from the same source. This suggests that sulphide is the most common source of Fe and Co (Wuana and Okieimen, 2011). Similarly, the high correlation observed for Pb and Co, Fe and Pb, and Cu and Zn suggests that the metals and ores are linked (Gomez et al. 2016). Heavy metals in soil typically have a complex relationship.

Assessment of potentially toxic metals pollution

Geoaccumulation Index (Igeo)

Table 3 displays the Igeo index values discovered in this study. Except for Mn and Pb, the difference in Igeo values between the highest and mean values is small at all sampling points. The difference between the highest Igeo value and the mean value is relatively small. This suggests that the data points are relatively close together, indicating that the data set is relatively consistent.

Table 2. Pearson's correlation coefficients for Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd and Pb in the mine soil samples.

	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb
Cr	1.00								
Mn	0.55	1.00							
Fe	0.58	0.50	1.00						
Co	0.52	0.43	0.99	1.00					
Ni	0.07	0.10	-0.40	-0.45	1.00				
Cu	0.15	0.74	0.28	0.22	0.53	1.00			
Zn	0.31	0.45	0.02	-0.05	0.89	0.81	1.00		
Cd	0.35	0.51	0.32	0.32	-0.67	-0.16	-0.48	1.00	
Pb	0.69	0.62	0.94	0.91	-0.05	0.51	0.36	0.15	1.00

Significant at $\alpha = 0.01$; correlation guide (Evan, 1996): $r = 0-0.19$ (very weak), $0.2-0.39$ (weak), $0.4-0.59$ (moderate), $0.6-0.79$ (strong), $0.8-1.0$ (very strong).

Table 3. Geoaccumulation Index (Igeo), Enrichment Factor (EF), quantification of contamination (QoC) and average Ecological Risk Index (E_{ri}^i) for the mean metal concentrations of ten sampling points around mining area and its grading classification.

Metal	Igeo (max)	Igeo (mean)	EF (mean)	QoC (%) (mean)	E_{ri}^i
Cr	2.9 ^b	2.2 ^b	34 ^d	575.71	10.5
Mn	3.1 ^c	1.3 ^a	54 ^e	260.00	3.6
Fe	2.3 ^b	2.1 ^b	1 ^b	-0.62	6.2
Co	2.2 ^b	2.1 ^b	25 ^d	1393.79	31.4
Ni	1.1 ^a	0.9 ^a	14 ^c	65.71	6.1
Cu	2.5 ^b	2.0 ^b	6 ^c	387.17	16.2
Zn	0.8 ^a	0.4 ^a	4 ^b	39.58	1.3
Cd	7.5 ^d	5.4 ^d	50 ^e	1463.67	625.5
Pb	3.5 ^c	3.3 ^c	16 ^c	752.67	74.6

Igeo a: uncontaminated; b: moderate contaminated; c: heavily contaminated; d: extremely contaminated.

QoC: anthropogenic sources (+ve); geogenic sources (-ve).

EF: a: minimal enrichment; b: moderate enrichment; c: significant enrichment; d: very high enrichment; e: extremely high enrichment.

In general, the mean Igeo values show low and moderate accumulation of Cr, Fe, Co, Ni, Cu, and Zn. Meanwhile, heavy and extremely heavy accumulation was observed only for Mn, Cd, and Pb. Based on the trend that the mean values of Igeo showed, there was no critical accumulation of heavy metal in the area. Mn and Cd are the highest accumulation factors among the essential metals and non-essential metals, respectively.

Enrichment Factor (EF) and Quantification of Contamination (QoC)

The enrichment factor (EF) and the quantification of contamination index (QoC) were evaluated to determine whether the metals were geologically or anthropogenically derived. Table 3 displays the mean values of EF and QoC for all metals in this study. Significant differences were seen in the EF index between different metals. Data showed that all metals of concern were significant to extremely enriched, with the exception of Fe and Zn, which were only slightly enriched. Extreme enrichment was found for Mn and Cd, while high enrichment was found for Cr and Co. Pb, Ni, and Cu, on the other hand, was only slightly boosted. The obtained mean values of the EF show that, relative to the amount of material exposed from the earth's crust, all the metals came primarily

from anthropogenic sources ($EF > 1$). The results of the QoC analysis can then be used to develop strategies to address the contamination. The analysis showed that all the QoC values observed were positive, which suggested anthropogenic sources of the metals, except for Fe (negative value), which possibly indicated geogenic sources. In this study, the magnitudes of anthropogenic impact (based on the QoC values) were in the order of Zn, Ni, Mn, Cu, Cr, Pb, Co, and Cd.

Potential Ecological Risk Index (PERI)

One useful method for assessing the threat posed by heavy metals at a specific site is the Potential Ecological Risk Index (PERI). It is a comprehensive index capable of demonstrating heavy metals' environmental impact. Table 4 displays the PERI values for each sampling location within the region. The obtained PERI values ranged from 159 to 821, indicating moderate to extremely high potential ecological risk. 30 percent of the PERI values fall between 80 and 160, indicating a moderate ecological risk, 40 percent fall between 160 and 320, indicating a high ecological risk, and 30 percent fall above 320, indicating a very high ecological risk. The average PERI values for the entire study area indicated a severe ecological threat.

Table 4. Potential Ecological Risk Index (PERI) at all sampling locations of iron ore mining site.

Station	Contamination factor									PERI
	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb	
S1	8.1	4.2	1.1	6.7	1.1	5.1	2.8	21.7	16.3	821
S2	8.4	4.2	1.1	6.7	1.2	5.4	2.9	14.2	16.0	598
S3	8.1	4.6	1.1	6.9	1.8	7.1	5.0	0.8	19.5	227
S4	7.7	3.0	0.8	5.2	1.8	4.9	3.9	0.6	12.8	165
S5	7.7	2.8	0.8	5.3	1.4	5.3	3.0	0.8	10.9	161
S6	7.8	2.5	1.2	7.8	1.1	4.3	2.6	0.4	19.1	195
S7	8.4	4.2	1.1	6.7	1.2	5.4	2.9	14.2	16.0	598
S8	8.2	4.6	1.1	6.9	1.8	7.1	5.0	0.7	19.5	225
S9	8.4	3.0	0.8	5.2	1.8	4.9	3.9	0.6	12.8	166
S10	7.0	2.8	0.8	5.3	1.4	5.3	3.0	0.8	10.9	159
Mean										331

Conclusion

The mean metal concentration (mg/kg) in soil samples collected randomly at ten sampling points around the selected iron ore mines follows the order of Fe, Mn, Cr, Pb, Cu, Zn, Co, Ni, Cd. The Geoaccumulation Index (Igeo) results showed that the samples were at least moderately contaminated, with Zn and Ni having the lowest levels of contamination. Cadmium (Cd) had the highest Igeo value, which was 5.4. Based on the EF estimate, all metals in the study site were at least slightly elevated. Mn and Cd had the greatest enrichment, with EF values of 54 and 50, respectively. All EF values were larger than 1, indicating that the metals found in the soil did not

originate from the Earth's crust but rather from human activity. The QoC analysis revealed that all of the sampled metals were of anthropogenic origin, with the exception of Fe, which indicated a geogenic source and lacked evidence of human influence. Pearson's correlation coefficient analysis revealed a link between heavy metals in soil samples and their likely source. Except for seven pairs that showed a negative correlation, almost all metals were positively correlated. Cd had a weak correlation with all of the metals in the soil samples, with Fe, Pb, and Co having the strongest positive correlation. This strongly suggested that the metals studied came from the same source as anthropogenic activities. The average PERI values for the area of the study

indicated a significant environmental risk. Several indices analysis discovered in this study indicated that the study area was significantly polluted with the studied metals, posing a grave threat to the ecological health of the area. This study suggests additional health risk assessments be conducted enhancing a comprehensive evaluation of the abandoned mine site.

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