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Evaluation of Environmental Aspects of Artisanal Gold Mining at the Tchaga Site in the Batha Province (in the East of Chad)

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Abstract

In the east of Chad, precisely in Tchaga, gold is mined in an artisanal manner. This gold panning activity contributes to the income of rural populations. However, this activity uses chemical processes involving mercury and cyanide which cause impacts on surface water and groundwater. In a context of favorable gold prices, the number of artisanal mines is increasing and it is interesting to dwell on the question, also understanding that few studies have been carried out, until now, on gold panning in relationship with environmental aspects. The present study then consists of evaluating the impacts of gold panning on the environment on the Tchaga sites. To understand the phenomenon and quantify it, it was necessary to carry out a combinatorial analysis of the surface and underground waters of the study area. The results obtained indicate that the negative impacts of gold panning on soils range from moderate to high with a reduction in arable land. The methodology used consists of water sampling, measuring physical parameters and using methods to determine the concentrations of cations and anions. After analyzing the results of ETM analysis in the water, it appears that the water is not very loaded with ETM and heavy metals. The water contains average concentrations (0.001 mg/l in As, 0.003 mg/l in Pb and 0.001 mg/l in Zn or even zero for mercury) which are generally lower than WHO standards. In surface waters, the concentration of Hg is 0.000 mg/l and that of Zn is 0.002 mg/l. Values below the limit values set by the WHO do not indicate any presence of apparent contamination by gold panning activities at least for the moment. In groundwater, the mercury concentration is zero compared to the limit value set by the WHO, this is due either to the quantity of the product, the sampling, or the time of contamination. On the other hand, zinc has a low value compared to the limit value set by the drinking water standards in Chad. While the arsenic concentration (0.002 mg/l) does not reach the limit value set by the WHO (0.01 mg/l).

Keywords

Gold Panning, Environment, Impacts, Products Used, Water Quality, Tchaga

1. Introduction

Artisanal exploitation of gold, commonly called "gold panning", as opposed to mechanized and intensive industrial exploitation, consists of the exploitation of this resource in an unplanned manner, by manual methods with rudimentary tools (Taylor & Thorpe, 2004; Jaques et al., 2006; Andriamasinoro & Angel, 2012). Artisanal mining is mainly focused on alluvial gold, generally located along rivers. In most sub-Saharan African countries and in Chad in particular, artisanal gold mining is widespread. Thus, in Chadian mining areas, like that of the locality of Tchaga, more than 30% of the population depends economically on artisanal gold mining. Despite the relatively delicate determining circumstances in which it operates, artisanal mining plays a considerable role in the movement of the local economy. It also provides support for the economy because it helps fight poverty and rural exodus (Tomicic et al., 2011). This activity offers rural populations more diversified basic economic activities such as jobs both in mining operations and in the related services that these operations would require (PNGE, 2009). In recent years, planet Earth has been marked by disruptions environmental problems with significant repercussions which are increasingly incompatible with the concept of sustainable development. These disruptions cause serious problems of equity between current and future generations on the one hand and between communities of current generations on the other hand in terms of availability and accessibility to natural resources (Ouédraogo, 2019).

Mainly located in rural areas, gold panning activities seem to interact with agricultural activities. If they compete for land and labor, they are, on the contrary, complementary by the increase in demand for agricultural products on mining sites and by the possibilities of combining the two types of activity at the level family units (Ouédraogo, 2019). Gold panning income can then be a source of financing for agriculture. Since the 2010s, gold panning activity has increased the land issue in rural areas since it results in the destruction of soil suitable for agriculture and, consequently, in a reduction in available agricultural land. It is also accompanied by the rural exodus and influx of population from different regions of Chad and neighboring countries into the gold-producing areas. Finally, it results in a transformation of the local economy (Ouédraogo, 2019).

Artisanal gold mining, due to its clandestine and informal nature, is of little or no interest to the State, which consequently creates a significant lack of information on the various risks associated with it. Furthermore, this activity provides substantial income for gold miners and their families. Indeed, gold panning is an activity that involves chemicals and practices that are dangerous for the environment. It should be noted that artisanal mining contributes to deforestation and deforestation, land degradation, air pollution by dust and water pollution by mining waste and chemicals (cyanide, mercury…).

2. Presentation of the Study Area

2.1. Geographical Framework

Le site d'orpaillage de Tchaga est situé à 65 Km à la direction Sud-Est d'Ati. Il se trouve entre la latitude 12˚71' et 13˚33' Nord et la longitude 17˚60'et 18˚40' Est (**Figure 1**). Tchaga couvre une superficie d'environ 5 Km^2. Il est implanté sur la rive gauche du fleuve Batha. L'orpaillage s'y est développé depuis 2016, date marquant le début de la ruée vers l'or au Nord du Tchad.

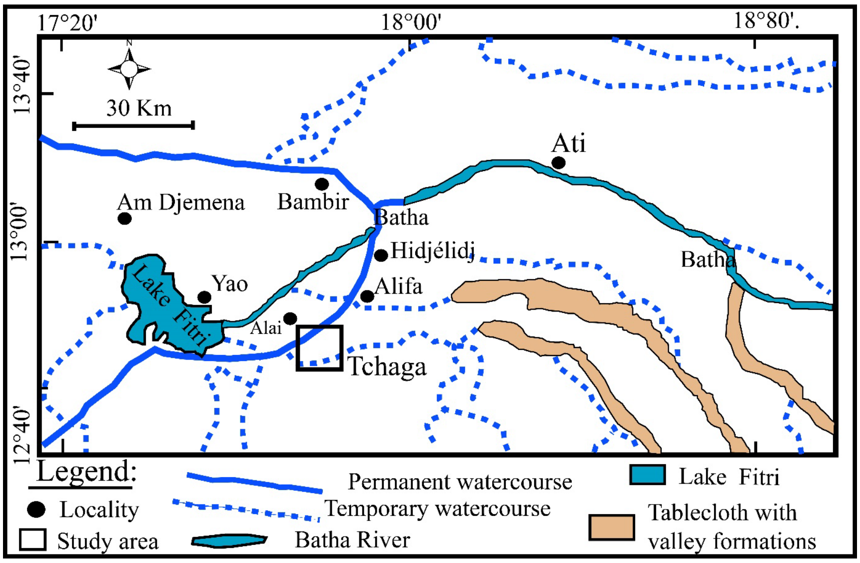

Figure 1. Map of the study area.

This attraction to the yellow metal has encouraged the installation of several homes in the area on an almost permanent basis as well as the development of several other economic activities indirectly linked to the exploitation of gold.

2.2. Geological Context

The Pan-African Range of Central Africa (CPAC) is part of a vast portion of a whole that includes the Pan-African tectonic belts of Central Africa, the Brasiliano belts of NE Brazil and the Trans-Saharan Pan-African Range (Toteu et al., 2001; Van Schmus et al., 2008). This chain extends across the African continent, in Nigeria, Cameroon, Chad, the Central African Republic (CAR) and continues eastward to Sudan, Uganda and Tanzania. From current knowledge, this domain is formed by convergence between the West African craton, the Congo-São Francisco cratons and the Latea and Saharan meta cratons (Castaing et al., 1994; Liégeois et al., 2000; Toteu et al., 2001; Abdelsalam et al., 2002). On the northern edge of the Congo craton, this chain shows the characteristics of a collision chain (Toteu et al., 2001), with external layers of regional extension, high pressure granulitic metamorphism, intense migmatization, regional scale strikes and the presence of molassic deposits (Toteu et al., 2001). Chad is located in a mobile Pan-African zone between the Congolese craton to the south, the West African craton to the west and the Nile craton to the northeast (rather poorly defined). The crystallophyllian rocks and ancient granitoids of Tibesti in the north, Ouaddaï in the east, the central massif in the center, Mayo Kebbi and the Baibokoum region in the south represent the base of these cratons. The Precambrian formations constituting these massifs were affected by the Pan-African orogeny (700 to 520 Ma).

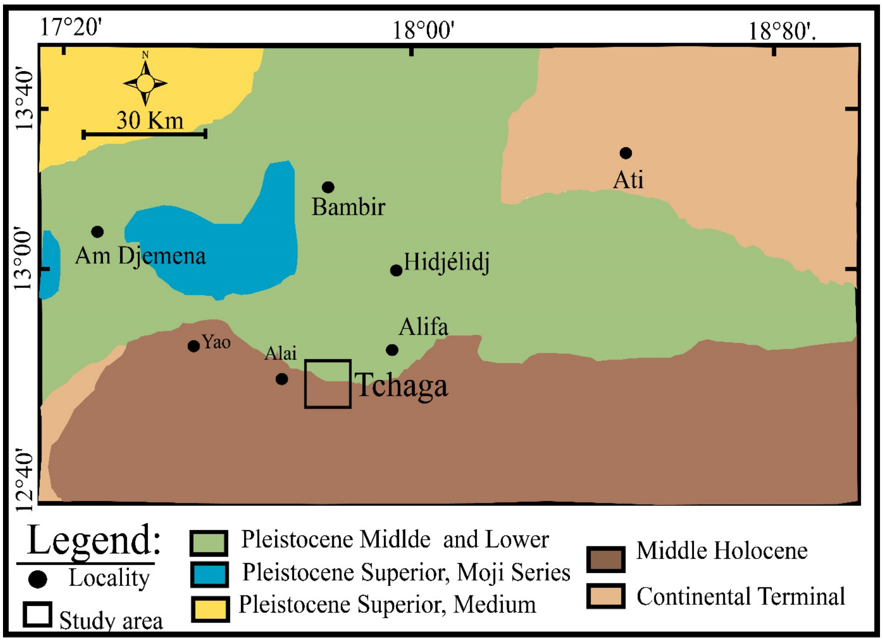

Figure 2. Geological map of the study area (Extract from Pias, 1960; redrawn).

A large part of Chad, Western Sudan, Northern Cameroon and the CAR would constitute "the Central African Belt" (Central African zone) of the Pan-African mobile zone. The southern limit with the Congolese craton is marked by the lineaments of Sanaga and Adamaoua (Cameroon), but that with the Nile craton is less obvious. For Vail (1978), most of eastern Chad, Sudan, eastern Tibesti up to Mayo Kebbi presents a Cratonic zone (Uweinat Craton, Archean).

The continental terminal is essentially composed of tertiary deposits covered by quaternary formations not exceeding a thickness of 50 m. We find in places slightly consolidated sandstone and clayey sand;

- the crystalline base often surfaces in the form of isolated massifs (inselbergs) crossing the sedimentary covering;
- fluvial deposits are represented entirely formed by formations in the form of

alternating lenses of sand and clay. In the study area, plutonic rocks are observed within the sedimentary terrains (**Figure 2**).

The hydrogeological plan of the Batha area is divided into two types of aquifers of unequal importance and distinct by their lithological nature, their depth and their power (Kusnir & Schneider, 1993). Continuous aquifers are made up of reservoirs whose formations are sedimentary types with predominance of alluvium and alterites and discontinuous aquifers made up of reservoirs of fissured or fractured rocks are smaller.

3. Methodology

3.1. Samples and Preparation

Deep water (wells and boreholes) and surface water (washes and rivers) were sampled (**Figure 1**) during this phase. During this phase, physical parameters of the water were carried out such as hydrogen potential (pH) and electrical conductivity using a multiparameter instrument. To find normal samples for laboratory analysis, the following steps are taken:

- the preparation of label sheets to attach to the bottles;
- use of latex plastics to avoid sample contamination;
- use of 750 ml and 1.5l major bottles previously sealed in sampling for chemical analyzes of cations and anions;
- filling the bottle while ensuring that there are no air bubbles in the bottle when closing the cap to avoid gas exchange with the atmosphere
- in the case of drilling, the water must be pumped for a while before taking the sample.

3.2. Measurements of Physical Parameters

The physical parameters were measured in situ to correlate with the concentration of heavy metals. Physical parameters such as hydrogen potential (pH) and electrical conductivity (µs/cm) were measured in the laboratory using a branded multimeter.

3.3. Laboratory Analysis Methods

Analyzes of groundwater samples were carried out at the Hydro-Geosciences and Reservoirs Laboratory (LHGR) of the University of Farcha and at the National Water Laboratory (LNE) for metals: (i) research focused on chemical elements major (cations, anions, alkalinity and heavy metals) (**Table 1**) and (ii) spectrometry by volumetric dosage, molecular absorption spectrophotometer and flame spectrometer (**Table 1**).

The samples taken during the field campaign were analyzed at the National Water Laboratory (LNE). The analyzes were carried out to meet the expectations of research focused on the major chemical elements: cations (Ca^{2+}; Mg^{2+}; Fe^{2+}; K^+; Na^+; NH_4^+); anions (Cl^-, NO_3^-, HCO_3^-, SO_4^{2-}), alkalinity and heavy metals (CN^-; Zn; Pb and Hg).

Volumetric dosing spectrometry is carried out by:

- the DR2800 type molecular absorption spectrophotometer (Fe^{2+}, SO_4^{2-}, NH_4^+, NO_3^-);
- the "BWB-XP" flame spectrometer (K^+, Na^+), (Cl^- , HCO_3^- , Ca^{2+}, total hardness).

The methods of **Table 1** are used to determine the concentration of cations and anions.

Table 1. Summary of analysis methods.

Elements	Reactive	Analysis methods	Devices used
Turbidité			Turbidimeter
Cl^-	Chromate de potassium	Volumetric dosing	
HCO_3^-	Hélianthine		
Ca^{2+}	Calgon and Tampon 12		
$CaCO_3$	Eriochrome Black T(NET), pH 10 Buffer		
Mg^{2+}	No reagent	Spectrometry	DR2800 Spectrophotometer
SO_4^{2-}	Sulfaver		
NH_4^+	Mineral Stabilizer and Nessler		
NO_3^-	Nitraver		
K^+, Na^+, CN^-, Hg, Zn, Pb.	No reagent	Spectrometry	flame spectrometer "BWB-XP"

4. Results

4.1. Study of Physical Parameters of Water (pH)

The analysis of physical parameters revealed that the pH obtained during the work varies at a maximum of 7.89 and a minimum of 6.54 for an average of 7.45. The waters studied in the area are neutral (**Figure 3(a)**). The pH values measured in the field are within the WHO standard set in 2011. The waters analyzed are basic to slightly basic (6.54 × pH × 7.89). It is a favorable environment for chemical and biochemical reactions. It is also a determining factor for the growth of microorganisms living in water, in particular bacteria since most of them prefer neutral or slightly alkaline pH values between 6.5 and 8.5 (Mara, 2004).

The conductivity of water is an indicator of changes in the composition of materials and their overall concentration. It is proportional to the quality of ionizable salts. It provides information on the degree of overall mineralization of surface waters. High temperatures act on electrical conductivity by acting on the mobility of salts. Natural waters serve as solvents for a considerable number of solutes, which in aqueous solutions are either completely associated into ions or partially ionized. High conductivity reflects either normal pH, or most often high salinity (Elmorhit, 2009). The value of electrical conductivity oscillates between 62.8

µs/cm and 4000 µs/cm. It is 4000 µs/cm) in the waters of Abdebe, therefore higher than the WHO 2011 standard. This explains that the water of Abdebe has a high mineralization compared to the others. The waters of the other sites have a very low conductivity value around 62.8 µs/cm, which could explain the low mineralization, i.e. lightly charged.

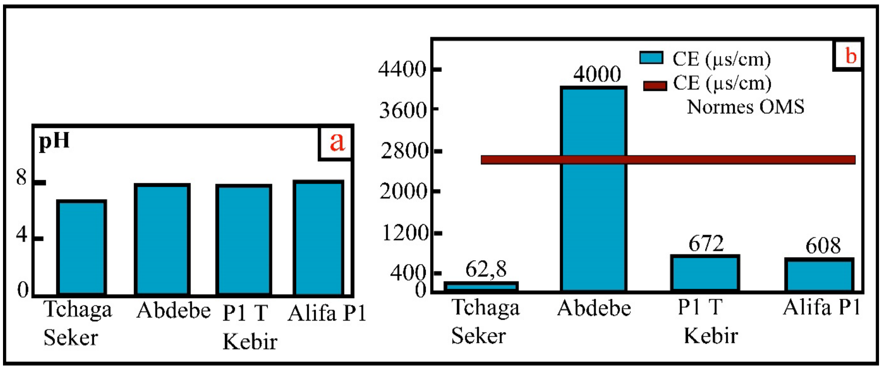

Figure 3. (a) Variation in hydrogen potential (pH) of Tchaga waters; (b) Variation in electrical conductivity of Tchaga waters.

4.2. Study of Water Chemical Parameters

4.2.1 Cation and Anions

- ✓ The Calcium (Ca^{2+}) contents of the water analyzed vary from 3.11 mg/l to 6.81 mg/l for an average (4.18 mg/l) which is lower than the WHO/Chad standard (**Figure 4(a)**). This low calcium content is linked to the formation of carbonates which produces less calcium.
- ✓ The magnesium concentration (Mg^{2+}) is between 4 mg/l and 84 mg/l for an average of 31.25 mg/l. On the other hand, the groundwater in Abdebe has a content of 82 mg/l which is higher than the WHO/Chad 2011 standard (**Figure 4(b)**).
- ✓ The sodium content (Na^{+}) oscillates between 6 mg/l and 386 mg/l (**Figure 4(c)**). While Abdebe water contains a very high content (386 mg/l) higher than the WHO standard. This explains the high sodium mineralization compared to other sites.
- ✓ Potassium concentrations (K^{+}) in the waters studied vary between 0.4 and 17 mg/l. On the other hand, Abdebe water has a high potassium content (18 mg/l) exceeding the WHO standard (**Figure 4(d)**).
- ✓ The content of 254.92 mg/l in Bicarbonate is lower than that of the WHO standard in 2011. The surface water of Tchaga Seker has a very low concentration of less than 50 mg/l in Bicarbonate but this concentration is high in the waters of the other sites (**Figure 5(a)**).
- ✓ The chloride (Cl^{-}) concentration of the water analyzed displays values oscillating between 0.3 mg/l and 3.89 mg/l with an average of 2.23 mg/l (**Figure 5(b)**). These levels are very low compared to the WHO standard (250 mg/l).

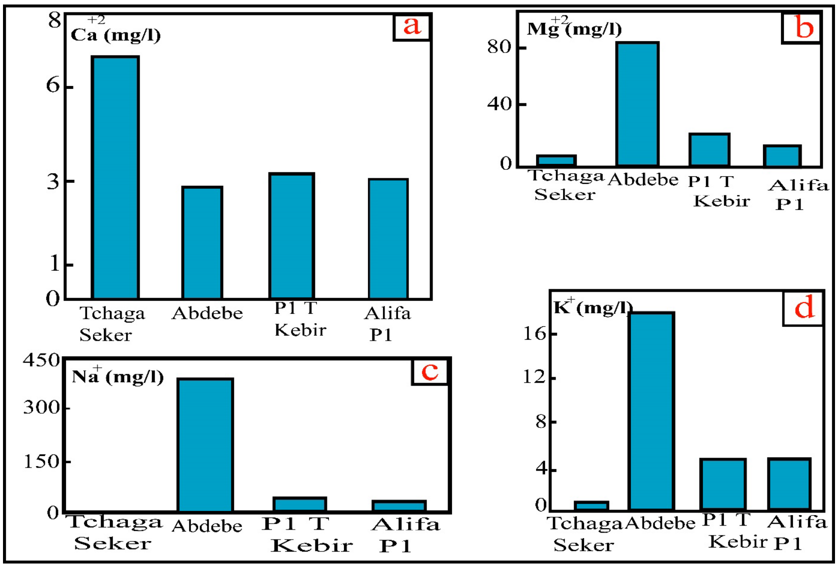

Figure 4. Variation de la teneur des cations: (a) Calcium, (b) Magnésium, (c) Sodium; (d) Potassium.

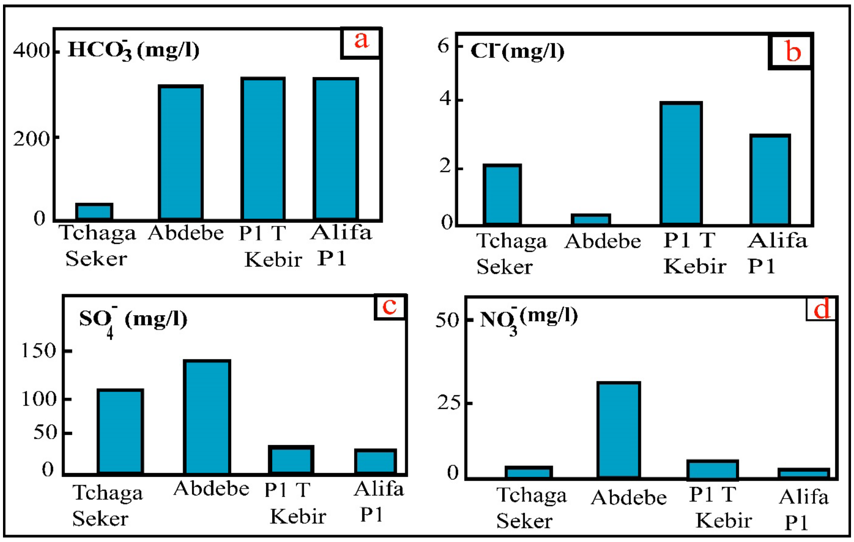

Figure 5. Variation in the content of anions: (a) Bicarbonate; (b) Chloride; (c) Sulfate and (d) Nitrate.

- ✓ The sulfate contents (SO_4^{2-}) of the waters studied are very variable and located between 13 mg/l and 130 mg/l for an average value of 65.25 mg/l (**Figure 5(c)**). The origin of sulfate in these waters could be explained either by the presence of evaporitic sedimentary rocks, notably gypsum ($CaSO_4$) or sulfur is present in sphalerite, chalcopyrite ($CuFe_2$), galena (PbS) and pyrite (FeS_2), the alteration of which is considered to be the reason for their presence in the environment (Rakotondrabe, 2017). The mineralization in the gold veins comes from quartz veins, which would support the high probability of the presence of sulfur according to Miquel (2001).
- ✓ The concentration of Nitrates (HCO_3^-) in the waters of the study area varies

from 2 mg/l to 27.1 mg/l (Figure 5(d)). The high content may be due to the leaching of fertilizers used in agricultural soils. They come naturally from marl-gypsum formations or by human effect using fertilizers for agriculture.

4.2.2. Heavy Metals

The heavy metal analysis results are recorded in Table 2.

Table 2. Heavy metal results.

Locality	Pb	CN^-	Arsenic	Zinc	Mercure
TCHAGA SEKER	0.000139	0.018	0.001	0.002	0.000
ARDEBE	0.000547	0.008	0.001	0.0001	0.000
P1 T KEBIR	0.000362	0.002	0.000	0.0001	0.000
ALIFA P1	0.000267	0.001	0.002	0.0001	0.000

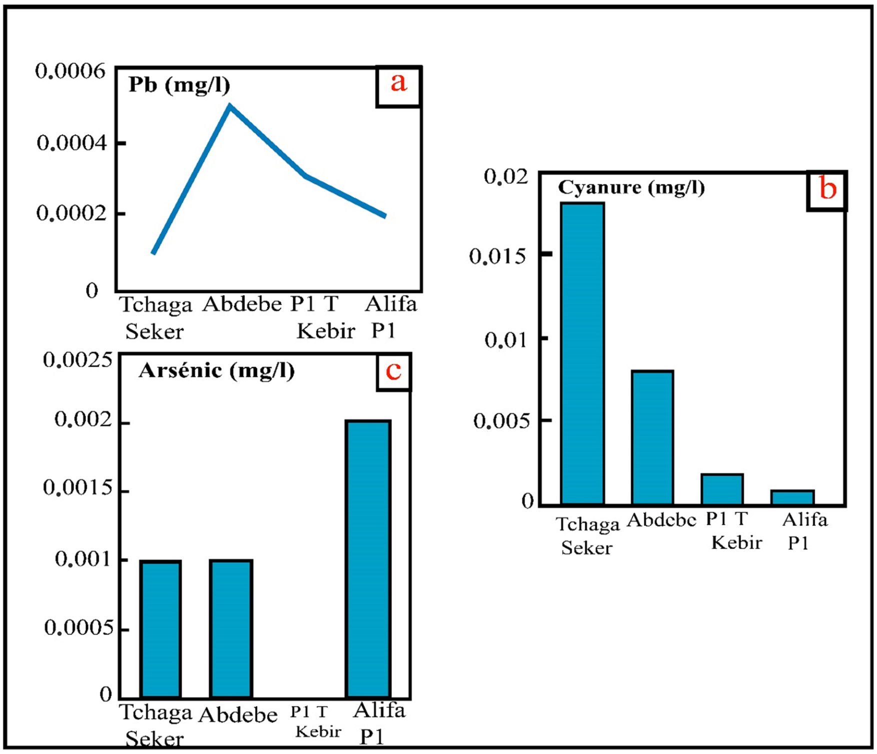

Figure 6. Variation in the content of heavy metals: (a) Lead; (b) Cyanide and (c) Arsenic.

- ✓ The cyanide content in the water sampled varies from 0.001 mg/l to 0.018 mg/l for an average of 0.007 mg/l (Table 2). The high cyanide content of Tchaga Seker water (0.018 mg/l) would be due to its abundant use in the extraction of gold, whereas the low value of other sites may be due to the fact that mining regulations prohibit its use (Figure 6(c)).
- ✓ On the other hand, the low concentrations of mercury, zinc, lead and arsenic in the different samples (Figure 6(a), Figure 6(b)) may be due to the nature of the mined rock, which is poor in these elements (Ouedraogo et al., 2024).

In Guyana, research carried out by Polidori et al. (2001) on the biochemical cycle of mercury showed the aggravating role of gold mining activity and particularly gold panning, on the one hand by the additional releases of metallic mercury and, on the other hand on the other hand by a certain erosion of the soil which favors the mobilization and transport of metallic mercury to the lowest points (lowlands, watercourses).

5. Interpretation and Discussion

5.1. Impacts of Gold Panning on the Environment

Mining activities pose a threat to natural ecosystems, particularly in protected areas and areas of high conservation value. Artisanal mining sites produce mining waste which can pollute the soil and waterways which subsequently pass through protected areas. In traditional gold panning techniques, the risks and dangers for the physical environment generally result in deforestation, the destruction of plant cover and soil, and the pollution of water resources often resulting from the use of gold mining products chemicals in treatments. The destruction of plants is also reinforced by the search for nuggets which are known to be found especially between the roots of certain plants. Finally, like any human settlement, we observe on artisanal mining sites, environmental pollution by waste and organic matter and a significant accumulation of rubbish and batteries from the torches used by gold miners in the mines. This results in land degradation which is then made unsuitable for agriculture. Gold panning is a generating activity that causes enormous disruption to the natural environment as well as to the health of gold miners and local residents. Indeed, the environmental impacts of mining activity are as numerous as they are visible in pollution and chemical contamination: soil, water, air, etc.

5.1.1. Impacts of Gold Panning on Water

The water used to clean the ore is often released directly into the natural environment without treatment (**Figure 7(a)**, **Figure 7(b)**). The use of settling basins is not systematized in Chad, more precisely in Tchaga, and if these settling basins exist, they are generally undersized (**Figure 7(a)**, **Figure 7(b)**). The water thus released is then heavily loaded with suspended matter and increases the turbidity of waterways. When sinking, the gold miners reach the water table which is at a depth of 20 to 25 m on average. They use motor pumps to release significant quantities of water. The use of motor pumps on the site leads to the evacuation of several liters of water per day, thus contributing to the reduction in the level of the groundwater table. Even if water consumption is negligible at this level, it should be noted the discharge of used oils and hydrocarbons which can pollute water resources. Washing and gold extraction using mercury are activities that consume a lot of water. Metals in acidic mining effluents are generally metabolic poisons, particularly heavy metals. The daily life of gold miners requiring a daily need for water (nutrition, laundry, shower, etc.) adds up to all these activities. The pumped water is used by residents of the site for daily needs (toilet, cooking food and drinking by some) which can constitute a source of poisoning for local residents. In short, the impacts on water are the depletion of water resources (massive use of water, water discharge during sinking) (Figure 7(a), Figure 7(b)). Mining waste (oil, hydrocarbons, human faeces, plastic, wastewater, waste rock residues and dumps, etc.) is also another important cause of pollution of water resources by leaching or infiltration.

Likewise, used batteries left inside wells can pollute groundwater resources. Chemicals used in mining, such as flotation reagents and solvents, can leach into nearby water bodies. This leads to water pollution which affects water quality and aquatic life. Indeed, the topography of the study site and of the Batha region in general decreases towards Lake Fitri. The holes are left open and the surroundings are littered with spoil and treatment residues (Figure 7(c), Figure 7(d)).

Figure 7. Photos: (a) (b) Wastewater, dumped on the ground at the Tchaga site; (c) (d) Large pits made to look for yellow metals at the Tchaga site.

5.1.2. Impacts of Gold Panning on Soil and Land

Prospecting and ore extraction activities degrade soil quality. In artisanal mines, concern for the environment does not exist in the minds of gold miners. Gold panning operations (excavation, use of explosives, gradual increase in mining depth) may be likely to affect the pre-existing state of equilibrium within the virgin rock mass (Poulard et al., 2017). When the Tchaga site was discovered, large pits were made (Figure 7(c), Figure 7(d)); which contributes to soil degradation through erosion. Man also contributes to irreversible soil degradation, associated with the abandonment of mining shafts and galleries not rehabilitated after exploitation, piles of abandoned mining waste rock and lithological inversions giving the depth elements towards the surface and vice versa. This situation greatly modifies the landscape (Affessi et al., 2016; Digbo et al., 2021), distorts the composition of the soils which become poorer over time (Keita, 2017). It impacts the vegetation regeneration process, endangers gold miners with the risk of accidents (Abdou Amadou, 2020) and triggers the phenomena of landslides and soil erosion (Minkilabe et al., 2018; Soma et al., 2021). The same is true during sinking during which shafts are dug in order to extract the ore. This irreversibly degrades the soil because the soil is not replenished after abandoning the sites, this leads to modification of the landscape. The sinking results in the degradation of the soil which is left to gully, soil erosion, soil pollution by the piles left in the well. Soil pollution results in the presence, at abnormal concentrations (different from those naturally present), on the surface or in the first meters of soil, of undesirable elements in the form of solid particles (Poulard et al., 2017). Ground pollution by mining waste (oil, hydrocarbons, human faeces, plastic, wastewater, etc.) produced on the site must be reported. Above all, there is the contamination of the soil by chemicals (mercury) used during the extraction of gold, with the disadvantages of erosion, infertility, pollution by mining waste, contamination by harmful substances. Indeed, soil degradation seems to be a factor in the reduction of arable land and also a factor in the displacement of the population in search of more fertile arable land. This is the cause of the reduction in agricultural productivity. Furthermore, waste (plastic bags, wastewater, used batteries, clothing) from extraction is spread all over the site. Even more, the soils are polluted by waste oil spills and by hydrocarbons from pumps.

5.2. Impacts of Heavy Metals on the Environment

5.2.1. Mercury

It has been shown that for each gram of gold obtained by amalgamation, approximately two (2) grams of mercury escape into the ambient environment, directly polluting soil and water, not to mention the inhalation of gas by the user and their neighborhood. During the operation, approximately 40% of the mercury would have escaped into nature in the form of metal balls or vapors (two grams of mercury "evaporate" per gram of gold recovered). The released mercury can then be drained into waterways and deposited in sediments where it is transformed by bacterial action into methyl mercury, an organic compound with high bioavailability which can easily enter the food chain. "Mercury vapors produced when amalgam is heated to temperatures above 350˚C for gold recovery. Mercury vapor can be carried quite far by winds. It is deposited on unprotected soil, water and food or even precipitated in the form of acid rain, etc. These vapors are partly absorbed by the gold miners and people on the site. Thus, chronic exposure to the product does not only affect direct users who inhale the vapors, but also more indirectly the entire population who live and find their food in the contaminated zone. Direct releases of mercury in liquid form during gold concentrate amalgamation operations in the soil, the leaching of which by runoff water causes the mobilization and dispersion of heavy metals in the environment, particularly in surface water (rivers, rivers, Lake Fitri and water reservoirs) and in groundwater by infiltration. The methylation of mercury is favored by the physicochemical conditions of the aqueous environment, thus leading to the most toxic and dangerous form of mercury for public health, etc.

When burning sponge gold in the open air, gold miners and anyone nearby can inhale large quantities of up to 80% of mercury vapors. Mercury vapors can remain on clothes and shoes and can therefore be breathed in for a long time after the operation. Also, the wind can transport a large quantity of vapor far from the place of emission where it can be deposited on homes, plants and the ground. The waters studied do not contain mercury because its content in all the samples analyzed is 0 mg/l (**Table 2**).

5.2.2. Arsenic

Arsenic is a toxic element which can cause dermatological problems after 5 years of exposure (Meek et al., 2011). Ingestion of arsenic through drinking water can cause peripheral neuropathy, skin, bladder and lung cancers. Cardiovascular system problems can also be observed in children consuming water contaminated with ars.

5.2.3. Cyanide

The chemicals used for gold processing (mercury and cyanide) will pollute waterways and aquifers (Fofana et al., 2009). Cyanide is a very toxic element. Exposure to hydrogen cyanide can cause neurological disorders including dizziness, confusion, headaches and can quickly lead to death in the event of acute poisoning. Dermal contact may cause skin irritation. Hydrogen cyanide vapors can cause eye irritation. Although some studies suggest lethality from 180 mg/l; INRS (2018) considers that absorption of a total dose of 50 to 100 mg of hydrogen cyanide is sufficient to cause death in an adult. SML effluents can contain more than 37 mg/l. As gold miners' effluent is unprotected, accidental ingestion can easily cause serious health problems. Although the discharge of cyanidation water has not shown contamination of surface water (ponds), this could happen in the future if the discharge is indeed true and continuous.

5.2.4. Lead

Lead is a chemical element harmful to human health. According to a WHO study, exposure to lead can cause cardiovascular disease, kidney problems, and reduced human fertility (Meek et al., 2011). Exposure to lead can also cause stunted growth in children. The case of Zamfara in Nigeria is very instructive on this subject since many children in several villages had died following exposure to lead from dust from artisanal gold mining activities. 400 children died from lead poisoning and more than 3000 children suffered lead poisoning. There is therefore reason to be seriously concerned about this given that the gold miners are in permanent contact with this water and that in addition there is the presence of children who work on the Tchaga site. It should also be noted that in this area, surface water is at a certain time of the year the only source of water for livestock but also for household chores.

5.2.5. Silica

During the crushing and sieving phases of the gold ore, enormous quantities of dust are released and spread into the ambient atmosphere. Inhalation of silica dust can cause numerous pathologies such as rhinitis, sinusitis, or broncho-pleuro-pulmonary manifestations with cardiac complications. Silicosis is the most well-known pathology linked to the inhalation of silica dust. The silicotic risk can occur several years after exposure, hence the need to take protective measures to protect workers as well as children who are most of the time also present on gold panning sites. Although dust measurements were not carried out on the Tchaga site, it is necessary to look into raising awareness among gold miners of the silicotic risk in view of the enormous quantities of dust released during the grinding phases and sieving of the ore and that the Chadian legislator must set the quantity of admissible dust according to the silica content.

6. Discussions

This article on gold panning activities shows points in common with those carried out by other authors. Furthermore, the use of mercury in the purification of gold and also certain chemical particles contained in stone and subsoil residues lead to sedimentary deposits which cause pollution of aquatic and atmospheric environments. What has been proven by authors in their research work. In Guyana, research carried out by Polidori et al. (2001) on the biochemical cycle of mercury showed the aggravating role of gold mining activity and particularly gold panning, on the one hand by the additional releases of metallic mercury and, on the other hand on the other hand by a certain erosion of the soil which favors the mobilization and transport of metallic mercury to the lowest points (lowlands, watercourses). In terms of human health, mercury vapors cause a real public health problem for gold miners and local populations. Studies relating to the use of mercury in the processing of ore carried out on 11 gold panning sites in Burkina (Ouédraogo, 2006) clearly illustrate the impact of artisanal gold mining on health. In urine, the average mercury value found is 194.5 ug/g. More than 98.9% people have urinary mercury concentrations above the reference values for the general population; 68.8% people have concentrations above professional reference values (35 ug Hg/g) and almost half (49.5%) have values above 100 ug Hg/g.

The occupation of river beds for exploitation purposes causes the destabilization of the banks. Massive sediment inputs locally become disruptors of the balance of rivers and increase water turbidity, compromising the productivity and biological diversity of Lake Fitri (Ousmane et al., 2013). The degradation of the plant cover causes strong erosion and ultimately, irreversible sterilization of the soil through the disappearance of the humus horizon. The severity of the direct impacts on the flora and indirect impacts on the soil, attributable solely to gold panning, appears to be moderate. However, when severity is studied cumulatively with pre-existing impacts, it remains high. The impact will continue throughout the duration of the activity and once the vegetation is destroyed, rehabilitation at least in its primary natural habitus will be difficult (Ousmane et al., 2013).

There is no evidence of contamination of soils in the study area by heavy metals, nor are the effects of acid mine drainage reflected in the chemistry of groundwater. Given that gold miners have mainly targeted oxidized ore, the risks linked to acid drainage have so far been limited on the Tchaga site (Ousmane et al., 2013).

7. Recommendations

To mitigate and prevent these harmful impacts on the environment, there are numerous measures to be taken by gold miners. These are:

- carry out intense campaigns to raise awareness among artisans on the risks of dangers associated with the use and handling of mercury without protection or precautions;
- set up small units on gold panning sites that do not use chemicals and increase their ore processing and gold recovery capacity;
- it is compulsory to wear protective equipment (gloves, masks, protective glasses, etc.) at ore processing centers during amalgamation operations;
- demarcate and develop single ore processing centers on the sites;
- involve beneficiaries of artisanal gold mining authorization or gold panning site managers in the fight against the uncontrolled use of mercury and the processing of ore outside the areas provided for this purpose on the site;
- regulate the sale, purchase, transport and use of mercury on all gold panning sites operated by the state and its branches;
- pay particular attention to the management of mining waste and particularly sensitive environmental components located near these mining operations;
- finally, identify all the important gold panning sites to be the subject of mapping and physico-chemical characterization studies with a view to better management of the mining environment.

8. Conclusion

In the Batha region and more particularly in the Tchaga sector, gold is mined in an artisanal manner using chemicals that are dangerous for human and environmental health. Although gold mining is an activity that can improve the living conditions of gold miners by giving them substantial income and employment in a context of progressive land degradation, and agricultural yields and resulting insecurity, it is a polluting activity. The use of heavy metals (mercury, cyanide, etc.) is confirmed on the Tchaga site with the corollary of the discharge of water from its products directly into the environment. The discharge of this water laden with heavy metals into the environment is the main anthropogenic source of contamination of surface water and even groundwater. Indeed, analyzes carried out on water samples taken from the site's galleries show that the concentrations of heavy metals and the physicochemical parameters still meet the standards. Likewise, the concentration of arsenic in groundwater is beyond the limit value set by the WHO. These high grades are the result of the acid attack of the metals that accompany the gold ore or added during the processing process. These chemicals used contribute to soil contamination. In essence, artisanal gold panning, by its scale, lastingly modifies the environmental landscape of Batha. In fact, analyzes demonstrate that the concentrations of mercury (Hg) in the waters of Tchaga seker and the concentrations of K, Mg, Na, SO_4^{2-} and NO_3^- in certain surface waters exceed WHO standards. The most visible dimension is soil degradation due to the progression of gold panning activity to the detriment of agriculture. The clandestine and limited use of mercury and/or cyanide in the homes of gold miners is well known, which makes control very complex.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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