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(Research Article)

Soil and environment quality in artisanal small-scale mining areas in western Côte d'Ivoire

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Abstract

Artisanal small-scale gold mining activities grow in different regions of Côte d'Ivoire, causing enormous soil and environmental damages. This study was conducted in the vicinity of illegal artisanal small-scale gold mining zones to investigate soil quality using environmental assessment tools, mainly pollution and geochemical accumulation indexes. The mining spoil from artisanal pits was sampled directly between 0 and 20 cm, collecting 500 g of soil per sampling point. Sub-samples of soil were analyzed for multi-element using X-ray fluorescence technique. The results of the XRF analysis revealed higher trace element levels at some sampling points than the recommended levels. High arsenic concentrations were identified at three sampling sites: cavally sites with 7.09 and 16.08 mg kg^{-1} and Zérégbo with 9.57 mg kg^{-1}. Moreover, significant concentrations of Cu and Pb were found at the Cavally site whilst Singouiné and Zérégbo showed high concentrations of Co and Cr. The study, globally, revealed the environmental hazards caused by the organized artisanal mining.

Keywords: Trace elements; Contaminants; Artisanal illicit mining; pXRF

1. Introduction

Trace elements (TEs) occur naturally and are present in soil at concentrations lower than 100 mg kg^{-1} [1]. However, the type and content of the trace elements in soils are largely determined by the nature of the parent materials [2]. While acidic rocks tended to be richer in other elements like Ba and Pb, ultrabasic and basic rocks incorporated bio-essential trace elements like Co, Ni, Zn, and Cr by isomorphous replacement of Fe and Mg in ferromagnesian minerals. The distribution of Cu, Mn, and, to a lesser extent, B, Mo, and Se is more even [3].

However, anthropogenic activities like waste disposal, manufacturing, agricultural inputs, and mineral extraction have led to the addition of significant amounts of trace elements to soils [1], [4, 5]. As previously mentioned, the small-scale gold mining sector in Côte d'Ivoire is a significant source of potentially toxic elements dispersion (PTEs) on soil surfaces [6].

These potentially toxic elements, including arsenic (As), chromium (Cr), cadmium (Cd), copper (Cu), lead (Pb), iron (Fe), manganese (Mn), mercury (Hg), nickel (Ni), zinc (Zn), uranium (U), and vanadium (V), have historically been connected to gold mining [7, 8]. As a result, the concentration of PTEs linked to gold mining sites may rise, which could lead to environmental pollution and constitutes a risk for phytotoxicity and zootoxicity [9, 12].

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Trace elements have drawn more interest from the scientific and legislative communities because of their prevalence and potential toxicity at high concentrations in soils [13]. The effects of their lack on soil, plants, and human health have also been studied [14]. Therefore, the purpose of this study was to investigate the levels of trace elements in the waste products from artisanal gold mining on surface soil.

2. Materials and methods

2.1. Soil sampling

The spoil from artisanal pits was sampled directly between 0 and 20 cm depth. The amount of soil collected was around 500 g per sample. The geographical coordinates of each sampling point were determined using Garmin 64S.

2.2. Soil analysis

Sub-samples of soil were analyzed for multi-element X-ray fluorescence technique [15]. The sub-samples were placed in the measurement window of the Niton Xl3t Goldd Analyzer. The "Soils" calibration, in the "soils and minerals" mode, to search for concentrations below 1% and trace elements, and the "Cu/Zn minerals" calibration to search for concentrations above 1%.

2.3. Data analysis

The collected data were used to calculate the soil pollution index using the following equation, as potentially toxic elements co-occur as combined contaminants in mining sites [16]:

$$IP = \frac{\frac{As}{6} + \frac{Co}{30} + \frac{Cd}{1} + \frac{Cr}{150} + \frac{Cu}{100} + \frac{Ni}{50} + \frac{Pb}{100} + \frac{Zn}{300}}{8}$$

If the pollution index is higher than 1, then the soil is affected by a polymetallic contamination.

A geo-accumulation indexing approach (Igeo) was used to assess the soil quality [4, 17, 18] and thereby evaluate the degree of anthropogenic contamination in different ranges of concentration. The background data used to compute Igeo were the permissible values of AFNOR [19]. The equation was as follows:

$$Igeo = \ln(\frac{Cn}{1.5XBn})$$

where Cn is measured concentration in mg kg^{-1}, and Bn is the geochemical background value in mg kg^{-1}.

Pearson correlation analysis and multivariate analysis using the clustering variables option with the complete linkage method were conducted with Minitab 17 [5, 20].

3. Results

The results of the XRF analysis revealed that the trace element levels at some sampling points exceeded the recommended level. These values—50 mg Ni kg^{-1}, 300 mg Zn kg^{-1}, 6 mg As kg^{-1}, 1 mg Cd kg^{-1}, 30 mg Co kg^{-1}, 150 mg Cr kg^{-1}, 100 mg Cu kg^{-1}, 100 mg Pb kg^{-1} —are suggested as safe. The following trace elements were discovered in dangerous amounts: As, Cd, Co, Cr, Cu, and Pb, apart from Ni and Zn, whose concentrations were below the acceptable limit levels. Three sampling stations with high As concentrations were identified: cavally sites with 7.09 and 16.08 mg kg^{-1} and Zérégbo with 9.57 mg kg^{-1}. Cd concentrations of 16.5, 21.65, and 12.89 mg kg^{-1}, respectively, were discovered at Singouiné, Zérégbo, and Floleu. Additionally, large concentrations of Cu and Pb were found at the Cavally site, and Singouiné and Zérégbo showed high concentrations of Co and Cr (Figure 1).

From these observations, it was determined that two sites, one in Cavally and the other in Zérégbo, accumulated each of the three trace elements at high concentrations: As, Cu, and Pb for the Cavally site, and As, Cd, and Cr for the Zérégbo site. Furthermore, As and Cd occurred at the highest frequency (0.16) at high concentrations.

Multielement pollution was detected at two locations in Singouiné with pollution indices of 2.07 and 1.03, as well as at Cavally, Zérégbo, and Floleu with corresponding pollution values of 1.57, 3.77, and 1.61. The Pearson correlation found a strong and highly significant correlation between As, Pb, and Zn on one hand, and Cu, Pb, and Zn on the other hand. Moreover, Pb and Zn, on one side, and Cd and Cr, on the other side, were significantly and strongly correlated (Table 1).

The preview observation was further supported by the result of the multivariate analysis. It showed that As, Cu, Pb and Zn coexisted in the soil at 79.34 level of similarity (Figure 2a). Also, Cd and Cr coexisted at the same level of similarity. The importance of Cr and Cd in soil pollution was revealed by clustering the variables with the index of pollution (IP) (**Figure 2b**). The clustering result showed that the occurrence of Cd and Cr in the soil implied a high pollution index.

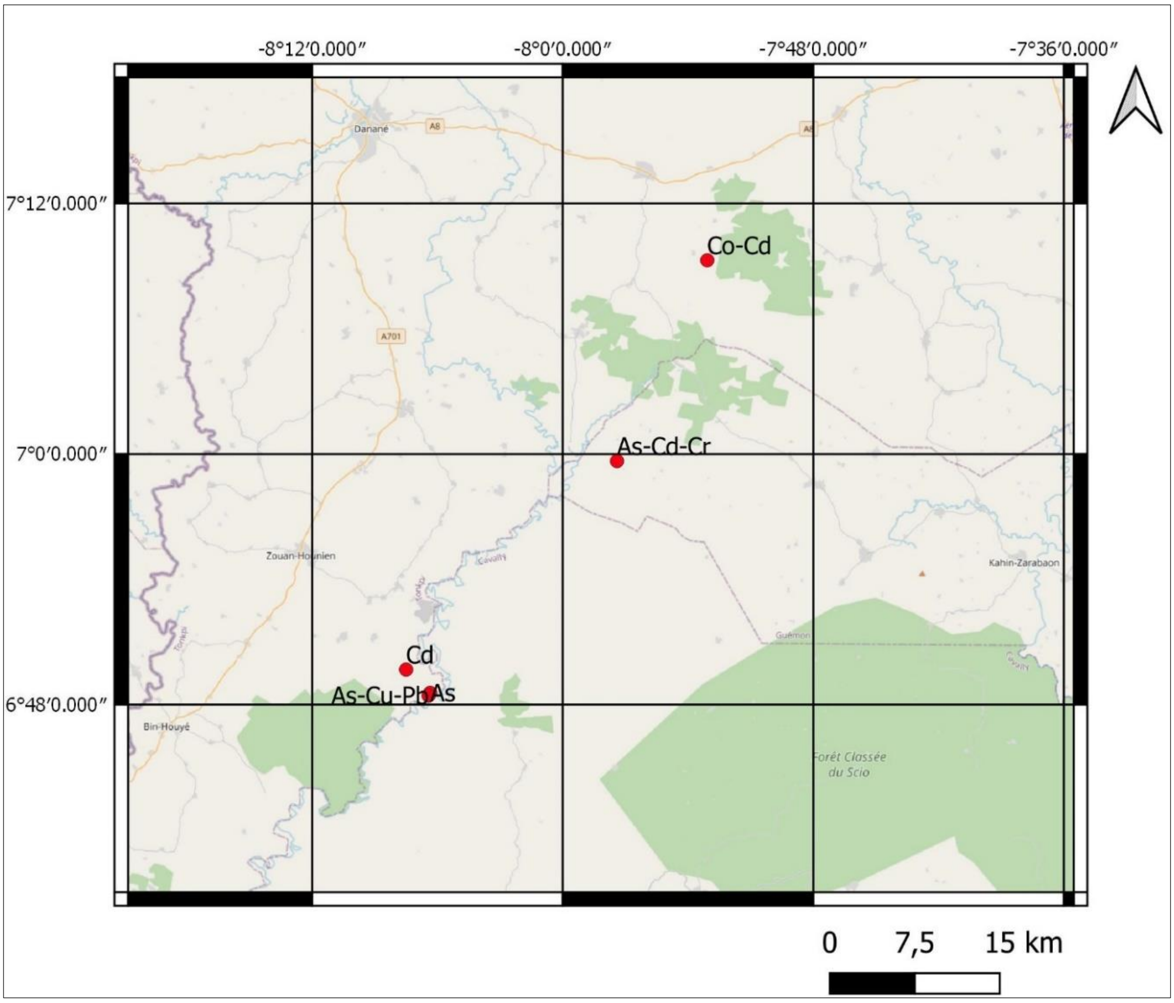

Figure 1 High contaminated sampled sites of Cd, As, Cu, Pb, Co and Cr.

Table 1 Correlation matrix showing relationship between potentially toxic elements occurrence in mining sterile on soil surface

	Ni	As	Cu	Pb	Zn	Cd	Cr
As	0.15						
Cu	-0.03	0.85***					
Pb	-0.11	0.72***	0.82***				
Zn	0.10	0.72***	0.78***	0.89***			
Cd	0.05	0.16	-0.1	-0.11	-0.24		
Cr	-0.15	0.38	0.13	-0.07	-0.13	0.70***	
Co	-0.15	-0.12	0.15	0.00	0.03	-0.09	-0.05

***significant at 0.001 probability level

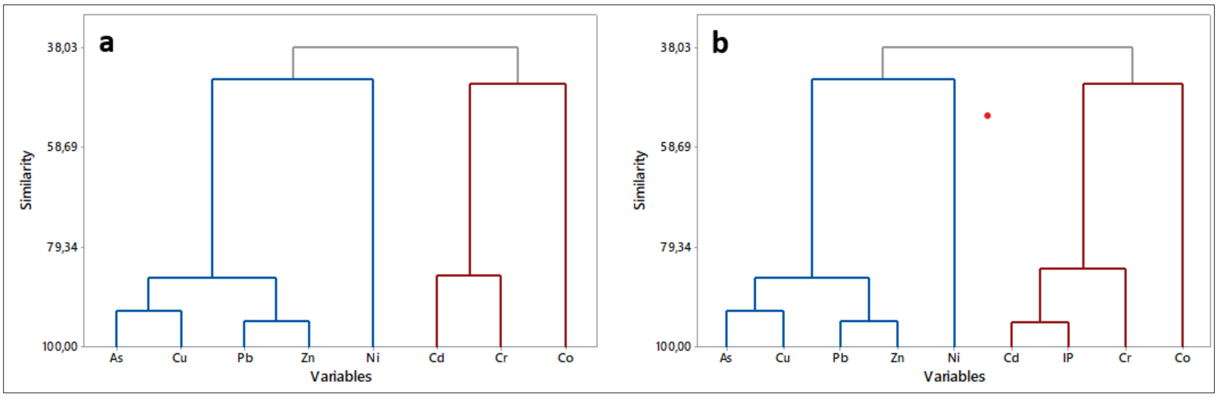

Figure 2 Soil chemical elements clusters

3.1. Soil quality assessment

The geo-accumulation indexes (Igeo) computed using permissible values as Bn revealed that arsenic contamination ranged from practically uncontaminated to moderately contaminated. The Igeo indexes of Cd belonged to the "heavily contaminated" class (Table 2).

4. Discussion

From the results, it was shown that some of the gold mining sites sampled were not contaminated by trace elements; their concentrations were found to be within the safe limits set [19]. The study did, however, discover that some artisanal gold mining sites had elevated levels of trace elements in their topsoil. Arsenic, Cd, Co, Cr, Cu and Pb were found at harmful concentrations in the soil where illegal artisanal gold mining activities were taking place. Such observations of high concentrations of trace elements at gold mining sites and their vicinity were realized in sub-Saharan Africa, where artisanal gold mining activities increase [16, 21, 23]. Moreover, the fact that some of the sites were not contaminated could be related to the parent materials. The difference in high trace element content in mining dumps was also previously observed [7].

Table 2 Soil quality assessment through geo-accumulation

	Practically uncontaminated	**Uncontaminated to Moderately Contaminated**	**Moderately Contaminated**	**Heavily contaminated**
As	+	+		
Cd				+
Co			+	
Cr			+	
Cu		+		
Pb		+		

This study also discovered multi-toxic elements soil contamination. Potentially toxic elements associated with gold are brought out during extraction and mostly left in the vicinity of the mining site. The contamination of surface soil by a combination of metals, also observed in western Niger [16], was shown by a pollution index greater than one (PI >1).

Relatively to computed Igeo of each element, the Cd contamination class was "heavily contaminated”, the highest among the evaluated elements. The harmful Cd contents found were 16.5, 21.65 and 12.89 mg kg^{-1} while it occurs generally in the lithosphere at 0.2 mg kg^{-1}, sedimentary rocks at 0.3 mg kg^{-1} and soil at 0.53 mg kg^{-1} [24]. Cd is a non-essential element that poses high threats to soil quality, food safety, and human health, even at low concentrations; it is a highly carcinogenic metal that can cause toxic reactions [25]. It occurs naturally in soil and minerals such as sulfide, sulfate, carbonate, chloride, and hydroxide salts, as well as in water [26]. It is one of the most mobile PTEs in the environment and can replace calcium in minerals due to its similar ionic radius, identical charge, and similar chemical behavior [27]. The higher mobility of Cd in soils implies that Cd can be easily absorbed by plants and enter our food chain [28]. However, the critical limit of Cd could depend on soil texture and crop species [29].

5. Conclusion

The study provided tangible data relative to potentially toxic elements contaminants in the surface soil in the artisanal small-scale gold mining activities in Côte d’Ivoire. It was shown that As, Cd, Co, Cr, Cu and Pb were found at harmful concentrations. Moreover, Cd Igeo belonged to the heavily contaminated class. Finally, this demonstrated how the accumulation of trace elements, which are toxic, constitutes a potential source of danger for soil quality and human health.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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