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Research Article

Anthropogenic Sources and Risk Assessment of Heavy Metals in Mine Soils: A Case Study of Bontesso in Amansie West District of Ghana

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Contamination of the environmental receptors with heavy metals due to mining is a major topical environmental issue in Ghana. This research investigates the possible ecological and human health risks of heavy metal impacts due to mining in the Amansie West District in Ghana. A total of 18 soil samples were taken from the Bontesso illegal mining site in the district and analyzed for the levels of arsenic (As), cadmium (Cd), copper (Cu), nickel (Ni), and lead (Pb) using atomic absorption spectrometry (AAS). From principal component analysis, cluster analysis, and correlation coefficient analysis, the metals are derived from multiple sources, with substantial levels of correlations. Using geo-accumulation index (I_{geo}), contamination factor (CF), degree of contamination (C_d), pollution load index (PLI), ecological risk index (Er), and noncarcinogenic and carcinogenic risks, respectively, the impacts of As (12.2 mg/kg) and Cd (1.3 mg/kg) are above the WHO stipulated limit. Findings for pollution indices indicate moderate contamination, while HQ < 1 for inhalation and dermal exposure route, except for ingestion which is HQ > 1. Based on the USEPA standard, the carcinogenic risk of the pollutants for humans is higher than the range of 1×10^{-6} to 1×10^{-4}. Furthermore, the ingestion route represents the highest contributor to cancer risk with arsenic posing the greatest risk. The results so far suggest that chemical components gradually accumulate and thus emphasize the importance of implementing the necessary mitigation methods to minimize the impacts of illegal mining activities in the study area.

1. Introduction

Regardless of the type of operation or process used, mining has severe effects on the environment and atmosphere [1]. The mining processing procedures utilized largely determine the extent of the damage [2], and without appropriate management, precipitation washes out tailings, which serve as a source of heavy metals contamination and could lead to ecological problems [3]. These environmental problems associated with mining activities, such as pollution and land degradation, have been emphasized in several studies in Ghana [4–7].

In Bontesso, the Amansie West District of Ghana, the industrial activities community dwellers are engaged mainly in are agro-industrial activities [8]. These agro-industrial activities include cassava processing (gari making), oil extraction, and distillation of local gin (akpeteshie) are among them [8, 9]. Wood processing into lumber, furniture making, and woodcarving are among the others with a few people working in jewelry fabrication and clothes design. Small-scale registered miners and illegal miners known as "galamsey" make up the majority of District's mining industry, except for Keegan Resources Gold Limited [10].

Due to the high return on the income generated through illegal mining, it has seen a large proportion of Amansie West District members are actively engaged in it [11]. Since their activities are illegal, their operations usually take place in sensitive areas employing the use of chemically sensitive substances such as cyanide and mercury [12]. In the process, pits are dug which are filled with water used for washing the extracted gold ores. This process exposes the workers at the mining site to the toxin (chemicals employed in the extraction process) through exposure routes such as ingestion, inhalation, and dermal contact. According to Baki et al. [13], exposure of the contaminant to humans even in small quantities can cause dangerous health implications which include skeletal and cardiovascular diseases, neurotoxicity, and infertility [14, 15].

Not only is human health affected but also the deterioration of the environmental receptors including the soil, water, and air. For instance, the chemical and biological constituents of the soil are impaired by the presence of these inorganic contaminants. This in the long run can determine whether the nutritional intake of a given product is safe for consumption considering the bioaccumulation of metals in food crops [16]. Also, Foli and Nude [17] reported that due to the nonbiodegradable nature of metals and their capacity to build up in the soil, they have the potential to infiltrate the groundwater systems. Opoku et al. [7] investigated the removal of heavy metals in illegally mined soil in Bontesso using indigenous species and concluded that the high concentrations of the examined contaminants could endanger both the environment and human health.

Although mining contributes significantly to Ghana's economy, the lack of environmental knowledge, resources, and training among artisanal miners has resulted in health concerns for the general public and environmental degradation in host mining communities [18, 19]. The majority of the populace, especially those involved in illegal gold mining, is unaware of the dangers posed by the usage of harmful chemicals in mining operations. In Bontesso, the Amansie West District, the full impact of illegal gold mining on the ecological and health risk has not been properly examined and documented. As a result, more research is needed in Bontesso, Ghana's Amansie West District, to investigate the possible ecological and human health risks of heavy metals.

2. Materials and Procedures

2.1. Study Area. The study took place in Bontesso, Ghana, which is part of the Ashanti Region's Amansie West District. Bontesso is located 42 kilometers north-west of Obuasi and about 60 kilometers north-east of Kumasi, the regional capital of Ghana's Ashanti Region, and about 600 meters north-east of Asanko Gold Mines [7]. The study area is located between the latitudes of 6° 19′40″ N and 6° 28′ 40″ N, and the longitudes of 2° 00′ 55 W and 1° 55′ 00″ W. It covers an area of around 1,230 square kilometers and is one of the Ashanti Region's highest districts. The research area's geography is undulating in general, with an elevation of 210 meters above sea level. The range of hills that spans the district's northwestern corner is the most conspicuous feature. The Offin and Oda rivers, as well as their tributaries such as the Jeri, Pumpin, and Emuna, form the main drainage system. The climate of the study area is wet semiequatorial, with a double maxima rainfall regime, with the major rainy season falling between March and July and the minor rainy season falling between September and November. Rainfall averages 855 to 1,500 mm per year. Throughout the year, temperatures are normally hot, with an average monthly temperature of around 27°C. The vegetation of the district is mostly rainforest and wet semi-deciduous. This makes the ground exceptionally fertile and appropriate for growing food and cash crops including cassava, maize, rice, citrus, cocoa, citronella grass, and oil palm, among other things. Figure 1 presents a map of the research area.

2.2. The Geology and Impacts of Illegal Mining on the Study Area. In the study area, gold-bearing quartz veins are discovered in tightly folded Birimian sedimentary rocks with dykes and granitoids intruding [20]. The intrusions are heavily brecciated and mineralized in the southern parts, and the topography is heavily influenced by the weathering profiles. Laterite, saprolite, and oxidized bedrock form weathering horizons at higher elevations, whereas alluvium or leftover tailings from prior alluvial operations cover lower elevations.

Illegal mining, popularly known as galamsey, have taken over at Bontesso, the Amansie District in the Ashanti Region. Their illegal activities have had devastating implication on the lives of rural community members even though it has improved the livelihood of a few but their impacts are huge. These devastating impacts embroil the loss of farmland which directly leads to unemployment not only on farmlands but also as a bad influence on the investment for the legal mining companies. In addition to this, there is also a loss of forest cover which is the main contributor to carbon sequestration to mitigate climate change.

2.3. Soil Sampling and Preparation. Using a reference point, a 30 m × 15 m plot (Figure 2) was divided into 6 equal subplots with 5 m intervals. Soil samples were obtained at three random sites of each subplot using a soil auger at 0–15 cm and 15–30 cm, with each 0–15 cm and 15–30 cm composited to generate a bulk sample. A total of 18 soil samples were taken at the study location, and they were placed in sample bags with their descriptions. Soil samples from the mining region were homogenized and air-dried at room temperature in the laboratory to achieve a consistent weight. The air-dried soil samples were sieved using a 2 mm filter for heavy metal analysis.

2.4. Heavy Metals Contents and pH Determination in Soil Samples. The samples were further pulverized and sieved using a 2 micron mesh to ensure the removal of high-solid particles. The sieved soil samples were digested in an aqua regia with HCl and HNO_3 acid in a 1 : 3 ratio. The mixture was heated on an electric plate for 1 hour at 100°C until it

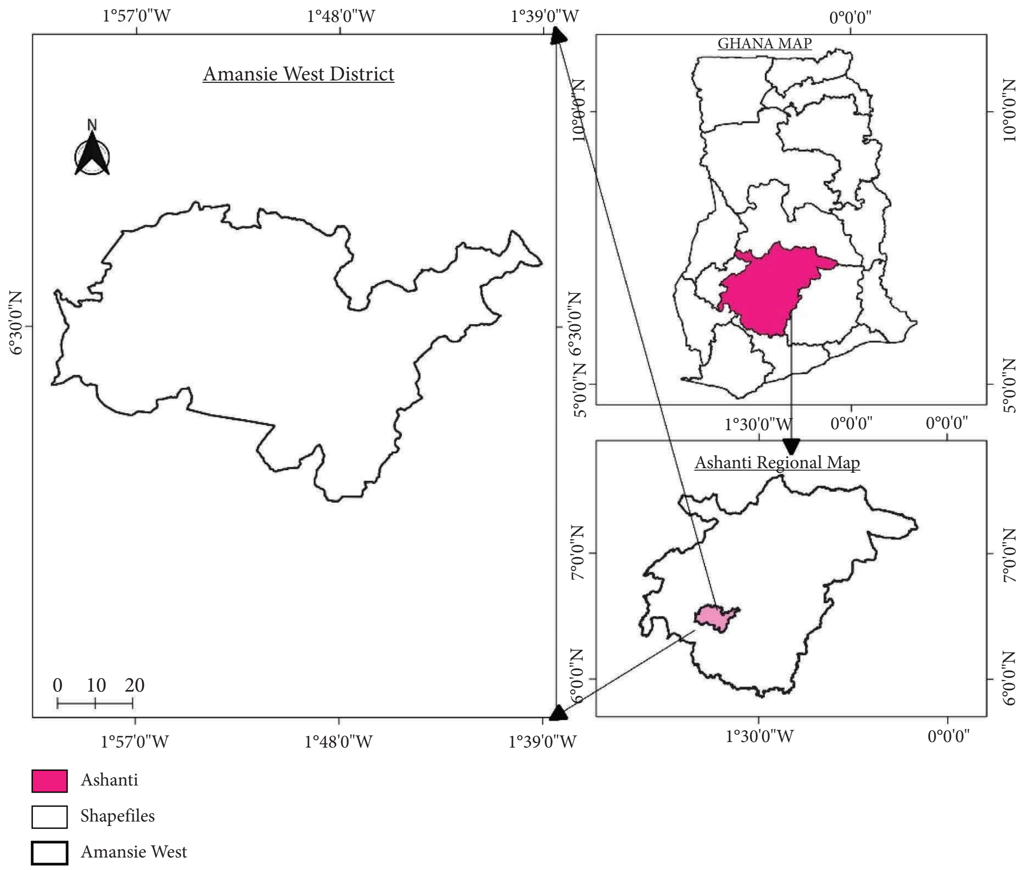

Figure 1: Map of Ghana showing the Amansie West District.

turned transparent, then allowed to cool. After that, the solution was pouring into the volumetric flask and diluted to 50 mL with distilled-deionized water. The quantities of As, Cd, Cu, Pb, and Ni were measured using atomic absorption spectroscopy (AAS, Buck Scientific VGP 210 Model) with detection limit of 0.02, 0.02, 0.05, 0.10, and 0.04 mg/kg.

The approach for determining the concentrations of heavy metals in soil was used as the procedure reported by Baah et al. [21]. 10 grams of soil sample and distilled water were mixed in a 50 mL beaker. The mixture was mixed for 5 minutes before being set aside for 30 minutes. By dipping the electrode of a Eutech 510 pH meter into the top surface of the mixture, the pH of the suspension was determined. The method was repeated for all of the other pH measurements in the study.

2.4.1. Quality Assurance and Quality Control. The quality assurance (QA) and quality control (QC) of the samples were assessed using standard reference materials that were acquired from Standard Global Services of Ghana, which is accredited by the Ghana Standards Authority GSA/HRD/33. The results were within $a \pm 10\%$ range of the permitted values, they were considered acceptable. Every soil sample was analyzed twice, and it was agreed that the relative standard deviation of the measurements between the two replicate samples should be less than 5%.

2.4.2. Analytical Validation Method. During the analytical validation at the laboratory, the first step was to optimize the atomic absorption spectrophotometer (AAS). After the optimum tool condition was obtained, it was followed by the optimization of the wet digestion process using a destructive device which includes the use of various reactants as destructors. After obtaining optimum digestion tools and processes with oxidizing variations, a calibration curve was made, followed by validation of the analysis method of As, Cd, Cu, Pb, and Ni contamination in soil with AAS which includes detection limits and quality assurance and quality control measures.

2.5. Heavy Metals Pollution Risk Assessment

2.5.1. Geoaccumulation Index (I_{geo}). The index of geo-accumulation (I_{geo}) was used to determine the amounts of heavy metal contamination in soil samples. According to Rahman et al. [22], this indicator was developed as a new geochemical principle for assessing heavy metals in soil worldwide and knowing the pollution status. It is important to note that the 1.5 coefficient was chosen to reduce the impact of changes in the background material. This possible change that occurs is generally associated with soil lithology and ground factors effects [23, 24]. Equation (1) was used to compute I_{geo} as provided by Frankignoul and Müller [25].

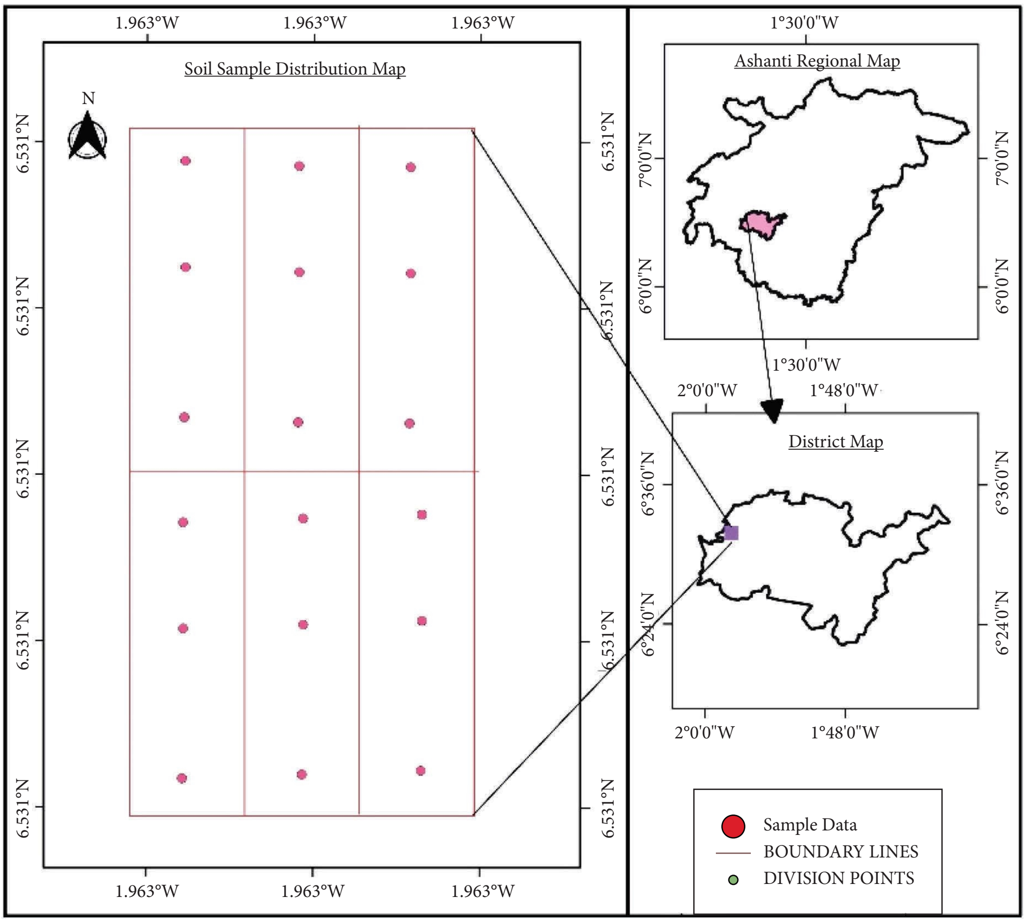

Figure 2: Distribution map of sampling site.

$$I_{geo} = \log_2 \frac{Cn}{1.5Bn}, \quad (1)$$

where Cn denotes the concentration of a chemical component in soil and Bn denotes the background concentration.

The natural concentration (Bn) is expressed as averages for worldwide soils, where As, Cd, Cu, Ni, and Pb are 5, 0.5, 25, 17, and 25 mg/kg, respectively [26].

The I_{geo} was classified as follows: $I_{geo} = 0$ (practically uncontaminated), $0 < I_{geo} < 1$ (uncontaminated to moderately contaminated), $1 < I_{geo} < 2$ (moderately contaminated), $2 < I_{geo} < 3$ (moderately to heavily contaminated), $3 < I_{geo} < 4$ (heavily contaminated), $4 < I_{geo} < 5$ (heavily to extremely contaminated), and $I_{geo} > 5$ (heavily to extremely contaminated) (extremely contaminated).

2.5.2. Contamination Factor (CF). The contamination factor was used to evaluate soil contamination as well as to indicate the contamination level of a specific harmful element [27, 28]. It gives a reflection of the study area's pollution characteristics and as well indicates a single pollution index in the environmental media of a given heavy metal. The contamination factor was calculated as the ratio of heavy metal content to the background content of the corresponding heavy metal [29]. It was computed using the following equation [28]:

$$CF = \frac{C_s}{B_n}, \quad (2)$$

where C_s represents the study area's metal content in the samples and B_n represents the baseline content (mean worldwide soils). The concentration factor was classified based on Hakanson [28] as follows: low ($CF < 1$); moderate ($1 < CF < 3$); considerable ($3 < CF < 6$); and high contamination ($CF > 6$).

2.5.3. Ecological Risk Factor (Er). According to Hakanson [28], the ecological risk factor (Er) indicates the level of contamination in soils and sediments that poses a concern. The ecological risk factor can provide a wide range of estimates of the risk of metal in the environment and the biological toxicity as it has been used in numerous studies. This factor is dependent upon the contamination factor and the toxic response factor (Tr) as estimated by Hakanson [28] in the following equation:

$$Er = T_r \times CF. \quad (3)$$

The T_r values for As, Cd, Cu, Ni, and Pb are given as 10, 30, 5, 5, and 5, respectively [30]. The ecological risk factors were classified into five classes as presented in Table 1 (Yuan et al. 2014).

2.5.4. Degree of Contamination (C_d). The sum of all contamination factors (*CF*) determines the total degree of contamination (C_d) from a particular sampling location. Equation (4) is used to determine the level of contamination, and the degree of contamination classified by Hakanson [28] presented in Table 2 as follows:

$$C_d = \sum_{1}^{n} \mathrm{CF}, \quad (4)$$

where *CF* denotes the single contamination factor and represents the total number of elements present.

2.5.5. Pollution Load Index (PLI). As proposed by Tomlinson et al. [31], the pollution load index is an experimental metric that compares the level of heavy metal contamination in different sampling areas. Thus, this tool is a unique index that is commonly used when comparing the rank of pollution that has occurred in different places [32]. The *PLI* was calculated using the relationship indicated in the following equation:

$$\mathrm{PLI} = \sqrt[n]{\mathrm{CF}_1 \times \mathrm{CF}_2 \times \mathrm{CF}_3 \times, \ldots\ldots \mathrm{CF}_n}, \quad (5)$$

where *CF* stands for contamination factor values for various pollutants and n stands for the number of metals studied.

According to Varol [33]; *PLI* values were classified into three groups; namely, $PLI > 1$ suggests the existence of pollution, $PLI < 1$ indicates there is no pollution of the examined metal, and $PLI = 1$ suggests that pollution of heavy metal loads are close to the background concentration.

2.5.6. Pollution Ecological Risk Index (PER). The pollution ecological risk index, which is statistically measured by the ecological risk factor, illustrates the harm posed by heavy metals (*Er*) [28, 34]. According to Hakanson [28] and Kasemodel et al. [35]; the *PER* levels were compared to *Er*'s environmental risk of heavy metal pollution as indicated in the following equation:

$$\mathrm{PER} = \sum_{1}^{n} E_r. \quad (6)$$

The *PER* values were grouped into four classes; *PER* contamination is low ($PER < 150$), *PER* is moderately contaminated ($150 \leq PER < 300$), *PER* is considerably contaminated ($300 \leq PER < 600$), and *PER* is highly contaminated ($PER \geq 600$) [28].

2.6. Risk Assessment for Human Health. The process of evaluating the chance of any given number of negative health impacts occurring over a particular period of time is referred to as risk assessment [36, 37]. Threat detection, exposure assessment, dose-response, and risk characterization are all part of risk assessment [21, 38]. Each contaminant's health risk assessment which is commonly based on an estimate of the risk level, and health hazards are categorized as carcinogenic (a substance that is capable of causing cancer over time resulting from continuous exposure) or noncarcinogenic (a chemical that is not known to cause cancer). In the Bontesso setting, the contamination of heavy metals and their associated carcinogenic and noncarcinogenic health risks generated by inhalation, dermal absorption, and ingestion of heavy metals in soils were estimated using the hazard index (HI), hazard quotients (HQ), and the Incremental Lifetime Cancer Risk (ILCR). The risks to human health associated with the metals under consideration were assessed in this study as described [39, 40]. Furthermore, the USEPA standards for assessing both noncancer and cancer hazards in human children and adults were followed.

Table 1: Classes of the ecological risk factor for heavy metals pollution.

Er	Interpretation of the classes
$Er < 40$	Low potential ecological risk
$40 \leq Er < 80$	Moderate probable ecological risk
$80 \leq Er < 160$	Considerable possible ecological risk
$160 \leq Er < 320$	High potential ecological risk
320≥	Very high ecological risk

Table 2: Classifications of the degree of contamination.

Degree of contamination	Contamination status
$Cd < 8$	Contamination is low
$8 \leq Cd < 16$	Contamination at a moderate degree
$16 \leq Cd < 32$	Considerable degree of contamination
$Cd \geq 32$	A high degree of contamination

2.6.1. Ingestion of Soil. The average daily intake of heavy metals from the soils was calculated using the following equation:

$$\mathrm{ADI_{ing}} = \frac{C \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}}, \quad (7)$$

where *ADI* is the average daily (mg/kg-day) intake of heavy metals from the soils, C is the concentration of heavy metals in the soil (mg/kg), *IR* is the rate of ingestion (years), the exposure frequency (days/years) is denoted by *EF*, the duration of exposure is denoted by *ED* (years), the conversion factor is denoted by the symbol *CF* (kg/mg), an individual's body weight is referred to as *BW* (kg), and *AT* denotes the average duration (days).

2.6.2. Inhalation of Soil. Also, the average daily intake of inhaled heavy metals from the soil was determined using the following equation:

$$\mathrm{ADI_{inh}} = \frac{C \times \mathrm{IR_{air}} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT} \times \mathrm{PEF}}, \quad (8)$$

where *ADI* is the average daily intake of inhaled heavy metals from the soil (mg/kg-day), IR_{air} is the rate of inhalation (m^3/day), and the particulate emission factor is abbreviated as *PEF* (m^3/kg). The other parameters have already been defined in equation (8) above.

2.6.3. Dermal Contact with Soil. The average daily intake of heavy metals through dermal contact with soil was calculated using the following equation:

$$\mathrm{ADI_{dems}} = \frac{C \times \mathrm{SA} \times \mathrm{FE} \times \mathrm{AF} \times \mathrm{ABS} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}}, \quad (9)$$

where *ADI* is the average daily intake of heavy metals through dermal contact with soil (mg/kg-day), *SA* represents the area of the skin (cm^3), the proportion of dermal exposure ratio is represented by *FE*, the soil adherence factor is represented by *AF* (mg/cm^2), and *ABS* denotes the percentage of the applied dose that is absorbed through the skin. Equations (7) and (8) define *EF*, *ED*, *BW*, *CF*, and *AT*. Table 3 displays the metrics used and their interpretation for assessing health risks via various pathways.

2.6.4. Estimation of Noncarcinogenic and Carcinogenic Risk Assessment. The noncarcinogenic and carcinogenic risk assessments from soil ingestion, inhalation, and skin contact were calculated using the average daily intake values. A hazard quotient (*HQ*) is used to express the noncarcinogenic health risk using USEPA recommendations [41]. For each chemical and exposure route, the hazard quotient is calculated as follows:

$$\mathrm{HQ} = \frac{\mathrm{ADI}}{\mathrm{RfD}}, \quad (10)$$

where *HQ* denotes the hazard quotient, *ADI* denotes the average daily intake of heavy metals from the soil via various exposure paths, and *RfD* denotes the oral reference dose via various exposure pathways.

For *n* number of heavy metals, the noncarcinogenic impacts on the population are calculated by adding all of the heavy metals' HQs together. The mathematical representation of these indices is shown in Equation

$$\mathrm{HI} = \sum_{k=1}^{n} \mathrm{HQ}_k = \sum_{k=1}^{n} \frac{\mathrm{ADI}_k}{\mathrm{RfD}_k}, \quad (11)$$

where HQ_k, ADI_k, and RfD_k represent values of heavy metals *k*. When $HI < 1$, the targeted demographic is unlikely to be exposed to noncancer risk, but if, $HI > 1$ occurs. Noncancer effects are likely for the targeted demographic [41]:

$$\mathrm{CR} = \mathrm{ADI} \times \mathrm{CSF}, \quad (12)$$

where *CR* is the cancer risk, the average daily intake of heavy metals from the soil through various exposure paths is referred to as *ADI*, and *CSF* stands for the cancer slope factor,

Table 3: Interpretations and values used for health risk assessment [41].

Parameters	Children	Adults
Body weight (kg)	15	70
Frequency of exposure (days/years)	350	350
Time of exposure (years)	6	30
The rate of consumption (mg/day)	200	100
Inhalation rate (air) (m^3/day)	10	20
Surface area of the skin (cm^2)	2100	5800
Adherence factor of soil (mg/cm^2)	0.2	0.07
Factor of dermal absorption	0.1	0.1
The ratio of dermal exposure	0.61	0.61
Emission factor for particulates (m^3/kg)	1.3×10^9	1.3×10^9
Conversion factor (kg/mg)	10^{-6}	10^{-6}
Average time		
Carcinogens	365×70	365×70
Noncarcinogens	$365 \times \mathrm{ED}$	$365 \times \mathrm{ED}$

which is calculated for each metal and exposure pathway. A cancer slope factor is a 95 percent confidence limit for the increased cancer risk from a lifetime exposure to a toxicant through ingesting, cutaneous, or inhalation exposure routes [41].

The total cancer risk from a lifetime exposure to each heavy metal for an individual is calculated for the different exposure routes using the following equation:

$$\mathrm{Risk_{total}} = \mathrm{Risk_{ingestion}} + \mathrm{Risk_{inhalation}} + \mathrm{Risk_{dermal}}, \quad (13)$$

where $Risk_{ingestion}$, $Risk_{inhalation}$, and $Risk_{dermal}$ are contributions from ingestion, inhalation, and dermal passages. Table 4 shows how to calculate the oral reference dose *(RfD)* and cancer slope factor *(CSF)* for noncarcinogenic and carcinogenic risk assessment.

2.7. Data Analysis. Statistical Package for Social Scientists (SPSS) Software, Version 20.1 was used to perform a one-way analysis of variance (ANOVA) on data collected for heavy metal concentrations. To compare the mean differences in heavy metal concentrations in soils, Tukey-B was employed with a 5% significance threshold. Factor analysis (FA) and Pearson's correlation analysis (PCA) were carried out to investigate the relationships between the selected heavy metals as well as to identify potential heavy metal sources. The agglomerative hierarchical cluster analysis (AHCA) was performed based on the normalized data, using Ward's method to minimize the error sum of squares between clusters [43] and Euclidean distance as a measure of similarity between the interdependent variables [44]. The output, called a dendrogram [45], provided a basis for identifying the data structure among observations and variables. All other calculations were performed using Excel.

3. Results and Discussion

3.1. Illegally Mined Soil Properties. One of the most effective markers for assessing acid soil conditions for successful revegetation is soil pH. The pH range of the illegally mined soil was found to be between 5.71 and 6.24. As expected, this

Table 4: Cancer slope factor and oral reference dose for individual heavy metals and different exposure routes [41, 42].

Heavy metal	Oral RfD	Dermal RfD	Inhalation Rf	Oral CSF	Dermal CSF	Inhalation CS
As	3.0×10^{-4}	3.0×10^{-4}	3.0×10^{-4}	1.5	1.5	1.5×10
Cd	5.0×10^{-4}	5.0×10^{-4}	5.7×10^{-5}	—	—	6.3
Cu	3.7×10^{-2}	2.4×10^{-2}	—	—	—	—
Ni	2.0×10^{-2}	5.6×10^{-3}	—	—	—	—
Pb	3.6×10^{-3}	—	—	8.5×10^{-3}	—	4.2×10^{-2}

pH range of 5.71 to 6.24 was considered to be slightly acidic. Acid soils are generated as a result of anthropogenic activities including mining, and they can kill plants. The slightly acidic nature of the soil from this study corroborates with other research works on mined soils [46, 47].

3.2. Heavy Metals Distribution in Illegally Mined Soil. The descriptive assessments of heavy metals in the mine soil of the research region are shown in Table 5. Heavy metal concentrations are measured and compared to WHO guideline values to evaluate the danger of heavy metals in soil for this study.

The concentration of arsenic (As) in the soil samples investigated ranged from 11.1 to 13.1 mg/kg, with an average of 12.2 mg/kg (Table 5). This average value is higher than the 12.0 mg/kg guideline quoted by Joint et al. [48]. The high levels of arsenic concentration in the illegally mined soil from the study area could be attributed to the presence of arsenopyrite [34]. Arsenic in soils may be detrimental to both plants and animals [49]. Reduced root and shoot growth, seed germination inhibition, and reduced fruit and grain yields are all indicators of As exposure [50]. An abrupt release of copper into the blood produces acute hemolysis and results in the animals' mortality when the liver's capacity for storing copper is surpassed. Similar to this, work done by Rostami et al. [51] on heavy metals in agriculture soils: environmental monitoring and ecological risk assessment, revealed higher As concentrations above their background concentrations.

Cadmium (Cd) values in soil samples varied from 1.1 to 1.3 mg/kg, with an average of 0.8 mg/kg (Table 5). The cadmium content was above the WHO guidelines of 1.3 mg/kg by Joint et al. [48]. Human activities such as mining operations may have increased the cadmium levels in the soil. Comparatively, Demková et al. [52] recorded Cd levels as exceptionally high and over the limit in all soil samples tested in a former mining location. High cadmium (Cd) concentrations can be harmful to soil microbes, influencing soil biogeochemical processes including soil organic matter (SOM) breakdown by affecting microbial biomass [53].

Copper (Cu) is one of the key macronutrients required by practically all animals, higher plants, and agricultural plants. The total copper concentration in the soils studied ranged from 29.2 mg/kg to 40.6 mg/kg, with an average of 34.6 mg/kg. The average content recorded from this study was below the maximum acceptable limit of 36.0 mg/kg provided by Joint et al. [48]. Despite the high concentration of copper in the soil, there were found to be below the permissible limit. However, elevated levels could be associated with porphyry [54]. Similar research conducted by Ogunkunle and Fatoba [55] in soils contaminated with heavy metals around the mega cement factory in Southwest Nigeria, recorded Cu contents below the international standard limits.

Table 5: The average heavy metals concentrations in analyzed mine soil samples (mg/kg).

Sample ID	As	Cd	Cu	Ni	Pb
1	12.1	1.1	29.2	27.6	47.5
2	12.6	1.2	34.2	26.5	46.6
3	11.1	1.2	36.1	25.9	49.4
4	12.6	1.3	35.2	28.5	35.1
5	13.1	1.3	40.6	26.4	41.1
6	11.6	1.2	32.3	30.4	45.6
Mean	12.2	1.3	34.6	27.5	44.2
Joint et al. [48]	12.0	0.8	36.0	35.0	85.0

Nickel (Ni) is considered one of the popular toxic environmental contaminants. Nickel concentrations in soil samples ranged from 25.9 mg/kg to 30.4 mg/kg, with an average of 27.5 mg/kg which is below the WHO guidelines of 35.0 mg/kg [48]. Work done by Opoku et al. [7] on the removal of heavy metals in illegally mined soil in Bontesso using indigenous species also indicated Ni content below the reference limit provided.

The average concentration of lead (Pb) found in soil samples from the research region ranged from 35.1 mg/kg to 49.4 mg/kg (Table 5). The average content of Pb recorded from this study is below the WHO guidelines of 85 mg/kg provided by Joint et al. [48]. Results from this study corroborate the findings of Rostami et al. [51] with Pb concentrations below the permissible limit.

3.3. Principal Component Analysis (PCA) and Correlation Analysis. Factor analysis was carried out by evaluating the principal component analysis (PCA) and computing the eigenvalues in order to determine the association of trace metals that will provide information about the source and distribution of metal pollution. Table 6 displays the factor loadings obtained by PCA with varimax for a number of heavy metals. The rotation of the principal components was carried out using the varimax method. Loadings having 0.60 and above marks are boldened in the table below.

The PCA analysis identified two components which were significant with eigenvalues greater than 1.0. Both components accounted for 83.53% of the total variance. Component 1 accounted for 56.34% of the total variance and is associated with Cd, Pb, As, and Cu. Components 2

Table 6: Principal component analysis of trace metals in reclaimed mine soil.

Parameters	Factor 1	Factor 2
Cd	**0.929**	
Pb	−0.918	
As	**0.746**	
Cu	**0.678**	0.643
Ni		−0.954
% Variance	56.34	27.19
% Cumulative	56.34	83.54

NB: bold loadings are statistically significant.

accounted for 27.19% of the total variance and have high Cu and Ni loadings as shown in Table 6. High loadings on chemical constituents Cd, As, and Cu were recorded under factor 1 and this suggests that mining operations are the major contributor of Cd, As, and Cu to soil contamination in the study area. However, the decrease in Pb concentration in factor 1 could probably be ascribed to gold ore as gold ore may contain low Pb in its chemical composition [56]. In factor 2, Cu (0.64) had high loadings and it implies the contribution of mining activities causing the pollution in the study site. The low loadings of Ni could be ascribed to its low constituents in the mineralogical properties of gold [57].

3.4. Supplementary File 1. The associated scree plot, shown in Supplementary File 1, displays the eigenvalues as a function of the principal component number, ranked from large to small.

Supplementary 1. Scree plot showing the eigenvalues sorted from large to small as a function of the principal component number.

The degree of correlation between the metal data logarithms can be determined using Pearson's correlation coefficient matrix. Table 7 below lists the findings of Pearson's correlation coefficient matrix for the heavy metals in the soil samples.

There is a positive significant linear correlation between cadmium and arsenic ($r = 0.51$) as compared to the other chemical elements, implying that they may probably share a common source of origin as reflected in the PCA results in Table 7. There is a strong negative linear correlation between heavy metals such as As vs Ni and Pb ($r = -0.757$ and -0.639, respectively) and could be traced to a similar source possibly gold ore since gold extraction releases these chemical constituents which can be combined and deposited in the soil. A strong positive linear correlation between Cu and Cd ($r = 0.835$) and this agrees with the results obtained in Table 6. However, there was a strong negative correlation between Pb and Cd ($r = -0.785$) and a weak negative correlation between Ni vs Cd, Cu, and Pb ($r = -0.039$, -0.472, and -0.272, respectively). Generally, there is a common origin for Cd, As, and Cu because of their mutual correlation in the soil.

Table 7: Pearson correlation coefficient matrix for trace metals in the soil.

	As	Cd	Cu	Ni	Pb
As	1				
Cd	0.511	1			
Cu	0.408	0.835	1		
Ni	−0.757	−0.039	−0.472	1	
Pb	−0.639	−0.785	−0.381	−0.272	1

* = Correlation is significant at the 0.05 level (2-tailed).

3.5. Cluster Analysis. The cluster analysis (agglomerative bottom-up approach) used to identify the spatial similarity between the sampling sites based on the levels of chemical concentration, grouped all sampling sites into three statistically significant clusters as depicted by the dendrogram (Figure 3). The dendrogram is essential in determining variables of significant importance and source of contamination for appropriate mitigation.

In Figure 3, two distinct clusters emerge from the grouping of heavy metals; and this is consistent with the PCA. Cluster 1 consists of Cu, Ni, and Pb and cluster 2 is comprised of As and Cd.

3.6. Soil Contamination Assessment

3.6.1. Geoaccumulation Index. The rate of heavy metal contamination in the soil was investigated using a variety of pollution parameters. The impacts of each heavy metal distribution in the soil investigated can be predicted using these pollution indices. To evaluate the extent of pollution, the geo-accumulation index (I_{geo}) was used as a reference in this investigation. The estimated average I_{geo} values for the samples studied are shown in Figure 4.

The mean I_{geo} value for the examined chemical component in illegally mined soil at Bontesso was less than one. However, As, Cd, Ni, and Pb recorded values of 0.7, 0.8, 0.1, and 0.2 which were classified as uncontaminated to moderately contaminated ($0 < I_{geo} < 1$) except for Cu which was found to be uncontaminated ($I_{geo} = 0$) in the soil. Also, among the examined elements, Cd had the highest I_{geo} values. The soils studied were classed as uncontaminated to moderately contaminated based on the I_{geo} values.

3.6.2. Contamination Factor and Ecological Risk Factor. Figure 5 shows the results of the contamination factor *(CF)* and the projected ecological risk factor *(Er)* for the studied heavy metals in the mined soils of Bonteso in Ghana's Amansie West District. The results revealed that the heavy metals in the mined soils had an average CF in the sequence Cu > Ni > Pb > As > Cd. This means that all the examined heavy metals tested for their contamination factor were categorized as moderate pollution ($1 < CF < 3$) in the samples of soil from Bontesso.

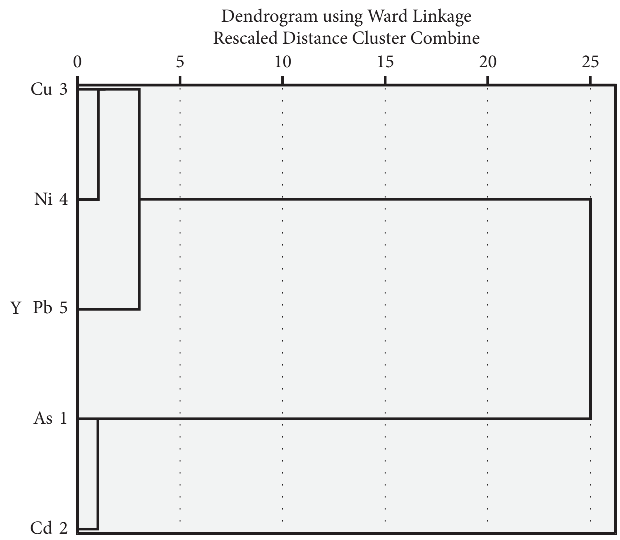

Figure 3: Dendrogram showing clustering of soil samples.

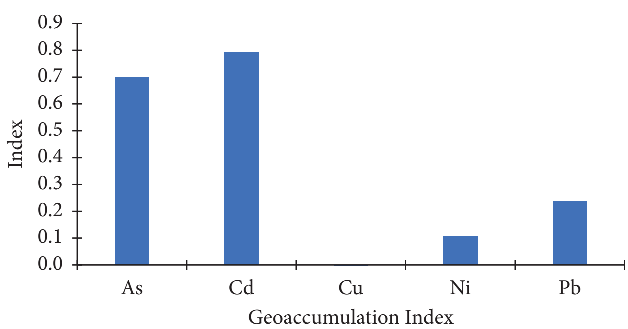

Figure 4: Geoaccumulation index in mine soils at Bontesso.

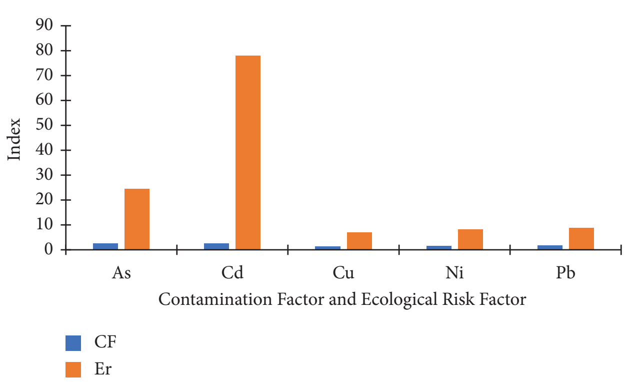

Figure 5: Heavy metal CF and Er in mined soils of Bontesso in the Amansie West District.

The estimated *Er* of metals in soils (Figure 5) showed that Cu > Ni > Pb > As > Cd had the highest *Er*. As (24.4), Cu (6.9), Ni (8.1), and Pb (8.8) were all classified as low ecological risk factors except for Cd (78) which was grouped as moderate ecological risk ($40 \le Er < 80$) (Table 1). As a result, based on *Er* estimates, the soils are deemed to pose minimal ecological risk.

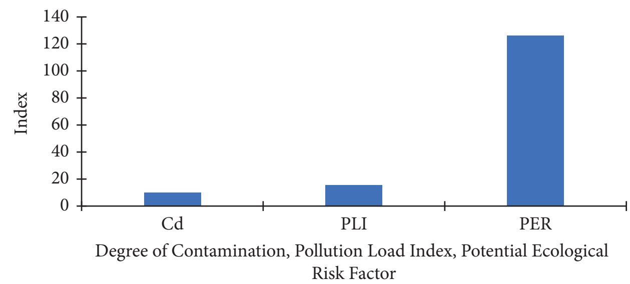

Figure 6: *Cd, PLI*, and *PER* of heavy metal in mined soils of Bontesso in the Amansie West District of Ghana.

3.6.3. Degree of Contamination, Pollution Load Index, and Potential Ecological Risk Factor. The quality of soil is more efficiently investigated when the pollution load index (*PLI*) is used Izah et al. [58]. Figure 6 depicts the results for the heavy metals' *PLI* values. The pollution load index was found to be high (15.6) in all of the samples tested, indicating that $PLI > 1$. This is also a sign of pollution, as chemical components were detected in all soil samples tested in the research region. The findings point to the probability of environmental contamination, particularly with C_d. All of the examined heavy metals in the soil samples have moderate degrees of contamination (C_d) values (Table 2).

As a result, the sample's *PER* estimates were 126.2, indicating that heavy metals provide a low potential ecological harm. Aside from that, *Er* reported means of 24.4, 78, 6.9, 8.1, and 8.8 for arsenic, cadmium, copper, nickel, and lead, respectively. According to Er, arsenic, copper, nickel, and lead had the lowest environmental risk, whilst C_d had the worst. This may be due to the combined effects of some geochemical conditions and the mobility rate of the metal [56, 59]. Their high environmental risk does not come as a surprise since, among the other investigated heavy metals, C_d had a high toxic response (*Tr*).

3.7. Assessment of Health Risks

3.7.1. Heavy Metal Risk Evaluation in Soils for Noncarcinogenicity. Using soil heavy metal content, heavy metals' daily average intake (ADI) associated with both adult and child health concerns from the soil was determined via cutaneous, ingestion, and inhalation pathways. Table 8 shows the average daily intake (ADI) values for noncarcinogenic risk for both adults. It shows the values of the hazard quotient (HQ) from ingestion, inhalation, and cutaneous routes. According to the findings in Table 8, all of the average daily intake (ADI) values estimated for adults and children via ingestion, inhalation, and cutaneous pathways recorded values lower than the oral reference dose provided by USEPA [41] and Kamunda et al. [42]. This means that the general public is consuming safe levels of the heavy metals under investigation via various routes of exposure.

When the *HQ* and *HI* are less than one, it indicates that there is no clear risk to community people involved in

Table 8: Heavy metal average daily intake (mg kg-1 day-1) values in soil for adults and children for noncarcinogenic analyses.

Exposure route		Average daily intake of heavy metals values As	Cd	Cu	Ni	Pb	Total
Adults	Ingestion	1.67×10^{-4}	1.78×10^{-6}	4.74×10^{-5}	3.77×10^{-5}	6.05×10^{-5}	3.14×10^{-4}
	Inhalation	2.57×10^{-9}	2.74×10^{-10}	7.29×10^{-9}	5.80×10^{-9}	9.32×10^{-9}	2.52×10^{-8}
	Dermal	4.14×10^{-6}	4.41×10^{-7}	1.17×10^{-5}	9.33×10^{-6}	1.50×10^{-5}	4.06×10^{-5}
	Total	1.71×10^{-4}	2.22×10^{-6}	5.91×10^{-5}	4.70×10^{-5}	7.55×10^{-5}	3.55×10^{-4}
Children	Ingestion	1.56×10^{-4}	1.66×10^{-5}	4.42×10^{-4}	3.51×10^{-4}	5.65×10^{-4}	1.53×10^{-3}
	Inhalation	6.00×10^{-9}	6.39×10^{-10}	1.70×10^{-8}	1.35×10^{-8}	2.17×10^{-8}	5.88×10^{-8}
	Dermal	1.99×10^{-5}	1.98×10^{-6}	5.26×10^{-6}	4.18×10^{-5}	6.73×10^{-5}	1.36×10^{-4}
	Total	1.76×10^{-4}	1.86×10^{-5}	4.47×10^{-4}	3.93×10^{-4}	6.32×10^{-4}	1.66×10^{-3}

Table 9: Heavy metal average daily intake (mg kg-1 day-1) values in soil for adults and children for carcinogenic analysis.

Exposure route		Heavy metal values consumption daily As	Cd	Cu	Ni	Pb	Total
Adults	Ingestion	7.16×10^{-6}	7.63×10^{-7}	2.03×10^{-5}	1.61×10^{-5}	2.59×10^{-4}	3.03×10^{-4}
	Inhalation	1.10×10^{-9}	1.78×10^{-10}	3.13×10^{-9}	2.49×10^{-9}	4.00×10^{-9}	1.09×10^{-8}
	Dermal	1.77×10^{-6}	1.89×10^{-7}	5.03×10^{-6}	3.99×10^{-6}	6.42×10^{-6}	1.74×10^{-5}
	Total	8.93×10^{-6}	9.52×10^{-7}	2.53×10^{-5}	2.01×10^{-5}	2.65×10^{-5}	3.20×10^{-4}
Children	Ingestion	1.34×10^{-5}	1.42×10^{-6}	3.79×10^{-5}	3.01×10^{-5}	4.84×10^{-5}	1.31×10^{-4}
	Inhalation	5.14×10^{-10}	5.48×10^{-11}	1.46×10^{-9}	1.16×10^{-9}	1.86×10^{-9}	5.05×10^{-9}
	Dermal	1.59×10^{-6}	1.69×10^{-7}	4.51×10^{-6}	3.59×10^{-6}	5.76×10^{-6}	1.56×10^{-5}
	Total	1.50×10^{-5}	1.59×10^{-6}	4.24×10^{-5}	3.37×10^{-5}	5.42×10^{-5}	1.47×10^{-4}

mining operations; however, if the recorded values are above one, it suggests that noncarcinogenic concerns should be considered [41]. The HQ values calculated for the adult population were less than one ($HI < 1$) for the analyzed heavy metals via inhalation and dermal routes, except for the ingestion pathway, which recorded $HQ > 1$ for all the examined heavy metals. This indicates that the adult population is at risk of noncarcinogenic effects. Furthermore, for the oral route of exposure, Cu is the most significant contribution to noncarcinogenic risk in adults. Also, there is no concern about the noncarcinogenic effect in the children population because they recorded *HQ* values of less than 1 for all exposure routes.

3.7.2. Heavy Metal Carcinogenic Risk Assessment for Adults and Children. Using equations (12) and (13), the additional lifetime cancer risks for the populace were estimated individually based on the individual average contribution of heavy metals in the soil. Table 9 shows the additional lifetime cancer risks based on the predicted *ADI* values' carcinogenic risk values. According to the US Environmental Protection Agency, the acceptable range for cancer regulatory purposes is 1×10^{-6} to 1×10^{-4} [41]. In this study area, both adults and children recorded values in the above acceptable range for the examined heavy metals except Pb via ingestion, inhalation, and dermal in adults and children. Furthermore, the results obtained show that, considering the exposure pathways, ingestion contributes to the highest exposure route to cancer risk, followed by *CR* dermal and inhalation, both in adults and children. Ingestion being the highest contributor to CR did not come as a surprise since it also recorded $HQ > 1$ for noncarcinogenic risk. Also, arsenic from the examined heavy metals represents the greatest threat to cancer risk within the study area.

4. Conclusion

Heavy metal (As, Cd, Cu, Ni, and Pb) concentrations in the mined soils of Bontesso in Ghana's Amansie West area were investigated in this study. All examined metals studied were below WHO guidelines except for As and Cd. The contamination status of the study area was evaluated and analyzed using single indices (I_{geo}, *CF*, and *Er*) and integrated indices (*PLI*, C_d, and *PER*). The values of I_{geo} indicated that As, Cd, Cu, and Ni were moderately contaminated, while Cu was uncontaminated in the soil from the study area. In addition, *CF* showed moderate contamination for all the analyzed heavy metals, whereas *Er* indicated a low ecological risk for As, Cu, Ni, and Pb, except for Cd which is classified as a moderate ecological risk. *PLI* for all the samples was found to be high ($PLI > 1$) and it implies that pollution exists, whereas C_d indicates that the tested heavy metals are contaminated to a considerable degree.

In the research area, *PER* demonstrated that heavy metals have a modest potential ecological danger. The findings also indicated a noncarcinogenic risk in the populace; the average daily intake values of heavy metals were below their respective oral reference doses through the different exposure routes indicating the populace is ingesting safe levels of the examined contaminants through exposure pathways. *HQ* and *HI* recorded values less than 1 for inhalation and dermal routes except for ingestion, suggesting that the adult population is at risk of noncarcinogenic effects. Cu is the most significant contributor to noncancer effects in adults. However, there is no concern about the noncancer risk effect in the children population. The cancer risk results show that both adults and children are ingesting levels above the acceptable regulatory limit. Similarly, the ingestion route represents the highest contributor to cancer risk in both children and adults with arsenic posing the greatest threat.

Based on these findings, it can be stated that heavy metals in the soil are steadily accumulating, highlighting the crucial need to implement measures to minimize unlawful mining in the studied region. In addition, remediation approaches such as phytoremediation which is environmentally friendly and cost-effective can be employed to immobilize the accumulated contaminants.

Data Availability

The data that support the findings of this study are made available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Supplementary Materials

Supplementary 1. Scree plot showing the eigenvalues sorted from large to small as a function of the principal component number. (*Supplementary Materials*)

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