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Research Paper

Impact of artisanal gold mining on soil trace elements content and social tissuein the Angovia region of Côte d'Ivoire

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ABSTRACT: *The purpose of this study was to look into how artisanal mining affects the social fabric and trace element content of the soil. Angovia, Kouakougnanou, and Akakro, three illegal small-scale gold mining operations in the Bouaflé area, were the sites where it was conducted. A soil sampling campaign was carried out after field observation and followed by a survey of miners, and interviews with residents of the villages close to the mining sites. The samples were dried before being sent to the University of Man's laboratory for chemical examination. The findings revealed significant levels of soil physical degradation at the various sites, including abandoned excavations, unrehabilitated soils, and most notably, a remarkable density of wells at Akakro. This study brought to light the unjust and covert exploitation of gold as well as the degradation of the soil quality caused by metallic trace elements with high levels of Cr, Mn, Fe, Co, Ni, Cu, Zn, As, and Mo on the sites. It did not, however, show that mercury was present in the soils under investigation. The rise of subsurface soils to the surface during gold mining was the cause of this accelerated pollution.*
KEYWORDS*: Ivorian mining site, contamination, edaphic environment, Illegal gold miners, soil micronutrients.*

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I. INTRODUCTION

Since gaining independence in 1960, the country of Côte d'Ivoire, which has a land area of 322,462 km^2, has primarily relied on agricultural activities, particularly those involving the coffee-cocoa binomial. However, over the past few decades, a variety of other sectors of the Ivorian economy have experienced growth, including the Ivorian mining industry, which has benefited from the discovery of numerous gold deposits [1]. These discoveries drew in foreign investors with substantial financial resources, but they also drained the less fortunate and financially weaker rural population, which engaged in artisanal exploitation practices that present a number of issues [2].

The majority of artisanal gold mining occurs in the central regions of Côte d'Ivoire. For this reason, artisanal gold miners are exerting a lot of pressure on the Marahoué region, where agriculture is the main economic activity due to the favourable pedo-climatic conditions. In fact, the area is surrounded by a lot of areas that are suitable for gold panning. Agriculture has been gradually abandoned as a result of this situation, or at the very least, it has taken a back seat. In many villages today, artisanal gold mining is still prevalent and is, in some ways, seen as a way to fight poverty.

However, the use of chemicals during the various stages of ore processing causes artisanal gold mining to have significant detrimental effects on the environment. Artisanal miners frequently use mercury to concentrate gold, but they also use chemicals like cyanide, zinc, sulfuric acid, and nitric acid in their operations [3].

As a result, their actions cause the soil to degrade rapidly and release pollutants, particularly trace elements, into other natural resources. The main dangers of this type of contamination include the decline or even loss of ecosystem services related to the soil (biodiversity, biomass production, organic matter degradation, water filtration), but they also pose a serious threat to the general public's health. In actuality, some metals, like Cd or Pb, are toxic even in small amounts [4].

Investigating environmental harm caused by gold panning activities is urgent in light of this. This research sought to advance understanding of the effects of artisanal gold mining on the social and ecological environment. In particular, it was done to determine the extent of trace element contamination of the soil and the social effects of artisanal gold mining.

II. MATERIALS AND METHODS

2.1. Location of study

Angovia, Kouakougnanou, and Akakro werethe three artisanal gold sites used for this study (Figure 1).Locations of Kouakougnanou (S2) and Akakro (S3) were picked because gold mining operations were active in these regions and the local populations lived right in the centre of artisanal mining, which is now their main source of income. The high attendance, accessibility, and availability of resources were additional factors in the choice of these locations.

Because of safety concerns, the reopening of an industrial mine in Angovia (S1) has slowed down the practice of artisanal gold mining. This resulted from the industrial mine's blasting, which causes landslides or extraction well collapses.

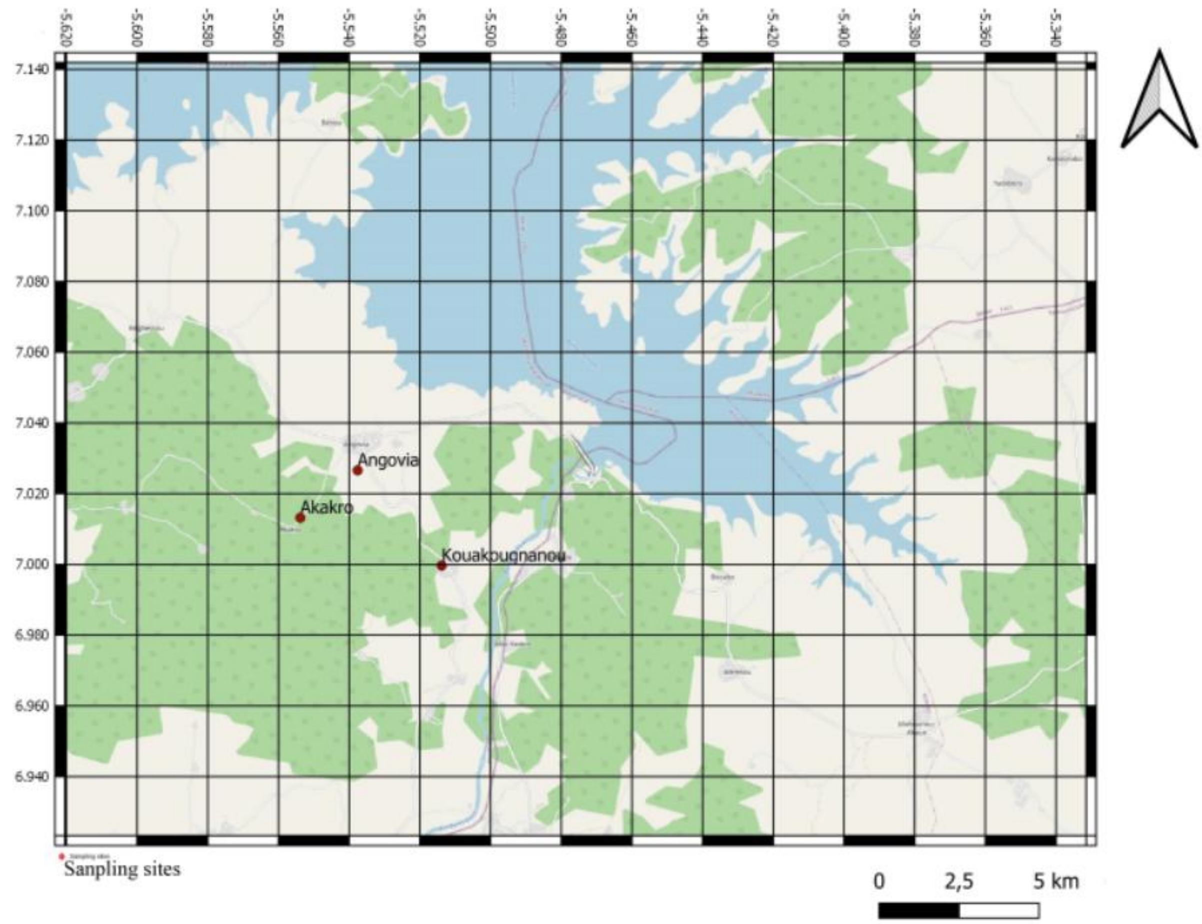

Figure 1: Sampling sites at the three localities of Akakro, Angovia Kouakougnanou

2.2. Data collection

2.2.1. Field observation

First, a field observation was carried out at each of the three mining locations. Through direct observations, this phase revealed information about the methods of treatment and extraction employed by gold miners in the study area, which had an impact on the local natural resources. Additionally, it gave a general overview of how the products used and the waste generated during operations are managed. Finally, it served as the foundation for developing the sampling strategy and ensuring the accuracy of the samples.

2.2.2. Sampling and survey

The survey was conducted on the three (3) artisanal gold mining sites and their surroundings over the course of six (06) days, from April 27 to May 02, 2022. Regarding the information required, a questionnaire with closed-ended questions was created. The methods of data collection favoured both quantitative and qualitative methods. Information was gathered using the diagnostic approach of participatory and random evaluation. Through comprehension interviews, the survey was conducted among ore crushers, grinders, washers, and refiners as well as local actors who reside close to the mines (farmers and market gardeners, local authorities, populations, and traditional and customary chiefs) **[5]**. The population of the survey was also chosen based on previously established criteria for gender, age, and educational attainment.

Both on and off site, soil samples were collected at locations thought to be extremely vulnerable and most likely to offer insightful data on the dispersion of metal pollutants in the soil. On-site and nearby locations both had composite soil samples collected. The technique combines judgmental sampling, which is conducted by visually or technically inspecting the sampling points, with simple random sampling, which was carried out in a random manner**[6]**. From a depth of roughly 15 to 20 cm, 1 kg of soil samples were collected. They were put into polyethylene plastic bags and kept at or below 25 °C after that.

2.2.3. Soil sample preparation and analysis

The Central Analysis Laboratory of the University of Man handled the sample preparation and analysis. In total, 16 soil samples were dried in total, away from the sun, in the lab. Then, they were ground in a roller mill from the Retsch RS200 series. To obtain the clay fraction of the soil, each sample was ground for 10 minutes before being sieved through a mechanical sieve with a mesh size of 2 m. Finally, the clay fraction was examined using the MESA-50-HORIBA type of XRF technique **[7][8][9]**.

By measuring the pH, soil acidity was determined. The $pH_{(H2O)}$ gave information on the current acidity, while the $pH_{(KCl)}$ gave information on the potential or exchange acidity, taking into account the exchangeable H+ cations fixed on the colloids. In order to measure $pH_{(H2O)}$ and $pH_{(KCl)}$, the soil/solution ratio was 1/2.5 (10 g of soil for 25 ml of distilled H2O or 25 ml of a 1 mol/L KCl solution). 25 ml of distilled water were added to a beaker containing 10 g of dry sol, after which the solution was stirred for 15 minutes with an electronic stirrer and a magnetic stir bar. The obtained solution is covered and allowed to stand for approximately one hour. An electronic pH-meter was used to measure the pH at the end [10].

2.2.4. Statistical analysis

KoboToolBox software was used in the conception and treatment of the data result in from the social survey**[11]**. In order to determine whether there was a correlation between the averages of the parameters taken into account using analysis of variance, the Minitab 17 software was used to compare the averages of the various sites with the significance level of $P < 0.05$. Regression analyses were also performed.

III. RESULTS AND DISCUSSION

3.1. The Typology of the actors

The age and gender breakdown of the population is shown in Figure 2. In comparison to an average of 23% of adults (aged 36 to 45), the results showed that 64% of the population were young (aged between 19 and 35). Less than 13% of the population were adolescents. Men made up 68% of the population, while 32% were women and girls.On the artisanal mining sites, however, young people predominate, which is immediately noticeable. The fact that young people need a lot of dynamism and energy for their activities may help to explain this observation.Additionally, the percentage of women working on the mining sites was much lower than the average up to 40-50 %of women engaged in artisanal and small-scale mining in Africa [12].

Furthermore, the number of women at gold panning sites remainedlower in comparison to the number of men. This underlines the fact that women's physical activity options are constrained (washing, catering, and trade). Similar to this, the gender and age breakdown of artisanal gold miners in Hiré, Tortiya, and Bouna's gold ore extraction activities shows that young people are the most active in this activity, with 44.5% of men and 36% of women [5]. It should be noted that children are employed in informal gold mining operations, even if only in small amounts[13][14]. According to a study 37.8% of children are in hazardousworks including artisanal gold mining **[15]**, in Côte d'Ivoire.

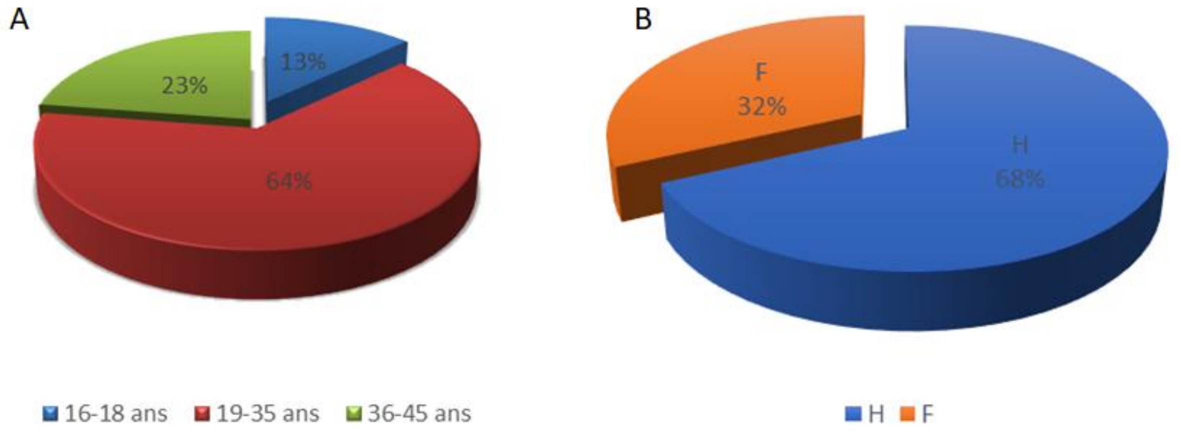

Figure 2: Typology of artisanal gold mining at Angovia region

3.2. Level of education of artisanal gold miners

The education level of the population surveyed who were engaged in illegal gold mining was highlighted. According to the data gathered during the survey, 22% of the population questioned had not completed primary school, while 23% had a secondary degree, meaning that 55% of the population was illiterate compared to a literate rate of 45%. In comparison to artisanal gold miners at the study sites, which had a level of education of 45%, gold miners in Burkina Faso had a level of education of 41% ([13].

Additionally, it was noted that the population of the gold panning sites had only completed secondary school. In light of the proximity of the sites to the villages and the apparent abandonment of studies, this would indicate. This observation supported [16]finding and was emphasized by Ahlerup[**17**]. A large presence of foreigners (Burkinabe, Malians, and Guineans) without any formal education and unable to communicate in French may help to explain the high average of uneducated people (55%) in the population.

3.3. Population perception of uncontrolgold panning impact on soil

On the one hand, all the gold mining areas surveyed have striking stripped surfaces and mining remnants with deforestation favouring the installation of savannah. Accordingly, 97% of gold miners and the general population were said to be aware of the destruction of agricultural land brought on by mining operations. The ground being stripped to access the mineralized area is commonplace for them, so only 3% of respondents were completely unaware. Additionally, an estimated 87% of the population in the survey believed that the vegetation in the mining zones was changing.

Some of the physical effects of gold panning on the local physical environment are depicted in Figure 3. Indeed, soil is a sensitive medium because it serves as a stabilizing foundation for plants, animals, and the storage and use of water. Its deterioration disturbs the plant cover, which encourages erosion and the depletion of surface water resources.

In addition, the entire population surveyed (100%) confirmed that there is no organization in their area working to protect the environment, even though 97% of respondents acknowledged the state of the environment.

Figure 3: Physical impact of gold mining activities on the ground showing gold extraction pits from deep eluviums and unrehabilitated sites. A: treatment sludge; B: waste rock dump; C: surface excavation quarry.

Additionally, based on the type of mineralization the miners encountered, various extraction methods or processes were employed on the three (03) gold panning sites. They used a method known as "hong-kong" to access the ore by making shallow excavations that were frequently made up of several holes that dug down to a depth of about 1 m. The majority of the time, this technique is used in already-exploited areas.

Prior to reaching the mineralized layer, the artisanal miners encountered non-vein deposits, forcing them to dig shafts up to 8 meters deep and even deeper. These methods call for the repeated overturning of the ground, the depositing of waste rock, tailings, and treatment sludge, which reduces the amount of arable land and makes the soil less fertile. In fact, the dispersal of waste rock and treatment by-products near mining sites alters the physico-chemical characteristics of the soil, depletes it, and permanently impairs its suitability for agricultural practices[**18**]**[19]**.

3.4. Soil chemical properties

3.4.1. Soil acidity

The pH of the soils ranged from slightly acidic to neutral; for the Kouakougnanou, Akakro, and Angovia sites, it was 6.5, 6.9, and 7.1, respectively. There was no discernible difference in soil acidity between the studied sites ($P > 0.05$). The mobility of trace elements can be affected by pH variation, whether it is natural or man-made. The pH values demonstrated that the study sites are not susceptible to pollutant migration. In fact, lowering pH encourages metal mobilization through proton exchange, the dissolution of insoluble salts, or even the destruction of the retention phase [20][21].

In general, a pH range of 6 to 7 is best for plant growth because the majority of plant nutrients are readily available [22]. As a result, plants experience growth challenges as soil pH rises because many crucial micronutrients may become unavailable. Over pH 7.8, calcium and magnesium are plentiful, but iron, manganese, copper, zinc, and especially phosphorus and boron, are insufficiently available. According to the regression equations, the pH of the soil solution at Akakro is more likely to rise than those at Kouakougnanou and Angovia (Table 1). That implies that, over time, there will be problems with plant growth in those areas, which will cause soil erosion in the absence of vegetation cover. The outcome of the linear regression equations also supported the prediction of soil solution acidity.

Table 1: Prediction of soil solution pH relative to reserve acidity in the colloids

Sites	Equations
Akakro	$pH_{H2O} = 2.09 + 0.798\ pH_{KCl}$
Angovia	$pH_{H2O} = 1.74 + 0.798\ pH_{KCl}$
Kouakougnanou	$pH_{H2O} = 1.40 + 0.798\ pH_{KCl}$

3.4.2. Impacts of gold panning on the macro-elements at soil surface of the extraction sites

Table I displays the amounts of certain nutrients that are essentially required for plant growth along with excess potassium and calcium concentrations. The Kouakougnanou site, however, revealed a phosphorus shortage. The phosphorus content at the Angovia and Akakro sites, however, was normal. At the three locations under study, the silicon content was typical. The fact that these zones have undergone numerous activities that have brought these elements from depth to the surface by gold mining activities may also explain why the contents of these soils' major elements (Ca and K) are higher as also observed elsewhere in traditional mining [**23**].

Table 2: Level ofsome macro-elementsof topsoil at the mining sites

Sites	Chemical elements (ppm)			
	Si	P	K	Ca
Akakro	203516,5	665,2	3795,0	16188,75
Angovia	275480,7	402,8	9970,0	9227,50
Kouakougnanou	228580,5	0,0	4594,0	28360,60

3.4.3. Impacts of gold panning on soil surface trace elements content

As demonstrated by **[8]**, the chemical analysis of soil samples revealed that the study sites contained significant levels of trace elements as a result of anthropogenic activities (Table 3).

However, there was no sign of mercury. The development of plants depends on the mineral components of soil. The "qualities" of mineral elements that are transferred to animals and people throughout the food chain depend on their concentrations in the soil. These trace elements are widely distributed in the environment, which presents serious issues for people. As a result of their necessity for plant growth and development, the majority of trace elements accumulated in soil in agriculture are absorbed by plants **[24].**

The element content in these soils is higher than the global average for soils **[8]**. Elements like Cr and Co had concentrations that were above the permissible limit for agricultural soils, and Zn has high values, with respective concentrations of 656.2500 mg kg^{-1}, 466.3333 mg kg^{-1}, and 490.3333 mg kg^{-1} for the Akakro, Angovia, and Kouakougnanou sites. The Cr content for each site, as well as for all the metals analysed, was noteworthy, with the exception of Hg, which had a nil value. The fact of abusive exploitation, which was manifested by the rise of chemical elements from the subsoil to the surface during the various extraction processes, could be the cause of the high levels of Cr, Mn, Fe, Co, Ni, Cu, Zn, As, and Mo on the sites. As many of the trace elements are essential micronutrients, the high concentration of these **[25][26]** could constitute potential sources of crop contamination, and thereby, a risk for human health. In fact, these are above those recommended for mud spreading threshold in agriculture [**27**].Moreover, the use of mercury on the sites was not justified in any way by the absence of mercury, though.

Table 3:Top soil trace element content at the mining sites (mg/kg)

Sites	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Mo
Ak	2029.5	2975.2	719873.5	1249.7	1318.2	1476.5	656.2	486.2	5923.7
An	1701.0	5723.1	657627.8	1711.3	929.1	1030.1	466.3	619.1	4737.0
Ek	2184.8	12599.0	688599.8	3827.3	1395.6	1144.5	490.3	274.0	4682.6
AFNOR NFU44-041	150.0	ND	ND	30	50.0	100.0	300	6.0	50

ND: no defined

IV. CONCLUSION

The investigation into traditional and illegal small-scale gold mining revealed the significant effects of these activities on the local communities, among which the miners' lack of education poses a potential threat (chemical misuse, child labour, etc.) to the entire community. It displayed unused spaces and abandoned pits in the physical environment. Additionally, the chemical analysis revealed that topsoil contained high levels of some elements.

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