Health and Environmental Risk Assessment at Gold Panning Sites in the Northern Region (Burkina Faso)

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Abstract

Gold panning has an important contribution in the economic development of Burkina Faso. However, the mining activities expose people and the environment to severe risks. The present study was initiated to estimate the impact of gold panning on health and environmental resources.

Samples of sweet pepper, water and soils were taken for mercury and cyanide content analysis. Mercury was extracted from the matrices by aqua regia and analysed by atomic absorption spectrophotometry. The cyanides were extracted from the matrices by centrifugation and analysed by colorimetry.

Analyses showed the presence of mercury in soil samples but with contents lower than the standard of culture setting soils (5 mg/kg) except one, which displayed a mercury content of 13.45 mg/kg. In the same way, sweet pepper sample contained 3.17 mg/kg of mercury. Soils samples taken in the agricultural field were strongly contaminated by mercury and presented a very high potential ecological risk. In surface water and groundwater, the results of mercury analysis were all lower than the detection limit of the method used (0.02 µg/L). With regard to cyanides, all the analysed fresh mud samples had contents higher than the standard of culture setting in force in Burkina Faso (0.5 mg/kg). Water taken from Sissamba school « A » water pump, contained 0.12 mg/L of cyanide. This study highlighted many health and environmental problems on the gold panning sites in Burkina Faso.

Keywords : gold panning, risk, health, environment

Évaluation des risques sanitaires et environnementaux sur les sites d'orpaillage dans la région du Nord (Burkina Faso)

Résumé

L'orpaillage apporte une contribution importante dans le développement économique du Burkina Faso. Cependant, les activités d'exploitation minière engendrent d'énormes risques pour l'environnement et pour la santé des travailleurs et des populations riveraines. La présente étude a été initiée pour estimer l'impact de l'orpaillage sur la santé et les ressources environnementales. Ainsi, des échantillons de poivron, d'eau et de sol ont été prélevés pour l'analyse des teneurs en mercure et en cyanure. Le mercure a été extrait des matrices à l'aide d'eau régale et analysé par spectrophotométrie d'absorption atomique. Les cyanures ont été extraits des matrices par centrifugation et analysés par colorimétrie.

Les analyses ont montré la présence de mercure dans les échantillons de sol, mais avec des teneurs inférieures

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à la norme de mise en culture des sols (5 mg/kg), excepté un échantillon, qui présentait une teneur en mercure de 13,45 mg/kg. De même, l'échantillon de poivron affichait une teneur de 3,17 mg/kg de mercure, soit 100 fois plus que la teneur maximale tolérée dans les denrées d'origine végétale destinées à l'alimentation humaine en France qui estt de 0,03 mg/kg. Les échantillons de sol prélevés dans un domaine agricole étaient fortement contaminés par le mercure et présentaient un risque écologique potentiel très élevé. Dans les eaux de surface et les eaux souterraines, les résultats des analyses de mercure étaient tous inférieurs à la limite de détection de la méthode utilisée (0,02 µg/L). En ce qui concerne les cyanures, tous les échantillons de boue fraîche analysés présentaient des teneurs supérieures à la norme de mise en culture des terres en vigueur au Burkina Faso (0,5 mg/kg). L'eau prélevée au forage de l'école de Sissamba " A " contenait 0,12 mg/L de cyanure. Cette étude a mis en évidence de nombreux problèmes sanitaires et environnementaux sur les sites d'orpaillage au Burkina Faso.

Mots-clés: orpaillage, risque, santé, environnement

INTRODUCTION

Burkina Faso's mining potential is mainly linked to the birimian furrows or formations whose surface area exceeds 70,000 km^2. These mineral resources include gold, zinc, copper, manganese, etc. They are widespread in the 13 regions of the country, and represent a real opportunity for the development of the national economy and local communities. In 2016, Burkina Faso had 12 industrial mining sites, including 10 in gold production, one in zinc and one in manganese mining. In addition to these industrial mining sites, there were also 448 artisanal gold mining sites, commonly known as gold panning, widespread throughout the country (1). But, these activities were concentrated in four regions. Each of these regions had more than fifty (50) artisanal gold production sites in operation as of February 28, 2017: the Centre-north region (110 sites), the South-west region (61 sites), the North region (61 sites) and the East region (53 sites) (1).

The mining sector's contribution to the country's economy has increased steadily since 2009. For example, the contribution of extractive industries in Gross Domestic Product (GDP) increased from 2.6 % in 2011 to 8.3 % in 2015 (2). The mining sector's contribution in terms of taxes to the budget in 2016 was 189.98 billion FCFA according to the Ministry of Mines (1). The ENSO-2017 revealed that the total annual artisanal gold production is estimated at 9.5 tons of gold, generating 232.2 billion FCFA (1).

In terms of employment, industrial mining activities employed 7,000 people in 2015 (2). The total number of workers directly linked to artisanal gold mining is estimated at 140,196 people, including 114,879 working in gold mining, 22,037 service providers and 3,280 working in gold purchasing (1). In total, according to the professional group of Burkina Faso's miners, the mines provide a livelihood for nearly 300,000 people.

The contribution of gold mining to Burkina Faso's economy is undeniable. However, it should be noted that mining activities create new health and environmental issues that the country face to. In French Guiana, the development of gold panning activities has resulted in increased exposure of human populations to mercury and its components (3). A study of gold panners and gold refineries in Brazil found an average level of 79 µg Hg per g of urinary creatinine, more than double of the organic standard for workers proposed by the American Conference of Governmental Industrial Hygienists (ACGIH), which is 35 µg/g of urinary creatinine (4).

The common symptom of chronic mercury poisoning is trembling (fingers, eyelids, tongue, lips and limbs). Other conditions that have been reported include impaired reproductive function, immune system damage and increase risk of cancer (3).

In the last decades, environmental pollution has been accelerated due to unplanned urbanization, extensive industrialization and mining activities (5). Consequently, soils have generally received excessive amounts of trace metals and other pollutants (6,7) which lead to the deterioration of the soil biology, functions and physicochemical properties and also create other environmental problems (8). In freshwater ecosystems, mercury are distributed between biota, water, sediment particles and sediment pore water. Sediments are long-term reservoirs for contaminants (9), acting as a home for benthic organisms in the lower trophic levels of aquatic food webs.

In Burkina Faso, a national survey reported that the use of chemicals, including acids, hydrocarbons, mercury and cyanide for gold extraction, is responsible for soil and water contamination (10). It also showed that poor hygiene, exposure to dust and moisture in the holes expose gold panners to all kinds of diseases.

While the practice and activities of gold panning are well visible in the field, the health and environmental consequences need to be determined. Therefore this study was initiated in order to estimate the impact of gold panning on health and environmental resources.

II. METHODS

2.1. Framework and site selection for the study

Burkina Faso had 448 artisanal and semi-mechanized gold production sites in 12 out of the 13 regions in 2017. Most of these gold sites were mainly located in the Central North region, the South-western and Northern regions (1). Thus, for this study, we selected the gold panning sites in the Northern region. Sites selection were done based on accessibility from the city of Ouahigouya, the capital city of the region, and also the availability of all the gold production steps: digging, crushing, shredding and scrubbing. The following sites were selected: Suiguinvoussé, Bango, Kouri and Sissamba. Figure 1 shows the location of these sites.

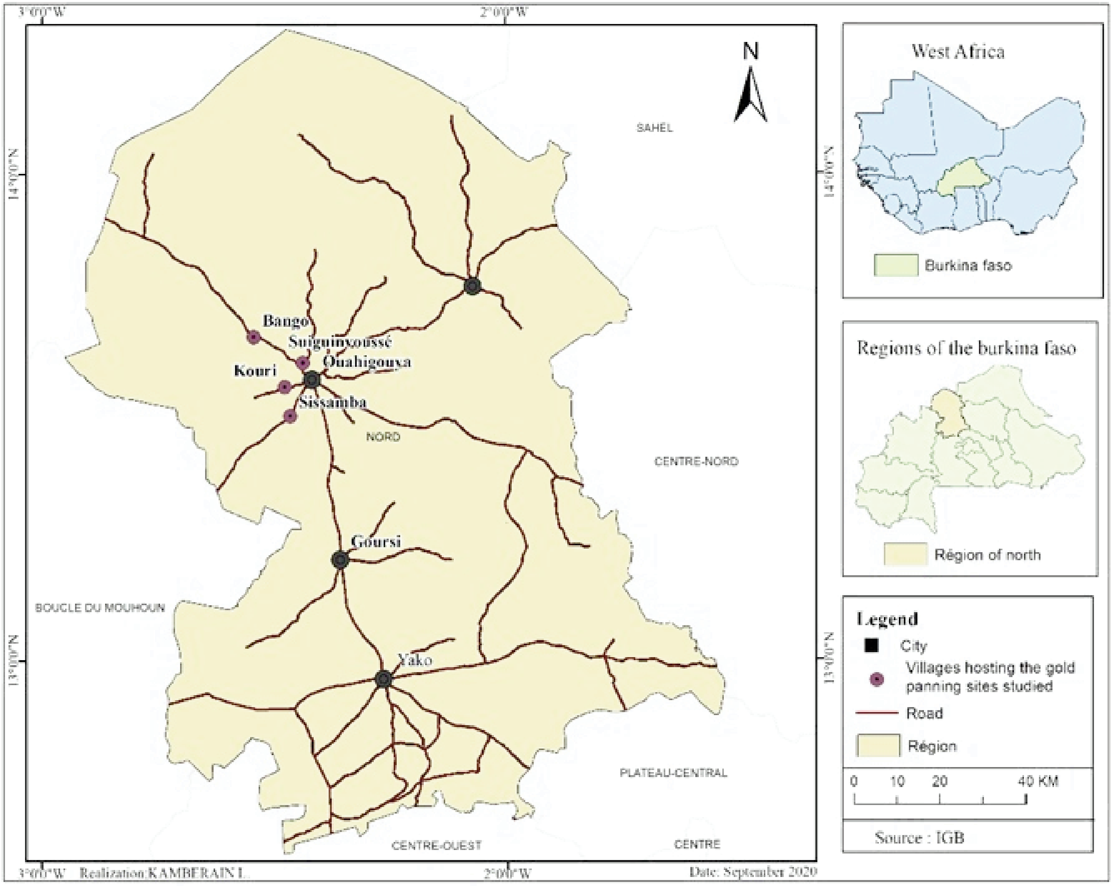

Figure 1: location of villages hosting gold panning sites studied on Burkina Faso's Northern region map

2.2. Data Collection

Identification and quantification of chemical substances used on gold mining sites

Because the number of workers at the gold panning sites fluctuated almost daily, it was not possible to determine the number of people to be surveyed statistically. With regard to the time and duration on the sites and the available resources a reasoned sampling of 32 workers per site was therefore adopted . The data collection was carried out by :

- interviews with a representative of municipality, the site manager and a health worker from the health facility of the site area;

- administration of a questionnaire to mining workers. The questionnaire included questions related to the form and quantity of chemicals used in each workstation and related to environmental and health risk.

Description of the gold panning activities

It was done using direct observation with photo capture using an ASUS smartphone

Collection of samples for laboratory analysis

To assess the level of mercury and cyanide pollution of natural resources, water and soil samples were taken. In total, mercury was determined in 9 samples and cyanide in 17 samples.

These samples were taken on the sites and their surroundings, taking into account the direction of water flow. Thus, on the sites, samples of sludge and water from the cyanidation ponds were taken. In the vicinity of the sites, soil, surface water (dam), groundwater (wells and boreholes) and vegetables from market gardening were sampled.

The water samples were collected in 250 mL plastic vials. For each sampling point, two vials were filled with approximately 200 mL of water including one for the determination of mercury and the other for the determination of cyanides. In order to stabilize the mercury, 2 mL of concentrated nitric acid (HNO_3) were added to the vials for the determination of this metal. For water samples taken for cyanide determination, two hydroxide tablets of sodium (NaOH) were added in order to alkalize the medium and thus stabilize the cyanide compounds.

Mud, soil and sediment samples were collected using a pickaxe or shovel according to their consistency. Thus, about 500 g of these matrices were taken and then introduced in polypropylene plastic bags.

For the vegetables, five peppers were harvested, including one from the four corners of the plot of land with the highest yield near the Gouinré dam and the fifth in the middle of the plot. These peppers were then introduced in a polypropylene bag.

All the samples were kept in a cooler containing ice-boxes in order to maintain the temperature between 4 °C and 8 °C, then transported to the laboratory.

2.3. Chemical analysis

Extraction and purification of pollutants

For mercury analysis, mercury was extracted from the matrices (soil, sediment and pepper) using the procedure described by Santoro et al. (11). This procedure consists of dissolving 3 g of soil, sediments or pepper in 28 mL of aqua regia and filtering the extract using filter paper. In this study, filtration was carried out using chromafil® Xtra filters with 0.45 µm diameter ports.

For mercury in surface and underground water, samples were simply filtered using the same filter.

Cyanides were extracted from the collected matrices (sludge, soil, sediment and pepper) by the ASTM 6888 method (12). This method consists of introducing 1 g of sample into Falcon tubes and adding 10 mL of a 1 N NaOH solution. The tubes are then centrifuged at 1000 rpm for 10 minutes. After centrifugation, the supernatant is collected for total cyanide analysis.

Water samples were just centrifuged to remove suspended solids and the supernatants have been collected for total cyanide analysis.

Pollutants determination method

Mercury was determined by the atomic absorption spectrometry method. This method uses basically the principle that free atoms (gas) generated in an atomizer can absorb radiation at specific frequency. Atomic-absorption spectroscopy quantifies the absorption of ground state atoms in the gaseous state. The atoms absorb ultraviolet or visible light and make transitions to higher electronic energy levels.

Mercury was measured on a Perkin-Elmer ASS T900 type apparatus equipped with a burner (premixing and 10 cm axial slit), a gas control unit (pressure and flow rate) and a Perkin-Elmer hollow-cathode mercury lamp. The transport solution consisted of 3 % hydrochloric acid and the reducing solution of a mixture of 0.2 % $NaBH_4$ and 0.5 % NaOH, all from VWR International (France). The mercury concentrations of the samples are determined by means of a calibration curve constructed from a 1000 ppm mercury standard solution from Perkin-Elmer (USA).

Cyanides were determined by the UV/Visible Molecular Absorption Spectrometry method. This method is based on the property of matter, and more particularly of certain molecules, to absorb certain wavelengths of the UV-visible spectrum. It allows to carry out dosages thanks to Beer-Lambert's law ($A= \varepsilon l C$), which shows a relation of proportionality between absorbance and concentration, as well as a structural study of complexes by studying the absorption spectra. For the determination of total cyanides, cyanivert reagents obtained from PermaChem (Australia) were previously mixed with the samples to form the colored complexes and the absorbances were read on a DR 3800® spectrophotometer at a wavelength of 612 nm.

2.4. Eco-toxicological risk assessment

The eco-toxicology risk has been assessed for mercury contamination.

To assess the level of mercury pollution in soils, the contamination factor C_i^f proposed by Hakanson (1980) (13) was used. The equation is:

$$C_f^i = \frac{C_{0-1}^i}{C_n^i}$$ Calculation of the contamination factor Cf

Where C^i_{0-1} is the mercury concentration of the soil under assessment and C^i_n is the value of the mercury concentration of a natural soil. This value was set to 0.07 mg/Kg in accordance with the value suggested by Curlík and Šefcík (14), and Kabata-Pendias (15).

The degree of soil contamination was determined using the table I established by Hakanson (13).

Table I: contamination level as a function of contamination factor (C^i_f) values

C^i_f classes	Soil contamination level
$C^i_f < 1$	Low contamination level
$1 \leq C^i_f < 3$	Moderate contamination level
$3 \leq C^i_f < 6$	Significant contamination level
$C^i_f > 6$	Very high contamination level

Calculation of the Potential Ecological Risk Index (PER)

The Potential Ecological Risk (PER) Index is a parameter proposed by Hakanson (13) to assess the level of soil pollution by metallic trace elements with respect to their intrinsic toxicity and the biological response of exposed environmental organisms (16,17). The PER value is determined by the following formula:

$$\text{PER} = \sum_i^n E_j^i$$

$$E_j^i = T_n^i \text{ X } C_f^i$$

With:

C^i_f = soil contamination factor by the metallic trace element

E^i_j = index of the potential ecological risk of element i

T^i_n = biological toxicity factor = 40 for Mercury (13)

In this study, only one metallic trace element (Mercury) was evaluated. The value of PER was therefore identical to that of E^i_j. Table II characterized the potential ecological risk index (17-19).

Table I: ecotoxicological risk level as a function of the value of the potential ecological risk index.

E^i_j values	Risk level
$E^i_j < 40$	Low risk level
$40 \leq E^i_j < 80$	Moderate risk level
$80 \leq E^i_j < 160$	Significant risk level
$160 \leq E^i_j < 320$	High risk level
$E^i_j \geq 320$	Very high risk level

Calculation of the bioconcentration factor (BCF)

The bioconcentration factor is defined as the ratio of the concentration of mercury (mg/kg) found in biological material to that found in soil (20). It is calculated using the following formula:

$$BCF = \frac{Content\ of\ biological\ material\ in\ Hg\ (\frac{mg}{kg})}{Soil\ content\ in\ Hg\ (\frac{mg}{Kg})}$$

BCF ≤ 1, the element does not bioaccumulate, BCF > 1, the element bioaccumulates (20).

In this study, the biological material was pepper (*Capsicum annum, Solanaceae*). This plant was chosen because of the ability of green plants to accumulate metallic trace elements (21) and the size of the plots on which it was planted during our data collection period.

2.5. Data analysis

The data were analysed using Epi info® statistical software in version 5.3.2. The graphics were created using Microsoft Excel® 2010. The GPS data were collected on google earth to produce maps showing the location of the sites studied and the sampling points.

2.6. Ethical and Administrative Considerations

Before the begining, letters were sent to the Governor of the Northern Region, the Regional Directors of Health and the Environment, and to the mayors of the municipalities with jurisdiction over the gold panning sites surveyed. Then, the informed consent of each worker was requested prior to the administration of the questionnaire. Finally, the anonymity and confidentiality of the data collected from staff were respected.

The results of the study were disseminated to the authorities in the Northern Region.

II. RESULTS

3.1. Description of activities on the site and analysis of associated health and environmental risks

- Forcing

This activity consisted of digging holes (Illustration 1, Photos A and B) of different geometric shapes using tools such as pickaxes, shovels and chisels. The digging was done along the vein so that it led to tunnels of varying depths. In the four sites studied, 71.88 % of the wells were between 25 m and 75 m deep. To ventilate the interior of the galleries, the workers used an ingenious ventilation system

(Illustration 1, Photo C). This system consisted of wrapping a plastic sheet and inserting it into the hole. A fan, powered by solar energy or a generator, was used to send the air to the bottom of the well.

When the well reached a certain depth, a rope was attached to a trunk bar shaft overhanging the hole (not found). The purpose of this rope was to allow i) the ascent and descent of the diggers ii) the ascent of the ore and iii) communication between the diggers and the outside world.

Illustration 1: hole dug by diggers (photo A), rope used by diggers to get down and raise up from hole (photo B) and holes ventilation system (photos C).

<u>Crushing</u>

The ore extracted from the shafts is in the form of large rock, which is then reduced to smaller granules by crushing. The equipment used is composed of hammers, anvils, mortars and pestle. After crushing the ore, the harvested granules are reduced to powder by the mills. At each of the sites, at least two mills are used to crush the ore granules. To ensure efficient shredding, the 50 kg bag is shredded on average twice and requires an average time of 50 min to 60 min. The mills ran on diesel fuel. Oils and greases are also used to lubricate the various components of the mill.

<u>Washing</u>

Amalgamation with mercury

Washing consists of mixing mineral powder with water and detergent. The mixture is then washed in a wool fabric deposited on a metal plate placed at an angle on the barrel (illustration 2). Heavy particles such as gold are retained on the carpet by gravimetry. The wool carpet is then collected and washed with water to collect the particles including gold particles trapped in the fibres in small containers for further amalgamation. The amalgamation consists of adding mercury in the mixture. The amount of mercury added depends on the estimated gold content of the ore. The richer it is in gold, the greater the amount of mercury added. On average, a 50 kg bag of ore powder requires the use of a mercury ball i.e around 15 g. The resulting amalgam is then purified by heating it with a butane gas torch, which removes the mercury by evaporation.

Illustration 2: ore powder washing station.

- <u>Extraction by cyanidation</u>

Cyanidation consists of recovering gold from the washed sludge or directly from the ore powders after grinding. It is carried out in cyanidation basins by mixing approximately 3.5 m3 of slurry or ore powder, 600 L of water and 1 kg of sodium cyanide pellet. There are two basins connected to each other by a small basin. A plastic sheet covers the bottom and walls of the large tanks, while the small tanks are made of cement. The mixture obtained is left at rest for 24 hours.

In the supernatant, water rich in golden cyanide is then redirected through the opening of a small orifice to the U-shaped tubes containing zinc chips and opening into the small basin. This operation is performed for 72 hours. The overflow of cyanide water from the small basin is discharged into the large basins. At the end of the operation, concentrated nitric acid solution is added to remove impurities such as ferrous and aluminium ions. This operation generates a very toxic gas, hydrocyanic acid.

The resulting product is left with water for 24 hours. After settling, the paillette is recovered and sent to foundries in Ouahigouya for further purification.

Cyanide wastes contained in sludge are dumped around the basins, forming real mountains of waste (Illustration 3). For wastewater containing cyanide, it is discharged around the basins or stored in other basins a few cable from the site.

Illustration 3: cyanidation sludge piles.

3.2. Nature and quantity of chemicals found on sites

Several chemicals and products containing chemicals are used on gold panning sites. These chemicals include mercury, cyanide, zinc, sulphuric acid, nitric acid, batteries, diesel and lubricants. Estimated quantities of each of these chemicals are given in table III.

Table III : quantity of chemicals found on the 4 gold panning sitesCaractéristiques sociodémographiques de la population enquêtée

Chemical products	Weekly quantities used on the 4 gold panning sites studied
Mercury	5.54 kg
Total cyanides	52 kg
Zinc	1.40 m^3
Sulphuric acid	130 L
Nitric acid	2.6 L
Used batteries	192
Lubricant	96 L
Diesel	192 L

3.3. Characterization of health and environmental hazards on gold panning sites

The gold panners noted that each work station involved the use of chemical substances and/or actions that could be harmful to human health and the environment.

In the mining process, for example, gold miners found that they were exposed to the risk of landslides, asphyxiation, snake bites and lung pathologies related to exposure to ore dust, which could expose them to respiratory and/or skin problems. According to the gold panners, sinking activities would lead to physical degradation of the environment by cutting down trees, digging holes into which animals could fall and accumulating earth in the form of mounds in the environment.

During the milling process, gold panners revealed that they are exposed to dust from the ore powder, the projection of ore granules and accidents (injuries, shoulder dislocation) that can occur when starting the mills. In addition, toxic fumes which would contain VOCs, PAHs, SO2, etc. emitted by the mills could also have a negative impact on their health and the environment.

In addition, after amalgamation and before combustion, some scrubbers would suck up excess water with a handkerchief, which would expose them to the oral absorption of mercury.

From an environmental point of view, the mercury vapours that evaporate during the combustion process could fall back to the ground as a result of precipitation. As a result, soil and surface water would be contaminated by runoff and groundwater infiltration. In addition, gold miners explained that liquid wastes contaminated with mercury were dumped directly on the ground, which would increase the risk of pollution.

Cyanide tank workers reported that they were exposed to both cyanides and acids. Indeed, in order to recover gold enriched zinc shavings, workers would descend unprotected into the cyanide-treated tanks, which would expose them to the product through their skin. In addition, the acid and gas vapours resulting from the chemical reactions to purify the gold would cause irritation to the skin and respiratory tract of the workers. From an environmental point of view, the discharge of cyanide-contaminated liquid waste and sludge without any prior treatment would, according to gold panners, be a real source of environmental pollution. Rainwater carries away mountains of cyanide sludge and the resulting concentrated cyanide water contaminates groundwater by infiltration and surface water by runoff (water tanks, dams).

3.4. Levels of water and soil pollution on and around the sites

Mercury and cyanide contents of the sampled matrices

Table IV shows the results of mercury analyses in the sampled matrices. These results showed that surface water (dam water) and groundwater (drilling water) were free of mercuric contamination. However, the water from a well in « Gouinré » used for vegetable production contained 17.42 µg/L of mercury. Soils, sediments and vegetables (peppers) contained mercury at concentrations ranging from 3.17 mg/kg to 13.45 mg/kg.

Table IV : mercury content in the samples analysed

Sampling sites	Analyzed matrices	Geographical coordinates		Mercury levels
		Latitude	Longitude	
Bango	Dry sediments	13°39’09.68’’N	2°30’59.80’’W	4.53 mg/kg
« Goinré » Vegetables field	Well waters	13°36’20.37’’N	2°26’07.83’’W	17.42 µg/L
	Soils of field			3,17 µg/L
	Pepper			4.86 mg/kg
« Goinré » dam	waters	13°37’27.77’’N	2°26’37.22’’W	0.02 µg/L
	Sediments			5.02 mg/kg
« Siguinvoussé »	Groundnut field soils	13°36’26.48’’N	2°26’43.55’’W	13.45 mg/kg
Ouahigouya slaughter house	Groundwater	13°35’39.54’’N	2°26’39.34’’W	0.02 µg/L
Sissamba gold panning site	Groundwater	13°30’35.43’’N	2°27’48.66’’W	0.02 µg/L

Cyanide analysis results are shown in table V. Sludge and water samples from the cyanidation basins showed high cyanide levels with maximum concentrations found at the Sissamba gold panning site. Differences were found in fresh sludge (5.3 mg/kg), in dry sludge (1.2 mg/kg) and in cyanidation water (6 mg/l). Groundwater samples were free of cyanide contamination, with the exception of the water from the borehole at Sissamba School "A", which had a cyanide content of 0.12 mg/L.

Table V : Total cyanides content in the samples analysed

Sampling sites	Analyzed matrices	Geographical coordinates		Tatal cyanides levels
		Latitude	Longitude	
Bango gold panning site	Cyanidation basin fresh mud	13°39'09.68''N	2°30'59.80''W	0.70 mg/kg
	Cyanidation basin dry mud			0.05 mg/kg
	Cyanidation basin water			0.54 mg/L
	Bango dam dry sediments			0.50 mg/kg
« Goinré » Vegetables field	Well waters	13°36'20.37''N	2°26'07.83''W	0.02 mg/L
	Soils of vegetables field			0.50 mg/kg
« Goinré » dam	waters	13°37'27.77''N	2°26'37.22''W	0.02 mg/L
	Sediments			0.40 mg/kg
« Siguinvoussé » gold panning site	Groundnut field soils	13°36'26.48''N	2°26'43.55''W	0.20 mg/kg
	Cyanidation basin fresh mud			0.60 mg/kg
	Cyanidation basin dry mud			0.30 mg/kg
	Cyanidation basin water			0.64 mg/L
Ouahigouya slaughterhouse	Groundwater	13°35'39.54''N	2°26'39.34''W	0.02 mg/L
Sissamba gold	Groundwater	13°30'35.43''N	2°27'48.66''W	0.12 mg/L

Determination of Contamination factor Cf

The contamination factor Cf was calculated for soils collected from the agricultural field located at about 50 meters from the gold panning site of « Siguinvoussé » and in the « Gouinré » vegetable farm. Table VI gives the Cf values found and the corresponding contamination levels.

Table VI: soil Cf values and corresponding contamination levels.

Soil sampling points	Hg concentrations measured (mg/kg)	Hg concentration in reference soil (mg/kg)	C_f values	Contamination level
« Siguinvoussé » Groundnuts field	13.45	0.07	192	Very high contamination level
« Goinré » vegetables field	3.17	0.07	45	Very high contamination

Calculation of the potential ecological risk index

For the two agricultural soils studied, the values of the potential ecological risk indices are given in table VII.

Table VII: Soil Eij values and corresponding potential ecological risk level.

Soil sampling points	$C^i_{f\ values}$	T^i_n values	E^i_j values $E^i_j = C^i_f \times T^i_n$	Ecological risk level
« Siguinvoussé » Groundnuts field	192	40	7680	Very high
« Goinré » vegetables field	45	40	1800	Very high

Bioconcentration factor BCF

The bioconcentration factor was determined from the mercury content in the pepper and the mercury content in the soil on which it was grown.

BCF $= \frac{4,86\ mg/kg}{3,17\ mg/kg} = 1.54$; therefore, mercury accumulates in the pepper grown on the soil of « Gouinré » vegetable farm.

III. Discussion

The activities on the gold panning sites were divided into mining activities including digging, crushing, washing and cyanidation and mining support activities such as cartering, shops selling stuff (cigarettes, coffee, batteries, etc.) and water business. The same types of organization are found in most gold panning sites in Burkina Faso (22-24) and in Guiana (3).

The use of chemicals in mining activities is regulated in Burkina Faso but the application of this regulation remains difficult as far as gold panning sites are concerned. Thus, the use of several chemical substances has been noticed in this study. These were mainly mercury, cyanide, acids, hydrocarbons, zinc and leaked chemicals from used batteries. These chemicals used on the northern gold panning sites seem to be imported to Burkina Faso from neighbouring countries, mainly Ghana and Mali (23).

With regard to health and environmental risks, workers were aware of the physical risks, including the risk of injury from the projection of ore pellets during crushing. However, they were not sufficiently aware of the toxic risk. Indeed, they were exposed to low concentrations of chemicals so that they were confronted with the cases of chronic intoxications rather than acute intoxications. Moreover, in Burkina Faso, 2/3 of the artisanal miners are reported to have chronic symptoms of mercury exposure (24). Furthermore, the health centre workers interviewed for this study stated that they had not received any specific training related to the management of cases of chronic intoxication exposure to chemicals used on gold panning sites; anything that further complicated the diagnosis and treatment of chemical poisoning on gold panning sites. Roamba (23), came to the same conclusion at the Zugnazagmligné gold panning site. The use of these chemicals without waste management system at gold panning sites has an impact on the natural resources of the northern region.

Mercury analyses in soil and sediment samples showed the presence of mercury. However, the levels found were below the standard value limit (5 mg/kg) for land used for agriculture (25). Similar results were found by Rouamba (23) in soil samples from the North Central region. However, in the present study, a sample taken from the groundnut field located about 50 m from the « Siguinvoussé » site was found to contain 13.45 mg/kg Hg, almost 3 times the land cultivation standard.

Another innovation of this study, compared to others already carried out on the same theme in other regions of Burkina Faso, the analyses carried out on market garden products. Indeed, an analysis of vegetables (peppers) grown in Gouinre's garden showed that they were contaminated with mercury. Thus, a level of 3.17 mg/kg of mercury was found in peppers, i.e. 100 times more than the maximum level of mercury tolerated in foodstuffs of plant origin intended for human consumption in France, which was 0.03 mg/kg (26).

This high mercury content in the pepper is related to the proximity of the « Siguinvoussé » gold panning site. Indeed, the use of mercury on the site led to its release into the air, surface water and soil. From the air, mercury could be deposited on the surface of leaves and stems from where it would be absorbed through the stomata in the form of particles or in dissolved form in rainwater or irrigation water (26). From the soil, it could be absorbed through the roots and distributed to other plant organs. This vegetable contamination can have health implication. Consumption of mercury-contaminated vegetables over a long period of time could lead to an accumulation of this metallic trace element in the body (27,28) and cause many diseases. Those diseases are as follows: weight loss, depression, movement coordination problems, hypersalivation, insomnia and renal failure (29-31). Based on contamination factor and potential ecological risk, soils collected from the « Siguinvoussé » groundnut field and the « Gouinré » vegetable farm were highly contaminated with mercury and presented a very high potential ecological risk. In general, mining activities were identified as problematic for the environment and ecosystems worldwide (32-36). In Slovakia, Angelovičová L and Fazekašová D (37) showed in their mercury pollution study that the Spiš Milieu region, which concentrated many polymetallic ore mining activities, was heavily contaminated with mercury.

Surface and groundwater, were not contaminated ($<$0.02 µg/L). This low mercury content in water could be due to the low mobility of this metallic trace element in the soil and its high volatilization due to very high temperatures up to 28.7°C in this region (38).

For cyanides, all fresh sludge samples analysed had levels above the Burkina Faso land cultivation standard (0.5 mg/kg). These results were different from those obtained by Bamba et al. (2013) (39) who found cyanide levels of less than 0.2 mg/kg in the soils of Dédougou, another gold panning region in Burkina Faso.

The highest concentrations of cyanide in sludge and cyanide water were found in Sissamba. In this village, analyses showed that the borehole water contained about twice as much cyanide (0.12 mg/L) as the World Health Organization (WHO) standard for human consumption (0.07 mg/L). The other part of the cyanide in the fresh sludge was washed away by rainwater and carried away by runoff into water reservoirs. Cyanide concentrations of 0.4 mg/kg and 0.5 mg/kg were found in the sediments of the « Gouinré » and Bango dams, respectively. The infiltration of cyanide can contaminate groundwater (39).

Artisanal gold mining makes an important contribution to Burkina Faso's economy. However, as practised by gold panners, it entails enormous risks to the environment and to populations' health. In order to minimize these risks, we recommend:

- the organization of awareness sessions for gold panners on the health and environmental risks associated with the use of chemicals. These awareness-raising sessions should focus on the geochemical cycles of chemical pollutants used by gold panners, their toxic effects with illustrative images and the importance of wearing Personal Protective Equipment (PPE);

- the strict application of the decree prohibiting the use of mercury for gold mining on gold panning sites;

- the elaboration of a regulation requiring the treatment of cyanidation sludge to reduce the toxicity of cyanides before their release into the environment;

- the training of gold miners in cyanidation waste treatment techniques;

- the establishment of a health monitoring system for foodstuffs of plant and animal origin produced in regions with several gold panning sites.

Conclusion

This study, which focused on the environmental risks associated with gold panning activities in the northern region of Burkina Faso, provided an understanding of the organization at gold panning sites. Each of these activities presents considerable health problems for workers and local populations and some serious environmental risks. The use of many chemicals mainly mercury, cyanide and acids, exposes populations to the risks of acute and chronic poisoning. These chemicals also pollute different areas of the environment such as water, soil, and vegetables, which exposes people and many aquatic and terrestrial organisms to chemical pollutants. This can be explained by gold panners limited knowledge about the health risks related to their profession. Thus, a study on knowledge, attitudes, and practices of gold panners and the impacts of their activities on health and the environment is necessary.

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