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Assessing the Impact of Gold Mining on the Quality of Water Resources in the Commune of Meguet, Burkina Faso

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Abstract

Despite its often illegal nature, artisanal gold mining in Burkina Faso contributes to the economic and social development of the country. However, the rudimentary techniques used in gold panning have a significant impact on the environment due to inappropriate practices and the use of various chemical substances. This study aims to assess the impact of artisanal gold mining on the quality of water resources in a rural community at Méguet, Burkina Faso. To this end, surface and groundwater samples were collected and analyzed at the BUMIGEB laboratory. Field results show that the waters are slightly alkaline (6.97 < pH < 8.1), weakly mineralized and conductive (124 < EC < 543 µS/cm), with temperatures ranging from 24.6˚C to 31.6˚C. In addition, trace metals (TMEs) analyzed from surface and subsurface waters show very high levels, generally deviating from the levels recommended by WHO guidelines for Burkina Faso. Trace metals contamination of water resources in the commune of Méguet is mainly due to Fe (3.78 - 11.12 mg/kg), Hg (0.03 - 0.29 mg/kg), As (0.01- 6.31 mg/kg) and Pb (0.01 - 3.8 mg/kg). This study can serve as a basis for guiding national environmental policies to protect the water resources of the Méguet mine.

Keywords

Gold Panning, Water Quality, Trace Metal, Méguet, Burkina Faso

1. Introduction

Mining is the process of extracting a natural material from the earth for profit.

Many precious metals (cobalt, nickel, iron, gold, etc.) are found in the earth. Platinum, silver and gold are the rarest and most sought-after metals in the world [1]. Their extraction has always been controversial in terms of protecting the environment and human health. Gold can be extracted by both industrial and artisanal mining methods. Although panning is done with rudimentary means and little or no mechanization, it is an activity that adds significant quantities of the "yellow metal" to the global gold cycle. In developing countries, tens of millions of people depend on artisanal and small-scale mining [2].

Hirwa *et al.* [3] states that, the most basic element required for the mining industry is water. According to Cole and Hogarth [4], water is used to operate equipment (e.g., drilling, grinding, flotation, smelting) and for health and safety (dust suppression, hydration), it can have a significant impact on local resources. Deteriorating water quality is growing concern worldwide [3]. This phenomenon is attributed to human activities that contribute to its increase ([5] [6]). Water pollution can take many forms: the most common are discharges from industrial processes such as mining, domestic wastewater, and spills of chemicals used in agriculture [7]. The major sources of wastewater from mining operations fall into three broad categories: mine water, process wastewater, domestic wastewater and runoff [8]. Mining activities produce wastewater containing a number of chemical contaminants that alter the quality of surface and groundwater and are often the source of significant pollution (Koryak [8] cited in Hirwa *et al.* [3]). According to Ellis *et al.* [9], the effects of water quality degradation are not only felt in the local area of the mine, but are often felt downstream of the mine, far away from the source of the pollution. Thus, the impacts of mining activities can cause problems in ecosystem functioning [10]. As affirmed by Koryak [8], that wastewater from waste rock dumps can be the cause of acid rain in rivers (cited in [3]). The author McMenemy [11] cited by [3], reported fish non-survival in Ely Brook River (USA) due to extremely poor survival and growth conditions caused by mining effluents.

In Burkina Faso, nearly 800 artisanal mining sites were identified in 2018. They are distributed throughout the national territory and employ more than two million miners. In addition, according to the National Survey of the Gold Panning Sector (ENSO) organized by the National Institute of Statistics and Demography (INSD) in 2017, artisanal production of 9.5 tons of gold was recorded in 2016 [12], with a value of FCFA 232.2 billion.

It is true that gold mining is a source of income for the country, but gold mining also has traditional characteristics that threaten the environment and human health. Toxic chemicals and certain heavy metals such as mercury, cyanide, zinc and nitric acid are used in the gold panning chain [13]. Of these, cyanide and mercury are of particular concern. The use of mechanical methods which are even more environmentally friendly by eliminating chemical treatment, could be a profitable and sustainable solution.

In view of the major challenges in the supply of drinking water to communities, the protection of ecological systems and the knowledge of the quality of water resources in the gold mining area remain a priority. The general objective of this study is to assess the impact of artisanal mining on the quality of water in the rural commune of Méguet in Burkina Faso. The aim is to ensure better qualitative and quantitative management. The levels of certain heavy metals and a number of physical parameters were determined. This research will therefore enable us to understand the existing baseline of the impact of mining activities on water quality in this gold mining area of Burkina Faso. It will also provide guidance for environmental policies for the sustainable management of mining in Burkina Faso.

2. Materials and Methods

2.1. Location of the Study Area

The area of interest is the Central Plateau region, located at 2˚15' and 0˚20' west longitude and 11˚45' and 13˚00' north latitude. The study area belongs to the Northern Sudan climatic zone, which is characterized by an alternating dry season from mid-October to mid-May and a rainy season from mid-May to mid-October. The average annual rainfall in the area varies between 650 mm and 800 mm and is characterized by a low spatio-temporal distribution. The average annual temperature in this zone is about 28.5˚C, with mean and absolute minima of 16˚C in December and January and mean and absolute maxima of 39˚C in March and April. The warmest months are March, April, and May, while the coldest months are December, January, and February.

The Central Plateau region is part of the geology of the West African Craton. The West African Craton is a magnet for mining industries and small-scale artisanal gold miners because of its numerous gold deposits. With respect to the geology of the study area, the bedrock is mainly leucocratic to sub leucocratic granite with biotite and sometimes muscovite. Banded and foliated granodiorite, tonalite and quartz diorite are also found, with significant quartz vein crosscutting (Castaing *et al.* 2003) [14] **Figure 1**.

The study was conducted in the rural commune of Méguet, located 26 km north of the commune of Zorgho, capital of Ganzourgou Province in the Central Plateau region, and about 100 km from the capital city of Ouagadougou, Burkina Faso. This rural commune which is the subject of our study has leached tropical ferruginous soils.

2.2. Sampling and Preparation

During this phase surface water (dams and site), groundwater (boreholes) and mine sediments were sampled (**Figure 2**). During this phase, physical parameters such as temperature, hydrogen potential (pH) and electrical conductivity were measured *in situ* using a multi-parameter instrument. To obtain samples ready for laboratory analysis, the following steps are followed preparation of sampling sheets and labels to be attached to the bottles; use of latex gloves to avoid contamination of the samples; use of 1 liter polyethylene bottles previously

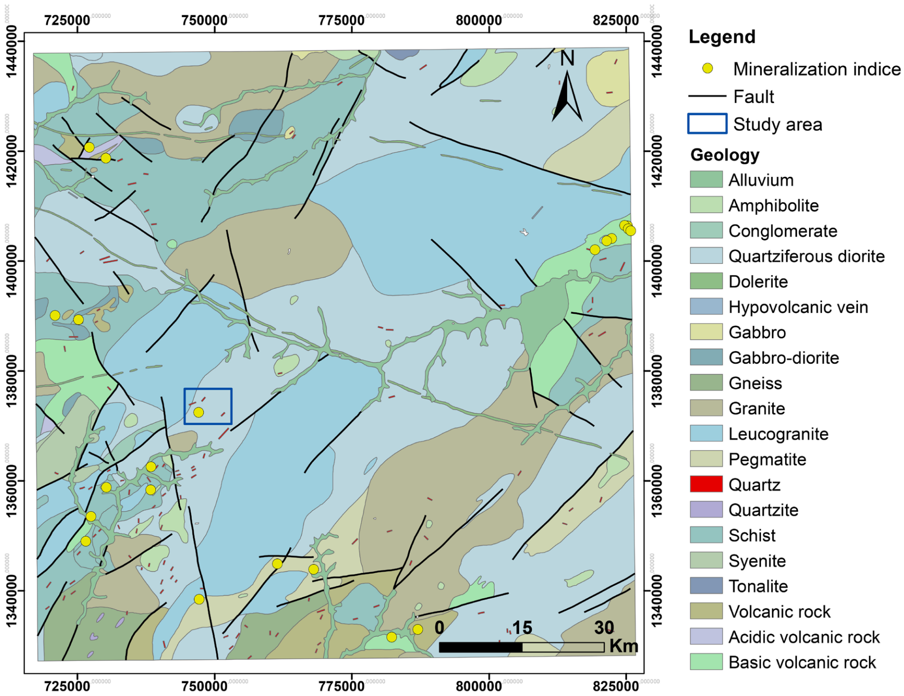

Figure 1. Geological and hydrographic map of the study area.

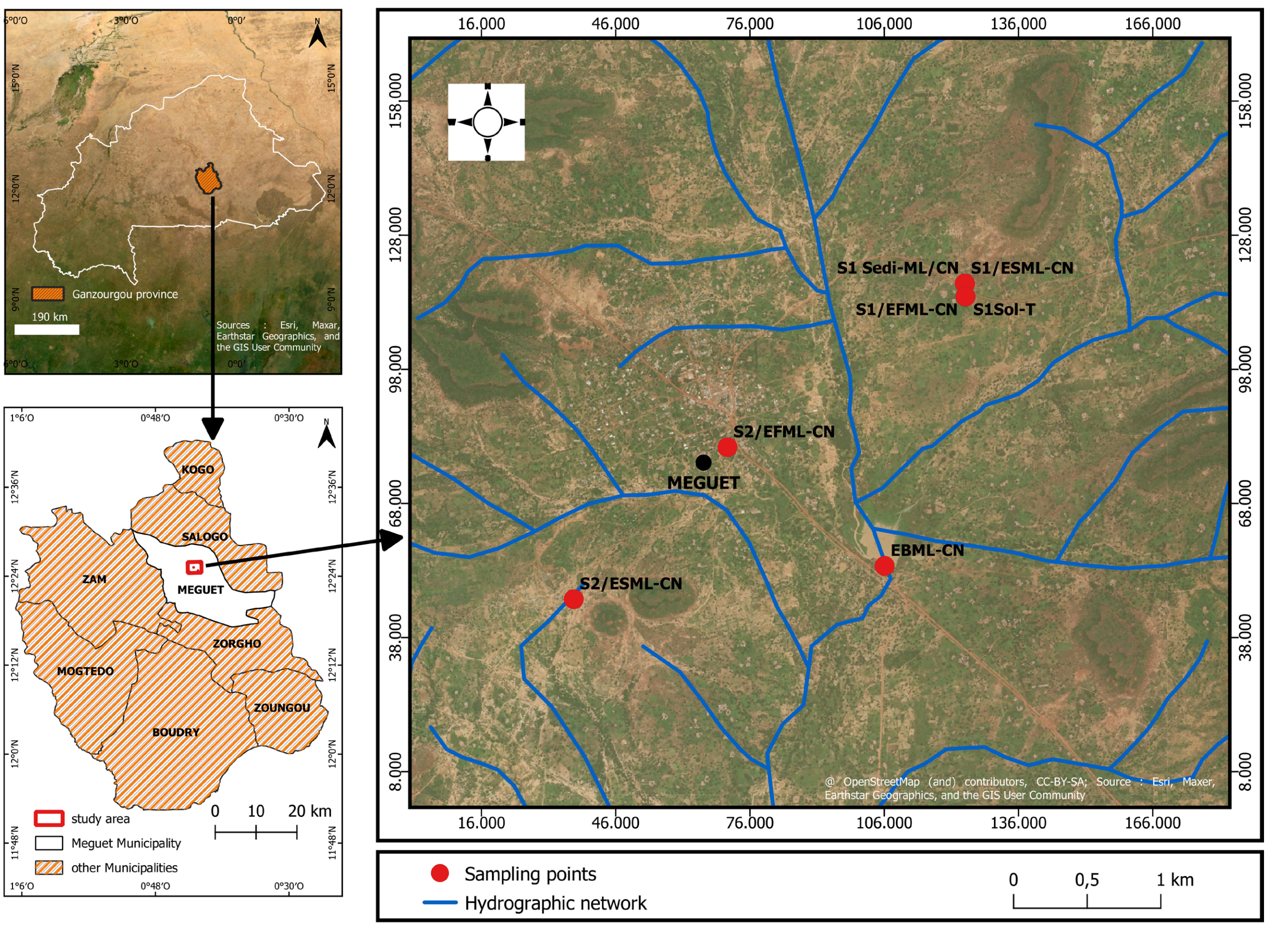

Figure 2. Sampling map of the commune of Meguet.

washed in distilled water, including two (02) per sampling point, one for heavy metals analysis and the other for free cyanide; use one bag to collect 1 kg of mining sediment from each site and another bag for 1 kg of control soil at a depth of 30 to 40 cm as a neutral sample; For heavy metals and cyanide analysis, rinse the water points for a few minutes to remove supernatants and obtain representative samples; thoroughly rinse the bottles at least three times with the water to be analyzed prior to sampling while wearing latex gloves; empty the bottle with the opening facing down before immersing it vertically in the water. When it's well submerged (about 30 cm), tilt it about 45˚, fill it halfway and add the stabilizing additive. Immediately rinse the cork and carefully close the bottle; use nitric acid (NHO_3, 1 ml) as a stabilizing additive in bottles intended for heavy metal analysis and sodium hydroxide (NaOH) as a stabilizing additive for cyanide analysis; use an airtight cool box with a cold preservative ("boxe glace") to keep the samples at a temperature below 4˚C suitable for laboratory analysis; return the samples to the laboratory within 24 hours.

2.3. *In Situ* Measurements of Physical Parameter

Physical parameters were analyzed *in situ* to study their correlation with heavy metal concentration. Physical parameters such as hydrogen potential (pH), temperature (˚C) and electrical conductivity (µS/cm) were sampled in the field using a branded multimeter. Sampling points were geolocated and coded by sample. Samples included wash sediments, drilling water, wash water, dam water and control soil.

2.4. Laboratory and Statistical Analyses

Heavy metals such as Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Ti, and Zn were determined by the Inclusive Coupled Plasma (ICP) method. Cyanide was analyzed using a titroprocessor equipped with a CN-specific electrode. However, the values obtained were subjected to statistical analysis. All statistical analyses were performed using Microsoft Excel 2013 for graphical presentation.

3. The Results

3.1. Presentation of Physical Parameters

All physical parameters of the water measured *in situ* are summarized in **Table 1**.

3.2. Correlation of Physical Parameters

A correlation graph (**Figure 3**) between the three parameters (pH, electrical conductivity and temperature) shows that the borehole water from Site 2 has the highest relative value for electrical conductivity, with a lower pH near of an average temperature of 29˚C.

3.3. Presentation of Heavy Metals

A total of 14 samples were analyzed for heavy metals (see **Table 2**) and another

Table 1. Physical parameters measured in the field.

Study sites	Geographic coordinates			Physical parameters *in situ*				
	Sample code	X	Y	pH	Cond (µS/cm)	Temp (˚C)	Date	Observations
Kietenga (site 1)	S1 Sol-T	750093	1375188	---	---	---	November, 15th 2022	Control soil sample
	S1 Sedi-ML	750088	1375278	---	---	---		mining waste
	S1/EFML	750089	1375277	7.39	359	30.4		Drilling near the site
	S1/ESML	750088	1375278	7.64	355	28.8		Mineral washing water (reddish to yellowish color)
Fatmatenga (site 2)	S2/EFML	748485	1374131	6.97	543	29.2		Nearby drilling, drinking water
	S2/ESML	747450	1373071	8.32	387	31.6		Reddish washing water
Dam	EBML	749560	1373319	8.01	124	24.6		Washing dam

Table 2. Heavy metal analysis results.

Number	Sample code	Content in ppm (mg/kg)												
		Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Ti	Zn
1	S1 Sedi-ML	0	6.31	0	0	387.5	19.4	32071	4.6	625.7	128.1	3.8	895.8	54.3
2	S1 Sol-T	0	7.43	0	0	55.2	40.7	48855	5.82	680.6	26.5	14.3	2067.4	50
3	EBML	0.04	0	0	0	0	0	0,03	0	0	0	0.01	0.5	0.07
4	S1EFML	0.01	0	0	0	0	0	0.1	0.03	0	0	0.01	0.48	0
5	S2EFML	0.09	0	0	0	0	0	0.1	0.03	0	0	0	0.47	0
6	S1ESML	0	0.02	0	0.01	0.04	0.02	11.12	0.05	0.03	0.01	0.02	0.51	0
7	S2ESML	0.04	0	0	0	0.01	0.01	3.78	0.29	0.04	0.01	0.01	0.49	0
8	WHO standard	--	0.01	0.003	0.07	0.05	2.0	0.3	0.006	0.5	0.07	0.01	--	3

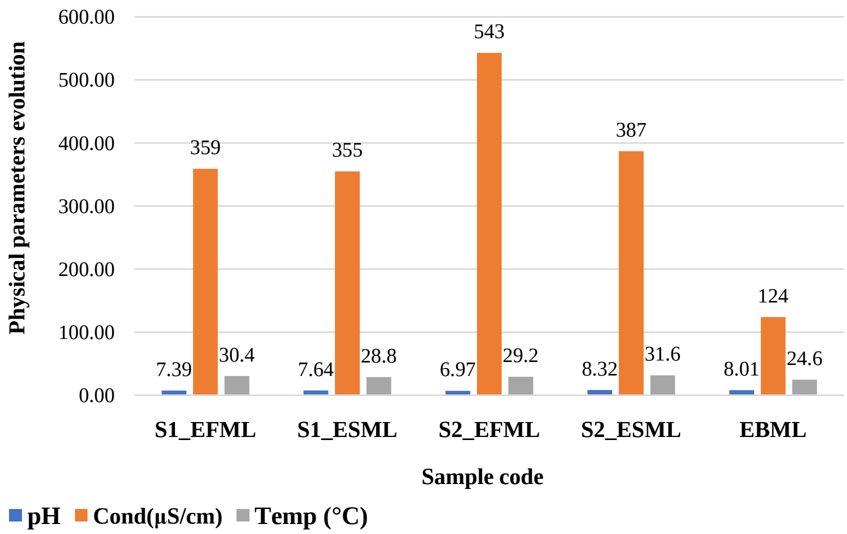

Figure 3. Correlation between physical parameters; pH, temperature and electrical conductivity.

seven samples were analyzed for free cyanide (CN) (see Table 3). The distribution and comparison of the elemental concentrations present in the samples

Table 3. Cyanide analysis results.

Number	Samples code	CN in ppm (mg/kg)
1	S2 Sedi-CN	0.00
2	S2 Sol-T	0.00
3	EBCN	0.00
4	S1EFCN	0.00
5	S2EFCN	0.00
6	S1ESCN	0.00
7	S2ESCN	0.00
8	WHO standard	0.005

from the two sites, as well as from the dams, boreholes and control soil, will allow us to determine their origin (natural or anthropogenic) and to conclude whether they are contaminated. In this case, the hypothesis of contamination by gold panning would be confirmed, in accordance with the World Health Organization (WHO) [15] standards in force in Burkina Faso.

4. Discussion

4.1. Physical Characterization of the Water

Analysis of *in situ* physical parameters revealed that the waters analyzed are basic to slightly basic (6.97 < pH < 8.1). This is a favorable environment for chemical and biochemical reactions. It is also a determining factor for the growth of micro-organisms living in the water, specially bacteria according to Roudier [16], since most of them prefer neutral or slightly alkaline pH values between 6.5 and 8.5 [17]. For this study, all samples had a pH well within the WHO standards (6.5 < pH < 8.5).

Temperature ranged from 24.6˚C to 31.6˚C. Between 10˚C and 30˚C, temperature has a negligible effect on metal mobility [18]. However, in a mining environment, an average temperature of 30.3˚C could affect acid mine drainage (AMD), which is the most significant environmental problem in the extractive industry [18].

The different electrical conductivity measurements (124 < EC < 543 µS/cm) indicate a low mineralization of the water in the analyzed samples. This low mineralization could be explained by the fact that the water at the sites studied is only slightly charged.

Mining mineralized veins releases more particles into the water. In fact, the waters of the study area are loaded with sediments from gold panning and farmland erosion as explained by Mboudou *et al.* [19], which promote the development of microorganisms and other aquatic plants.

4.2. Chemical Characterization of the Water

Analysis of the samples revealed metal concentrations well above the normal range [15], especially in the solid samples, *i.e.* the control soil and the ore washing sediments.

These unusually high concentrations in the solid samples prove that trace metals have a natural origin in the environment and are the signature of existing geological formations. They are present in small quantities in rocks [20]. This natural presence, under the effect of transport agents such as water erosion by runoff, wind and infiltration, most often favored by agriculture and gold panning activities, could lead to a very high mobility of these elements towards water points (streams, rivers, dams, boulders and boreholes) for consumption or gardening. This abnormal distribution could contaminate the entire food chain, causing health problems for humans and wildlife, as well as the decline or disappearance of certain plant species and the impoverishment of the land.

The concentration of free cyanide (CN) monitored in the various samples was zero. This may be due to the fact that mining regulations prohibit its use in gold panning. In addition, we did not have access to certain ore processing areas that were considered highly suspect. On the other hand, the absence of cadmium (Cd) and cobalt (Co) concentrations in the various samples may be due to the nature of the mined rock, which is poor in these elements.

The results obtained from the liquid samples show low or very low levels of certain heavy metals. Mercury (Hg) and iron (Fe) were found in all liquid samples, with concentrations mostly above WHO recommended standards. These two elements are found in very high concentrations, especially in surface water and ore washing water at the two operating gold panning sites. Sulfur and iron are present in sphalerite (ZnS), chalcopyrite ($CuFeS_2$), galena (PbS) and pyrite (FeS_2), whose alteration is thought to be the reason for their presence in the environment [21]. The mineralization in the gold veins comes from quartz veins, which would support the high probability of the presence of sulfur according to Miquel, [22]. In addition, studies have shown that iron content is generally high in West Africa due to leaching from lateritic terrains [23]. Manganese generally accompanies iron in rocks and water. Not surprisingly, manganese concentrations in groundwater are on average 10 times lower than iron concentrations [24]. In our case, the concentrations of manganese are significantly lower than those of iron. The presence of manganese in water is primarily an organoleptic (metallic taste) and aesthetic (black color) nuisance. This nuisance can be perceived by the consumer at a concentration of 0.03 mg/L [22]. The mercury is therefore partly due to the geology of the area, although the high concentrations observed are directly related to its use in amalgamation during ore concentration.

The content of As, Cr, Ni, Mn, Cu, Pb and Zn in some liquid samples is below the WHO standards for Burkina Faso. This could be justified by the geological nature of these environments, which are probably low in these elements. High levels of trace metals in surface waters analyzed in a mining context are generally attributed to mining activities. In fact, for Mengnjo [25], the substances found in the surface waters of the region are derived from the chemical alteration of mineralized bedrock and gold panning, as surface water is the main transport route. All of the chemical elements monitored occur naturally in rocks, and their presence in surface water is also normal. They are also present in the groundwater surrounding the sites, in varying concentrations in the places where monitoring is required. In fact, given the interconnectedness of these waters, it would not be out of the question to find levels of certain chemical elements that are not recommended for drinking in some wells used by local residents.

Based on the results of our field surveys and chemical analyses, which revealed water concentrations that generally deviated from natural levels of heavy metals, we can confirm our initial hypothesis that gold panning contributes to water pollution. This study allowed us to determine the extent of the elements analyzed and to specify the elements with which these waters are polluted. Among the elements analyzed, we found that Hg, Fe and, to a lesser extent, Pb and As, are at the origin of the pollution.

In short, metals are naturally present in trace amounts in the human body. They are essential for the proper functioning of our organism. For example, we have traces of calcium, potassium, iron, zinc and magnesium.

On the other hand, they can be toxic when present in excessive amounts. For example, cadmium damages the liver; lead causes lead poisoning, which is particularly serious in children; mercury is neurotoxic [22].

Chronic exposure to TMEs often results in fatigue, headaches, sleep disturbances, difficulty concentrating, mental disorders, and digestive problems. TMEs appear to be associated with the development of serious diseases such as multiple sclerosis and neurodegenerative diseases such as Alzheimer's and Parkinson's.

TME damage the respiratory and digestive systems and can cause kidney failure. Heavy metal contamination can have both short- and long-term side effects, damaging systems and organs that cannot always be completely reversed by treatment in cases of prolonged overexposure.

5. Conclusions

In the Central Plateau region, and more specifically in the Kietenga and Fatmatenga areas of the Méguet commune, gold is mined on an artisanal basis, sometimes using chemicals that are harmful to human health and the environment.

Although gold panning contributes to improving the living conditions of gold miners by providing them with substantial income and employment in a context of gradual land degradation, and consequent agricultural yields and insecurity, it is a polluting activity. The clandestine and limited use of mercury and cyanide in the homes of gold miners is well-known, making control very complex. The discharge of these heavy metal-laden waters into the environment is the main anthropogenic source of contamination of surface water and even groundwater.

This study allowed us to make a bibliographic summary of certain environmental problems caused by gold panning in general and its impact on water resources in particular. The analytical synthesis of the laboratory results also revealed the presence of significant levels of mercury in sediments, soils, water resources (ground and surface) and aquatic resources (dams). In addition to the elemental mercury used in the production of the gold-mercury alloy, the population of Méguet is exposed to methylmercury through the consumption of fish contaminated by mercury discharges from ore washing at a nearby dam. This exposure can lead to adverse health effects such as kidney, autoimmune, and neurological disorders, all of which are effects of mercury exposure.

In fact, our analyses show that mercury (Hg) concentrations in all liquid samples and Fe concentrations in surface water exceed standards. Concentrations of arsenic (As) and lead (Pb) in surface water at the site1 exceed WHO limits.

The concentration of these same metals in the water produced by ore washing far exceeds the environmental discharge standards set by mining regulations in Burkina Faso. These high levels are the result of acid attack by the metals which either accompany the gold ore or are added during the treatment process. This solubilization and addition of mercury leaches these elements into the groundwater consumed by the population. This can lead to a number of health problems associated with the ingestion or inhalation of metals.

Analyses of collected soil samples have also shown that gold panning has contributed to the exposure and abnormal expansion of elements in the soil to heavy metals. The practice of gold panning does not leave the physical environment indifferent either. The physical degradation of the environment and the deforestation of trees and shrubs also accompany artisanal gold mining in the Central Plateau. It is with great hope that we believe that the recommendations formulated at the end of this study will make it possible to significantly improve the practice of gold panning in Méguet sites, while preserving the miners' health and the environment in which they live. As part of the implementation and monitoring of these measures, it is equally important that the mining administration, such as the National Agency for the Supervision of Artisanal and Semi Mechanized Mining operations (ANEEMAS), adopts these recommendations.

The presence of the mining administration in gold panning areas should not be limited to the sale of the gold panner's card or the collection of taxes. It must also ensure compliance with health and environmental measures and raise awareness of good environmental practices among gold panners. Over time, this awareness should lead to the adoption of more responsible, environmentally friendly artisanal gold mining practices. In conclusion, we dare to believe that EMAPE has a bright future ahead of it in Burkina Faso.

Conflicts of Interest

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

References

[1] Matallah, M.A.A. (2006) Marché mondial des oléagineux. Master's Thesis, Institut

National Agronomique (INA), Algiers.
http://195.154.40.39/08/08/1485/m_marche-mondial-des-oleagineux114.html

[2] WHO (2017) Environmental and Occupational Health Hazards Associated with Artisanal and Small-Scale Gold Mining.
https://iris.who.int/bitstream/handle/10665/259451/9789242510270-fre.pdf?sequenc

[3] Hirwa, H., Nshimiyimana, F.X., Tuyishime, H. and Shingiro, C. (2019) Impact of Mining Activities on Water Quality Status at Wolfram Mining and Processing (WMP), Burera, Rwanda. *Journal of Materials and Environmental Sciences*, **10**, 1214-1220.
https://jmaterenvironsci.com/Document/vol10/vol10_N12/JMES-2019-10-120-Hirwa.pdf

[4] Cole, M. and Hogarth, R. (2011) Mining Sector Working Paper. Appendix B. Smith School of Enterprise and the Environment (SSEE)-University of Oxford, Oxford.
https://climatechange.gov.rw/fileadmin/user_upload/Mining_Sector_Working_Paper_-_Rwanda_Green_Growth_Strategy.pdf

[5] Nshimiyimana, F.X., El Blidi, S., El Abidi, A., Faciu, M.E., Udahemuka, J.C, Benammi, F., Lazar, G., Soulaymani, A. and Fekhaoui. M. (2016) Groundwater Quality from the El Aarjate Zone (Morocco). *Journal of Materials and Environmental Science*, **7**, 2760-2770.
https://www.jmaterenvironsci.com/Document/vol7/vol7_N8/289-JMES-2266-Nshimiyimana.pdf

[6] Jameel, A. and Sirajudeen, J. (2006) Risk Assessment of Physico-Chemical Contaminants in Groundwater of Pettavaithalai Area, Tiruchirappalli, Tamilnadu-India. *Environmental Monitoring and Assessment*, **123**, 299-312.
https://doi.org/10.1007/s10661-006-9198-5

[7] A & C Black (2006) Dictionary of Agriculture. London.
http://dspace.vnbrims.org:13000/jspui/bitstream/123456789/4578/1/Dictionary%20of%20Agriculture.pdf

[8] Dharmappa, H.B., Sivakumar, M. and Singh, R.N. (2006) Wastewater Characteristics, Management and Reuse in Mining and Mineral Processing Industries. Encyclopedia of Life Support Systems (EOLSS), Vol. 1, 262.
https://www.eolss.net/sample-chapters/c07/e2-14-02-06.pdf

[9] Koryak, M. (1997) Origins and Ecosystem Degradation Impacts of Acid Mine Drainage. United States Army Corps of Engineers, Washington, DC.

[10] Ellis, K.V., White, G. and Warn, A.E. (1989) Surface Water Pollution and Its Control. Macmillan, London, 116.
https://link.springer.com/book/10.1007/978-1-349-09071-6
https://doi.org/10.1007/978-1-349-09071-6

[11] McMenemy, J. (2001) District Fisheries Biologist for the Vermont Department of Fish and Wildlife. Personal Communication, Waterbury, Vermont.

[12] BDO Tunisie Consulting (2018) Initiative pour la Transparence des Industries Extractives Burkina Faso. Tunis.
http://cns.bf/IMG/pdf/rapport_itie-bf_2018_version_finale_signe_30122020.pdf

[13] Kumar, V., Kumar, V. and Bhalla, T.C. (2013) *In vitro* Cyanide Degradation by Serretia Marcescens RL2b. *International Journal of Environment Sciences*, **3**, 1969-1979.

[14] Castaing, C., Billa, M., Milesi, J.P., Thieblemont, D., Le Metour, J., Egal, F., Donzeau, M., *et al.* (2003) Notice Explicatif de La Carte Géologique et Minière à 1/1 000 000e du Burkina Faso. BUMIGEB, Ouagadougou.

[15] Edition, F. (2011) Guidelines for Drinking-Water Quality. *WHO Chronicle*, **38**,

104-108.
https://iris.who.int/bitstream/handle/10665/44584/9789241548151_eng.pdf?sequence=1

[16] Roudier, P. (2004) Technique de réhabilitation des sites et sols pollués. Fiches de synthèse. Techniques de L'Ingénieur, Saint-Denis.
https://doi.org/10.51257/a-v1-g2670

[17] Mara, D. (2004) Domestic Wastewater Treatment in Developing Countries. Earth scan, London, 310 pp.
https://www.pseau.org/outils/ouvrages/earthscan_ltd_domestic_wastewater_treatment_in_developing_countries_2003.pdf

[18] Yapi, Y.H.A., Dongui, B.K., Trokourey, A., Barima, Y.S.S., Essis, Y. and Etheba, P. (2014) Evaluation de la pollution métallique des eaux souterraines et de surface dans un environnement minier aurifère à Hiré (Côte d'Ivoire). *International Journal of Biological and Chemical Sciences*, **8**, 1281-1289.
https://doi.org/10.4314/ijbcs.v8i3.41

[19] Mboudou, G., Fozao, K., Njoh, O. and Agyingi, C. (2017) Characterization of Alluvial Gold Bearing Sediments of Betare Oya District-East Cameroon, Implication for Gold Exploration and Recovery. *Open Journal of Geology*, **7**, 1724-1738.
https://doi.org/10.4236/ojg.2017.711115

[20] Foucault, Y., Durand, M.-J., Tack, K., Schreck, E., Geret, F., *et al.* (2013) Use of Ecotoxicity Test and Ecoscores to Improve the Management of Polluted Soils: Case of a Secondary Lead Smelter Plant. *Journal of Hazardous Materials*, **246**-**247**, 291-299. https://doi.org/10.1016/j.jhazmat.2012.12.042

[21] Rakotondrabe, F., Ngoupayou, J., Mfonka, Z., Rasolomanana, E., Nyangono Abolo, A., Asone, B., Ako Ako, A. and Rakotondrabe, M. (2017) Assessment of Surface Water Quality of Bétaré-Oya Gold Mining Area (East-Cameroon) *Journal of Water Resource and Protection*, **9**, 960-984. https://doi.org/10.4236/jwarp.2017.98064

[22] MiqueL, G. (2001) Rapport sur les Effets des métaux lourds sur l'environnement et la santé. Office parlementaire d'évaluation des choix scientifiques et technologiques, 365 pp. https://www.senat.fr/rap/l00-261/l00-2611.pdf

[23] Kouassi, K.F. (2016) Risques environnementaux et sanitaires liés à l'utilisation des produits chimiques dans l'orpaillage: cas du cyanure et du mercure sur le site de Galgouli. Master's Thesis, Institut International d'Ingénierie de l'Eau et de l' Environnement (2iE), Ouagadougou.
http://documentation.2ie-edu.org/cdi2ie/opac_css/doc_num.php?explnum_id=2980

[24] Mahamane, A.A. and Guel, B. (2015) Caractérisations physico-chimiques des eaux souterraines de la localité de Yamtenga (Burkina Faso). *International Journal of Biological and Chemical Sciences*, **9**, 517-533. http://ajol.info/index.php/ijbcs
https://doi.org/10.4314/ijbcs.v9i1.44

[25] Mengnjo, J. (2017) Seasonal Hydrological Inputs of Major Ions and Trace Metal Composition in Streams Draining the Mineralized Lom Basin, East Cameroon: Basis for Environmental Studies. *Earth Systems and Environment*, **1**, Article No. 22.
https://doi.org/10.1007/s41748-017-0026-6