Gold rush in West Africa: ecological and health impacts in the Bougouriba River sub-basin, Burkina Faso

Corrida do ouro na África Ocidental: impactos ecológicos e na saúde na sub-bacia do Rio Bougouriba, Burkina Faso

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ABSTRACT

In a context where artisanal gold mining is expanding rapidly in West Africa, particularly in Burkina Faso, the debate focuses on the positive and negative impacts of this activity on the environment and human beings. This article analyses the environmental changes, the ecological crisis, and the impacts on human health caused by gold panning in the Bougouriba River catchment area in the southwest of the country. To achieve this, a methodology was adopted that combined the collection, processing, and geospatial analysis of data collected from 100 people chosen at random from the various gold panning sites. The results show that the tools and chemicals used by gold miners cause almost irreversible damage to natural resources and create a risk of disease for the miners themselves, people living in the surrounding villages, and animals. Despite the perceptible harmful effects, gold panning is seen as a 'necessary evil' in this basin. The study suggests that the sector needs to be better supervised to reduce the negative impact on the environment and the health of gold miners and neighbouring communities.

Keywords: Gold rush. Bougouriba River sub-basin. Ecological crisis. Environmental health impacts.

RESUMO

Num contexto em que a extração artesanal de ouro se expande rapidamente na África Ocidental, e particularmente em Burkina Faso, o debate centra-se nos impactos positivos e negativos dessa atividade no ambiente e nos seres humanos. Este artigo analisa as alterações ambientais, a crise ecológica e os impactos na saúde humana causados pela extração de ouro na bacia hidrográfica do Rio Bougouriba, no sudoeste do país. Para tal, foi adotada uma metodologia que combinou a coleta, o tratamento e a análise geoespacial de dados de 100 pessoas escolhidas aleatoriamente nos vários locais de garimpo. Os resultados mostram que as ferramentas e os produtos químicos utilizados pelos garimpeiros causam danos quase irreversíveis aos recursos naturais e criam riscos de doenças para os próprios garimpeiros, para as pessoas que vivem nas aldeias vizinhas e para os animais. Apesar dos efeitos nocivos perceptíveis, a garimpagem de ouro é vista como um "mal necessário" nessa bacia. O estudo sugere que o setor deve ser mais bem supervisionado, a fim de reduzir o impacto negativo no ambiente e na saúde dos mineiros e das comunidades vizinhas

Palavras-chave: *Corrida ao ouro. Sub-bacia do Rio Bougouriba. Crise ecológica. Impactos na saúde ambiental.*

1 INTRODUCTION

In different parts of the world, gold mining activity plays a great role in enhancing livelihoods (Mencho, 2022; Ontoyin; Agyemang, 2014). According to this author, it is estimated that thirteen million households were directly involved in mining operations around the world. Casso-Hartmann *et al*. (2022) and Vergara-Murillo *et al*. (2022) note that artisanal and small-scale gold mining (ASGM) directly and indirectly employs more than 100 million people in over 70 countries around the world. An estimated 10–15 million people work directly on ASGM activities worldwide, out of which 4–5 million are women and children. Macro-scale mining operations provide sources of employment, income, and foreign currency (Mencho, 2022). This is due to the increasing consumption of gold, as well as other mining raw materials throughout the globe (Mencho, 2022). Even though, mining simulates vital economic growth and development, unattainable mining operations can harm the environment. However illegal mining activities blatantly violate international laws (Basta *et al*., 2023; McMillen, 2024). According to Casso-Hartmann (2022), South America is the largest emitter of mercury pollution from ASGM (53 %), followed by East and Southeast Asia (36 %) and Sub-Saharan Africa (8 %).

In West African countries, mining, whether industrial or artisanal, has been booming since the cost of gold rose in the early 2000s. In this part of the continent, gold mining is practised in two forms: the first, which is older, is artisanal and practised by local people, while the second, which is more modern and recent, is industrial or semi-industrial and practised by large foreign mining companies (Kiemtoré, 2012). Although the Sahelian zone experienced a boom in mining just after Western colonization in 1960, it was the great droughts of the 1970s that forced people looking for alternatives to survive to mine the riverbeds and gradually dig tunnels in search of gold (Soma *et al*., 2021). In rural areas, artisanal gold mining is now an inescapable reality and a source of income on par with agriculture and livestock farming (Affessi *et al*., 2016). According to these authors, the actions of gold miners, in their quest for well-being, are undoubtedly causing social and territorial changes with harmful environmental consequences.

In Burkina Faso, several analyses have been carried out in recent years on the actual contribution of gold panning to gold production in general. According to Kiemtoré (2012), artisanal gold mining began between the 15th and 18th centuries. However, it was from the 2000s onwards that this gold mining activity exploded, impacting the economy of the people and the country (Kaboré, 2014). Indeed, the gold sector is an essential component in the country's economic and social development with an estimated 30 metric tons per year (National Institute of Statistics and Demography, INSD, 2017, Sollazzo, 2018). Gold mining's share of Gross Domestic Product (GDP) is growing and is estimated to reach 12.2% in 2023. Gold also accounts for almost 43% of the country's exports and has brought in nearly $336 346 800 a year since 2010, making it the country's leading source of foreign currency, ahead of cotton (Konkobo; Sawadogo, 2020). According to the Ministry of Mines and Quarries, the gold panning sector has directly and indirectly employed between 1 and 1.2 million people, representing 10% of the working population in 2018. According to the Department of Artisanal and Semi-Mechanised Mining (Roamba, 2014, p.1), there are more than 800 gold-panning sites in Burkina Faso, of which only 217 have a mining license.

Artisanal mining, particularly of gold, is therefore seen as an alternative source of poverty alleviation and direct and indirect job creation, such as catering and trade on gold panning sites. However, at all levels, the negative effects of this poorly controlled artisanal activity on the environment and people's health are perceptible, even if they are not regularly assessed. There are many associated factors that, insidiously or explicitly, contribute to the almost irreversible degradation of the environment and the exposure of populations to health risks due to soil, water, and air pollution, thus creating an ecological crisis (Ki *et al*., 2013).

The Bougouriba sub-catchment, which contains one of the country's largest rivers (2,774 km) in the south-western part of the country, as well as numerous classified forests and towns, are exposed to

pollution and resource degradation as a result of gold-panning activities that have been taking place there for the past twenty years. This situation can be attributed to some unsuitable practices, including the use of dangerous chemicals. However, people living in the river's sub-basin use the water, plant resources, and soil for a variety of uses. While artisanal gold mining in the river's sub-basin may be seen as a lucrative activity because of the great enthusiasm it arouses among gold miners, it has many perceptible harmful effects on natural resources and human health.

Given this situation, this study raises the following main question: What are the environmental changes and health problems caused by gold panning in the Bougouriba River sub-catchment? The main objective of the study is therefore to analyze the various changes in natural resources due to gold panning in the river's sub-catchment area and the risks to the health of gold panners and local populations. Specifically, the aim is to identify gold panning practices in the Bougouriba River sub-catchment, describe the environmental changes brought about by gold panning, and understand the vulnerability, health risks, and perceptions of stakeholders concerning artisanal gold panning.

The article is structured around the following key points: location of the study area, analysis method, and tools, results of the study, and discussion.

2 METHODOLOGY

2.1 DESCRIPTION OF THE STUDY AREA

The Bougouriba river sub-basin is part of the Mouhoun River Watershed, which covers all or part of six regions of Burkina Faso: the *Boucle du Mouhoun*, the Cascades, the *Hauts Bassins*, the *Centre-Ouest*, the *North* and the *Southwest* (Soma *et al*., 2021). This sub-basin covers an area of 1,52695 square kilometres, with several rivers, the most important of which is the Bougouriba (the province bears its name), the *Poni*, the *Bambassou*, and the *Koulbi*. The Bougouriba sub-basin is drained by the Bougouriba River, the longest and most important watercourse in the South-West region, which flows for 95 km at a rate of 147 m3/s. It rises in the sandstone of the Cascades region at an altitude of 500 m and flows towards the centre-west of the *Hauts-Bassins* region on a very gentle gradient, making a bend in the Mou forest and receiving the water from its effluents, and heads south to penetrate the territory of Ghana's republic before flowing into the Atlantic Ocean (Ministry of Economic and Development, 2006). In addition, the Bougouriba River sub-basin covers a dozen classified forests and partial reserves, 4 urban agglomerations, 22 administrative villages, and 68 farming hamlets (Geographical Institute of Burkina Faso, 2012). The figure below shows the location of the sub-basin within Burkina Faso.

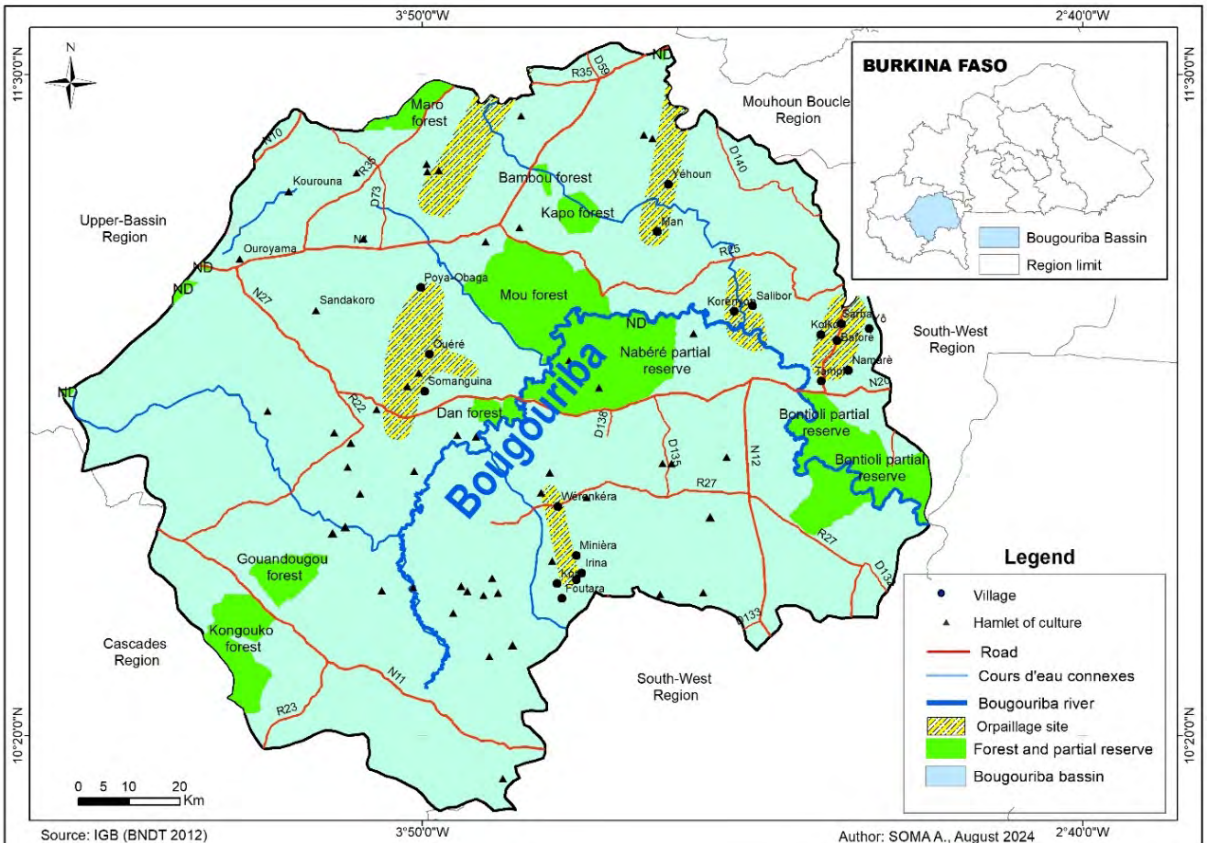

Figure 1 – Location and configuration of the study area

Source: Geographical Institute of Burkina (2012), Soma (2024)

2.2 METHODOLOGICAL APPROACH

To carry out the analysis more effectively, a traditional methodological approach has been followed. It consisted of collecting primary and secondary data on the sub-catchment, from gold miners, people living along the river, local authorities and the technical services of the Mouhoun water agency, the environment, and health and hygiene service workers. Secondary data were collected through documentary research in various libraries and online search sites. Primary data was collected successively in March 2022, June 2023 and September 2024 using questionnaires, individual interviews through interview guides, and site observations. The questionnaire was designed using KoboToolBox software. The demographic sample used to collect the necessary primary data was 500 gold miners (Table 1) out of an estimated 5000.

Table 1 – Breakdown by locality of stakeholders surveyed

Localities	*Headcount*	*Men*	*Women*	*Children*
Namaré	50	30	15	5
Baforé	52	32	15	5
Ouéré	55	25	17	13
Somanguina	55	35	15	5
Salibor	40	21	14	5
Foutara	60	35	15	10
Miniera	42	15	15	12

Localities	Headcount	Men	Women	Children
Irina	45	17	15	13
Werankera	55	30	15	10
Man	46	22	14	10
Total	**500**	**262**	**150**	**88**

Source: Soma (March 2022, June 2023 and September 2024)

This sample was chosen randomly to collect the perceptions of those involved about the practice of gold panning and the risks to their health and the environment. Men (between 20 and 60 years old) represent 52,4% of the population surveyed. Children (between 8 and 16 years old) surveyed represent 17,6% of the population. Individual interviews were carried out with resource people to gain a better understanding of the institutional and regulatory provisions governing the management of gold panning and the risks to people's health and the environment. The participants included five local authorities, two managers from the technical services of the Mouhoun water agency, two environmental managers, and two health officers.

MS Excel 2016 ArcGIS 10.4 software has been used for graphical, statistical, and cartographic processing of the data collected for the presentation of the study area and the analysis of gold panning sites.

In sum, the methodology used for this study complies with the standards of ethical considerations in research expected by all parties involved in the act of publication of this article.

3 RESULTS OF STUDY

The methodological approach followed produced results presented under three main headings: the methods and practices adopted, the environmental and biophysical changes brought about by gold panning and the health risks, and the perceptions of those involved in artisanal gold mining.

3.1 GOLD PANNING METHODS AND PRACTICES IN THE SUB-BASIN

Several methods and techniques are used by gold miners for artisanal gold extraction.

3.1.1 METHODS AND ORGANISATION OF ARTISANAL GOLD MINING ON THE SITES

Two main methods of artisanal gold mining were observed on the various sites visited. These are open-pit mining and underground mining. Open-pit mining, also known as alluvial or open-cut mining, consists of removing all the barren ground covering the gold to be mined, which allows easy access to the ore. It is done by stripping the overburden and then extracting the gold. This method is generally used when the gold is relatively close to the earth's surface. At this level, the gold-bearing alluvial deposits are clayey and sandy, more or less rich in pebbles. There are therefore two phases to this type of mining: stripping and ore extraction. Underground gold mining is used for deposits with mineralization at a depth of more than ten meters. To ensure the health and safety of gold miners, this method requires careful dewatering, lighting, ventilation, and lining of the galleries dug, as noted by Kaboré (2014) and Soma *et al*. (2021).

Moreover, artisanal gold mining is a strenuous activity that requires good organization if it aims to be exploited collectively. Thus, on the gold panning sites created along the banks of the Bougouriba River, there are individual practices (especially on the eluvial and alluvial sites along the river), the family

form of exploitation by a group of gold panners made up of members of the same family or from the same village, the associative form in groups of gold panners either by region or by private organization of gold panners, or in the form of gold panners' cooperatives.

3.1.2 THE VARIOUS STAGES OF ARTISANAL GOLD MINING ON THE SITES

Gold rush in the Bougouriba River sub-basin follows the traditional approach and methods used by gold miners on any gold panning site. It essentially comprises seven stages: prospecting, sinking, ore testing, crushing, grinding or milling, washing, refining, cyanidation, and refining-cyanidation-recovery of the gold (Kaboré, 2014; Soma *et al*., 2021).

- Prospecting or site identification

This is the very first stage in gold extraction. In the Bougouriba River sub-basin, prospecting is most often carried out by experienced former gold miners walking around and observing the area. The aim is to find an indicator of the presence of gold on the site. It is generally done intuitively or using ore detection equipment, supported by tools such as pickaxes and shovels to dig and clear the rock in the direction of the gold vein.

- Sinking

This involves digging cavities to reach the gold ore. Depending on the ore bed, the cavity can be vertical or horizontal, varying in size from 1.5x1 m to 3x2 m, and in depth from 4 to 20 meters. Some craters reach the water table. To prevent landslides and consolidate the walls of the excavations, support structures are built using solid tree trunks cut from classified forests, averaging 20 trunks per meter of depth.

The sinking equipment consists of shovels, picks, hammers, picks, bags, ropes, machetes, and battery-operated torches to light the diggers inside the hole. Because of the low resistance of the soil, dynamites are rarely used on the sites. The extracted ore is taken outside in sacks and transported to the stockpile by cart. Sinking is the most arduous stage in artisanal gold mining in the river sub-basin.

- Testing the mineral

The third stage involves testing the ore to check whether it contains gold. If the test is positive, the ore is recovered for the rest of the processing chain; if not, it is deposited, i.e. left on the ground. The equipment consists of a mortar and a metal pestle to break up the rock, a plate, and a bowl to pre-wash the ore and assess its gold content.

- Crushing

This fourth stage consists of reducing the size of the extracted ore to a small size using a hammer, an anvil (made of iron, granite, or quartz), and a sack knot to avoid splashing particles and protect the fingers.

- Grinding or milling

This fifth stage consists of reducing the ore entirely to a powder known as flour. The ore is ground in mills using fuel and then dried to reduce the moisture content.

- Washing

The sixth stage involves washing the ground floor. The flour is placed in 50 kg sacks, mixed with water, and washed on a ramp. The washing process is meticulous: first, a small quantity of the mixture is

placed in a sieve, and then water is poured to liquefy the flour. The ramp is covered with a carpet that gravimetrically traps the gold, and the light material is drawn down into a hole, as shown in the following photograph. The carpet is rinsed in a basin of water to remove the gold.

Figure 2 – Washing ore at the Bontcholi gold mine

Source: Image credit, Bancé A. L. (2018)

After washing, the light material recovered from the hole is left to settle, and then the sludge is recovered for further processing. The concentrate with added mercury is rubbed with a bare hand to obtain the gold-mercury amalgam.

- Refining, cyanidation, or gold recovery

This is the last and most dangerous stage in artisanal gold extraction. The first sub-stage involves refining. This involves heating the resulting gold-mercury amalgam with a blowtorch over an empty gas cylinder to remove the mercury by evaporation and dispose of the gold. This technique is called mercury amalgamation. The second sub-step is cyanidation. This process involves separating the gold by immersing the ore in an alkaline cyanide bath (using gloves) and then recovering the gold for weighing.

3.1.3 WORK TOOLS

Gold miners use a variety of tools to extract gold from sites in the Bougouriba River sub-watershed. Despite the ban on the use of chemicals in gold panning throughout Burkina Faso, gold miners continue to use them on a massive scale.

Various pollutants are used on all the gold panning sites in the study area, including mercury, cyanide salts, sulfuric and nitric acids. Detergents, gas cylinders, hydrocarbons, and battery components are also pollutants used in the activity. Mercury is the most toxic chemical of the pollutants used on sites to amalgamate gold. Cyanide, which is used to capture the gold in the ore, is also volatile and very harmful to health, especially when combined with sulfuric and nitric acid. Detergents are used to rid the ore of oils from the crushing and grinding mills. Hydrocarbons are used at various sites to run work equipment such as motor pumps, dynamites, mills, and motorbikes. Torch batteries are used to light shafts and galleries. They are essential for all sinking work because of the darkness in the shafts.

3.2 ENVIRONMENTAL AND BIOPHYSICAL CHANGES CAUSED BY GOLD PANNING

Artisanal gold mining in the Bougouriba River sub-basin causes several environmental problems. The negative effects are perceptible on water resources, plant cover, wildlife, air quality, and soil.

3.2.1 EFFECTS ON WATER RESOURCES

Water is used in almost every stage of artisanal gold mining. The washing and mercury extraction stages are the most water-intensive. According to the surveys carried out, for example, it takes around 200 litres of water to wash a 50-kilogram sack of ore powder during gold extraction. Furthermore, the use of chemicals such as cyanide and mercury dangerously compromises the health of water resources in the river's sub-basin. These chemicals, which are lost through amalgamation, as well as the production of solid and liquid waste, find their way into drainage systems, causing progressive contamination of the river, its tributaries, and other water reservoirs, as illustrated in this picture.

Figure 3 – Pollution and silting of the Bougouriba River

Source: Image credit, J K, Sidwaya (2023).

Also, the dumping of used batteries inside shafts during sinking contributes to the pollution of groundwater resources. In addition, even if water consumption is not significant for cooling the mill engines after crushing and grinding the ore, this practice near or in the major river bed contributes to the discharge of used oils and hydrocarbons, which pollutes water resources that are heavily laden with suspended matter and thus increases their turbidity. In addition to all these activities, the gold miners themselves have a daily need for water for drinking, eating, washing, and showering, all of which add to the pressure on the Bougouriba River.

In short, the effects of gold panning on water are the depletion and pollution of surface and groundwater in the Bougouriba River sub-basin.

3.2.2 EFFECTS ON PLANT COVER AND WILDLIFE

The installation of gold miners necessarily requires clearing, cutting of wood and straw for mining, construction of houses, huts, sheds, chairs or makeshift beds for living or trading purposes, and firewood for cooking meals. The plant cover, particularly in classified forests and savannah, is thus exposed to unprecedented deforestation, despite the control and dissuasion measures taken by the technical services in charge of the environment. According to the surveys, to support shafts and galleries during the sinking, for example, 15 tree trunks are cut for every meter of depth, i.e. 400 to 500 tree trunks for a 30 meters shaft, to serve as a ladder for descending and consolidating the walls to prevent landslides. All around the sites visited, nature has been stripped of its plant cover, as this photograph shows.

Figure 4 – Unauthorised installation of gold miners in the Nabéré classified forestr

Source: Mouhoun Water Agency (2018).

In terms of wildlife, gold panning and related activities contribute to the migration of certain species due to deforestation, the destruction of ecological niches, and deafening and stressful noise emissions for animals. The asphyxiation of the aquatic environment resulting from the increase in the concentration of suspended solids (dyes) in watercourses receiving ore processing sludge by cyanide and mercury is also a reality in the various watercourses of the Bougouriba River sub-basin.

3.2.3 EFFECTS ON SOIL AND AGRICULTURAL FIELDS

Mineral prospecting and extraction inevitably degrade soil quality. Artisanal mining operations effectively degrade arable land. Turning over the soil and piling up the spoil also destroys the arable land used by farmers in the surrounding villages. Shafts and galleries abandoned after mining expose the soil to gullying, leaching, and intensive erosion. These phenomena are virtually irreversible and can become catastrophic, creating an ecological crisis.

In addition, pollutant discharges are affecting market gardens and agricultural fields, reducing their fertility and hence their productivity, according to 100% of those surveyed.

3.2.4 EFFECTS ON THE AIR

Air pollution comes from mining dust (ore crushing, alluvial ore winnowing) and gas emissions from the use of chemicals, particularly mercury vapour during amalgam burning. This is very noticeable at the various sites visited. The air is also polluted by the decomposition of solid and liquid waste generated by gold panning activities and released into the environment without any treatment measures.

Another perverse effect is the faecal peril caused by the fact that gold miners (60% of those surveyed) defecate in the wild, either for lack of infrastructure or for pleasure. This practice contributes to air pollution by dust, which is particularly harmful to health.

Noise pollution from water pumping and ore sinking and washing equipment also contributes to the deterioration in the quality of the living environment for local residents.

In short, solid, liquid, gaseous, and noise emissions from artisanal gold mining activities in the Bougouriba River sub-watershed have harmful consequences for the various components of the environment. They undoubtedly expose various categories of stakeholders to various health risks.

3.3 HEALTH RISKS AND PERCEPTIONS OF ARTISANAL GOLD MINERS

Artisanal gold mining in the Bougouriba River sub-catchment presents health risks. However, the activity is perceived differently by the stakeholders.

3.3.1 HEALTH RISKS AND ASSOCIATED DISEASES

Gold panning exposes its actors and other categories of people to various health risks due to the precarious living and working conditions on the sites (Figure 5). Depending on the stage of the operation, a distinction is made between the risks incurred by diggers or smelters, mechanical processors, washers and refiners, and those responsible for cyanidation. However, it should be emphasised that the various risks are also incurred by other people living on the gold panning sites or in the neighbouring villages.

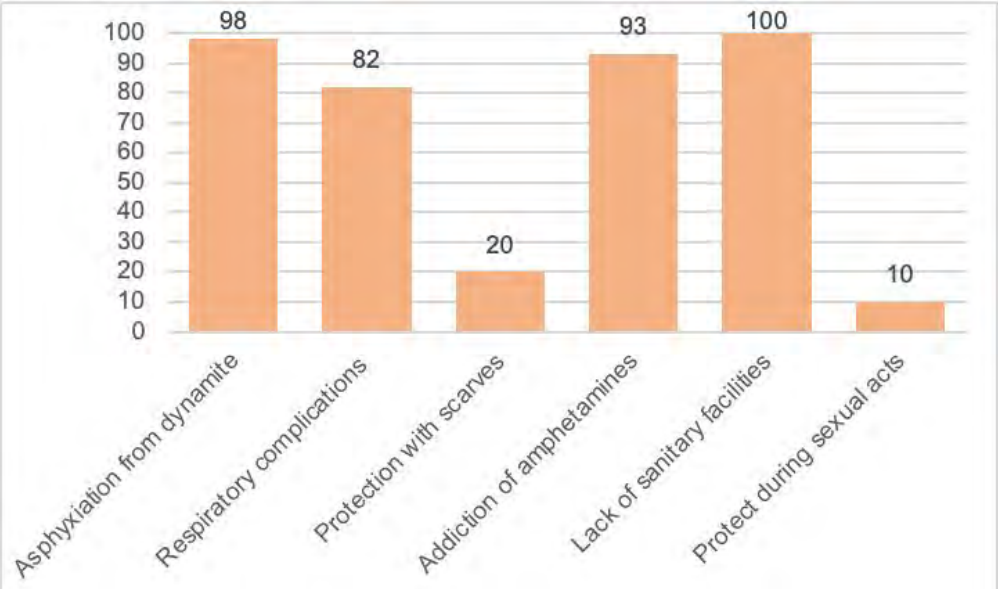

Figure 5 – Health risks and associated diseases according to actors surveyed

Source: Soma (September 2024).

Because of the methods used to extract gold, miners are exposed to major physical hazards, in particular the risk of asphyxiation from motor-driven pumps or dynamite, and the risk of collapsing shafts and galleries, which can lead to death. The use of motor-driven pumps and dynamite releases toxic gases such as carbon dioxide and nitrogen, which reduce the quality of the air in the wells. They are also exposed to skin absorption of harmful rock constituents, ore dust, and reptile bites in shafts and galleries. These hazards were experienced at least once by 98% of the people surveyed.

Like the miners, the majority of mechanical ore processors or preparers (crushers, grinders, millers) work without protective equipment. Of the 50 preparers surveyed, only 12, or 24%, protect themselves with goggles or a muffler when crushing or grinding ore. However, the dust raised during these operations and the gas produced by the mercury are inhaled directly by the workers, causing respiratory complications over time. This was noted by 82% of those surveyed. They are also subject to injuries from hammering or being thrown by crushed ore. Stone throwing, although prevented by the use of sack knots, often results in injuries to limbs and eyes. They are also continuously exposed to smoke from crushing and grinding machinery.

For washers and refiners, the main risk is skin and oral absorption of mercury during gold-mercury amalgamation. Before being burnt with a blowtorch, the amalgam is pressed with a handkerchief to remove the water it contains. This water, which still contains mercury particles, is unfortunately sucked up by some washers, resulting in oral absorption of the mercury. The mixture also produces dust, which is breathed in by those involved. The rate of protection, often with makeshift means such as scarves, also remains low in this stage of ore processing, at 20% of those surveyed.

Once the ore has been extracted, the aggregates are treated with cyanide to extract the fine gold particles. Unfortunately, those in charge of cyanidation often handle the chemicals at this stage without protection against toxic gases and hydrocyanic, sulfuric, and nitric liquids. Similarly, some operators enter the tanks containing cyanide to extract gold-enriched zinc, which exposes them to depigmentation and skin absorption of the chemicals. These lesions have been observed in some people in the field.

In fact, 93% of gold miners, especially the ‘excavators, claim to use amphetamines ‘to increase their physical strength and endurance, and to give them the courage to face the darkness and even death in the holes’. These products, commonly referred to by gold miners as ‘missiles’, are for the most part doping agents whose regular use leads to dependence, which is one of the causes of behavioural problems among many gold miners.

In addition to these various risks incurred directly by gold miners, there are other risks referred to as domino effects on the gold mining sites and in the surrounding villages. The fact that gold miners, the majority of whom are illiterate, have no control over chemical mixtures and reactions is often the cause of explosions and fires, endangering the lives of people on the sites. This was the case in February 2022, when a large explosion occurred in the market square at the Gomgombiro gold panning site in the locality of Gbomblora, killing more than 60 people. In addition, the storage of mercury balls in makeshift sheds, under which women usually rest with their children, exposes the latter to danger. Children sometimes accidentally handle the balls within their reach, exposing them to mercury absorption through the skin and nose. Women may also use the basins used for gold-mercury amalgamation for washing up or doing the laundry. This practice also leads to accidental oral and dermal absorption of mercury. Similarly, the risk associated with the use of water from streams or wells for cooking or drinking is noted at the sites. At most of the sites, the problem of drinking water remains crucial, forcing people to consume contaminated water. This is undoubtedly at the root of certain pathologies, as the water is infected by microbiological and physico-chemical organisms and metallic elements. What's more, the stagnation of treatment water is also a breeding ground for mosquito larvae, vectors of diseases such as malaria and yellow fever.

Other actors, such as buyers and resellers of the metal who require assistance in refining the extracted gold 'to avoid theft', find themselves exposed to the mercury vapour that escapes because they are unprotected. Similarly, the inhabitants of the surrounding villages are exposed to the harmful effects of cyanide and mercury left in the environment without prior treatment. Surface and groundwater, soil, and crops for human consumption are all exposed to pollution and degradation, reducing the productivity of fields and market gardens.

In short, all this risky behaviour is a source of disease for both gold miners and the local population. The extent of the risk varies according to the activity and the degree of intervention in the various stages of gold extraction and exposure, depending on proximity to the sites. The major diseases commonly encountered on the various gold panning sites in the Bougouriba River sub-watershed are diverse. They have been grouped into three (03) categories. These are diseases caused directly by gold panning, diseases linked to living conditions, and behavioural diseases.

100% of those surveyed said that the illnesses caused directly by gold panning were traumatic injuries, acute respiratory infections, and skin lesions. Tiredness, headaches, eye aches, backaches, etc. are also reported among gold panners. This is linked to the endurance of their activity and the inhalation of dust and chemicals. According to 95% of those surveyed, illnesses linked to living conditions are mainly due to the lack of sanitary facilities, drinking water, the quality of food, the nature of the habitat, and the use of amphetamines. Digestive disorders (bloody and non-bloody diarrhoea, parasitosis, gastritis, ulcers, etc.) caused by bacteria, viruses, or parasites living most often in contaminated water, and malaria, are the most common illnesses. And for 18% of those surveyed behavioral illnesses result from the different attitudes that gold miners have in their daily activities. They are generally encouraged by the consumption of amphetamines, adulterated alcohol, and drugs. The main causes are sexually transmitted infections (STIs) and AIDS. In almost all the sites, prostitution is a fact of life. Field visits revealed the presence of young girls commonly known as 'sex workers' or 'joy girls' on the sites. The sexual disorder of the gold miners and these young girls, often under the influence of stimulants, facilitates the spread of STIs and AIDS. In fact, out of 20 people who gave their opinion on this practice, 10 said they did not protect themselves during sex. This option is often justified by the fact that 'it's good luck once you're in the hole looking for gold' or 'to get money quickly, it's better to become a gold digger's mistress'. According to the head nurse at the Health and Social Promotion Centre (CSPS) in the village of Djakaribougou, 20 cases of HIV/AIDS were recorded in 2021, the victims of which come from gold panning sites.

In addition, faecal peril was noted as a factor in behavioural illnesses. It appears that sanitary conditions are not a priority for some gold miners, for whom 'it's enough to have a hidden place in the wild to relieve themselves and get on with their work'.

3.3.2 STAKEHOLDER PERCEPTIONS OF ARTISANAL GOLD MINING

Artisanal gold mining in the Bougouriba River sub-catchment is perceived differently by stakeholders (Figure 6).

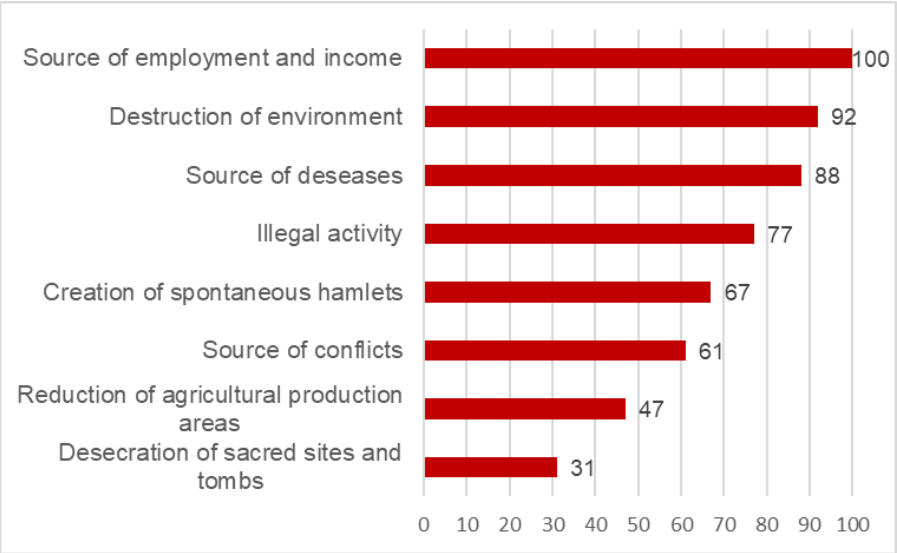

Figure 6 – Stakeholder perceptions of artisanal gold mining

Source: Soma (September 2024).

For 100% of the gold miners surveyed, this activity is a source of employment and income, and thus a means of combating unemployment and poverty. It has enabled many people to build private infrastructure, including luxury homes, hostels, restaurants, schools, shops, and so on. A. S., who has lived on the Kapo site since 2016, said:

> 'Thanks to gold panning, I've been able to build houses and shops in the village, of Ouagadougou. With this activity, I take care of my two wives and my ten children, one of whom is away studying. So I can say that it's a very profitable business'.

However, some gold miners are aware of the negative effects of their activities on the environment and their health: '*We are well aware that our activity destroys the forests, the water in the marshes, the river, and the soil, but we have no choice. We have to feed our families*' according to K. A.

For the local authorities, gold panning in the Bougouriba River sub-basin is having harmful consequences and threatening the survival of natural resources. According to the Mayor of the rural commune of Gbomblora for instance, gold-panning activities have made the water in the river and other related watercourses murky and reddish. He added that cyanide pits created without respect for standards and controls are exposing groundwater to underground pollution, and this has been going on for years without anything being done to stop these practices.

According to the technical services for the environment and water, 'the largest watercourse in south-west Burkina Faso, as well as the classified forests in the river's sub-catchment area, are threatened with pollution as a result of gold panning'. Indeed, 'following the first rains of 2020, we have witnessed a fish kill in the river', said the Chief Inspector of Water and Forests. 'We called on people not to eat these fish, but unfortunately, they were already being sold on the market,' he lamented. He added that species such as crocodiles and certain rare varieties of fish such as clarias and eels, no longer able to live in this uncomfortable environment, are disappearing or dying out. In addition, according to the High Commissioner for Bougouriba province, the supply of drinking water to the population by the National Office for Water and Sanitation has been disrupted because of suspected pollution of the river. According to him, 'in connection with the processing of ore along the Bougouriba River, the office had to take these measures, as it did not have the special equipment needed for treatment in the event of proven cyanide contamination'.

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For the health workers interviewed, all the abnormal or risky practices and health problems encountered on the sites make the gold miners themselves and the local populations vulnerable and expose them to various diseases.

In sum, the gold rush and mining activities are seen as a "necessary evil" supported by both state and municipal authorities as by the population. Indeed, unable to offer decent employment to all young people, the State is obliged to authorise the practice of gold panning, despite the existence of regulations governing the sector. Gold panners take advantage of this lax attitude on the part of the government and local authorities to rush into mining sites, which they exploit in an uncontrolled manner, with harmful consequences for the environment and human health. The conclusion is that this "necessary evil" of gold panning benefits the miners more than the government and local communities.

4 DISCUSSION

Various studies have documented the impacts of mining on the environment and population health. Some conclude that ASGM miners and nearby communities are often directly and indirectly exposed to dangerous substances such as mercury and other highly hazardous pollutants associated with the mining activities. Others address the harmful effects of mercury in soils, macroinvertebrates, fish, and humans.

The results of this present study are similar to those carried out by other authors in a critical and in-depth manner. While artisanal gold mining in the Bougouriba River sub-basin may appear to be an income-generating activity, given the great enthusiasm for it, it has many negative effects, both biophysical and especially on human health. This is demonstrated by Affessi *et al*. (2016), Casso-Hartmann *et al*. (2022), Cordoba-Tovar *et al*. (2023), Goh (2016), Martins Filho *et al*. (2023), and Mencho (2022) who note that although gold panning contributes to socio-economic development, it has harmful effects on the environment and the health of the miners themselves and other stakeholders, due to the dangerous methods and chemicals used. For instance, Vergara-Murillo *et al*. (2022) mention that recent studies in a Colombian Artisanal and Small-Scale Gold Mining Community, have shown that mercury is a powerful neurotoxic and induces serious health effects, such as irreversible neurological disorders, damage to the bone system, teratogenicity, oxidative stress, hormonal alterations, kidney injury, hearing loss, endocrine effects, infertility, menstrual alterations, spontaneous abortions, and other adverse health conditions. In Brazil, Ellwanger (2023) notes that indigenous peoples are currently suffering from similar health problems due to mercury contamination linked to illegal gold mining activities in the Amazon from 2010 to 2020. Kaboré (2014) and Soma *et al*. (2021) also point out that the tools used for gold panning (hammers, pickaxes, crowbars, shovels, wooden or rope ladders, buckets, calabashes, plastic or jute bags) are rudimentary and a source of physical health risks for the miners.

In terms of methods and practices, the study notes that artisanal gold mining in the river sub-basin follows a traditional approach and methods used by gold miners at all sites. It essentially comprises the following stages: prospecting, sinking, ore testing, crushing, grinding or milling, washing, refining, cyanidation, and refining-cyanidation-recovery of the gold using two main mining methods: open-pit mining and underground mining. These methods and practices are also described by authors such as Affessi *et al*. (2016), Kaboré (2014), Martins-Filho *et al*. (2023), Ofori *et al*. (2024), Soma *et al*. (2021), and Tilo (2014). For instance, Martins-Filho *et al*. (2023), note that historically, mercury has been used to amalgamate gold particles in the Brazilian Amazon (Malm, 1998), allowing for their easy separation from the ore.

Concerning environmental changes, the study shows that artisanal gold mining in the Bougouriba River sub-basin is causing several disruptions to the environment and the biophysical milieu. The negative effects are perceptible on water resources, plant cover, wildlife, air, and soil quality. This observation is also made by Affessi *et al*. (2016) and Soma *et al*. (2021), who note, for example, that the use of mercury in gold purification and certain chemical particles contained in rock and subsoil tailings lead to sedimentary deposits that pollute aquatic and atmospheric environments. The same analysis is made by the Programme for Forest Investment (PIF, 2017), which points out that the discovery of gold in the village of Siguinoghin, for example, has greatly degraded the plant cover of the National Park of *Deux Balé*, where gold miners illegally cut down hundreds of trees as part of their activities. Kiemtoré (2012) points out that the environmental changes caused by gold panning are reflected in landslides, pollution, and the degradation of natural resources. For Doucouré (2014), gold panning has given rise to problematic development in the Kédougou region in south-western Senegal, leading to a phenomenon of 'multidimensional phagedenism', i.e. the tendency for changes and problems on the social, economic, and environmental levels to spread, develop and worsen. He also notes that the lack of site rehabilitation, backfilling of artisanal mines in particular, contributes to soil degradation and the disfiguration of the natural landscape of gold mining villages (Doucouré, 2014). Martins Filho *et al*. (2023) show that mining activity creates a favourable environment for the breeding and spread of Anopheles mosquito species, as the dredging of ravines generates pools of water that serve as artificial breeding sites in the Brazilian Amazon.

Concerning the risks incurred and associated diseases, it emerges that gold panning exposes its actors and other categories of people to various health risks due to the living and working conditions on the sites. This finding corroborates that of other authors such as Kaboré (2014), who notes that the risks incurred on gold panning sites can be distinguished at three levels: by 'diggers', mechanical processors, washers, and refiners, as well as the risks incurred by cyanidation employees and other actors. According to Roamba (2014), nearly 2/3 of artisanal mine workers in Burkina Faso suffer from symptoms of chronic mercury exposure. The same observation was made by Obase *et al*. (2018), Ouédraogo (2006), Richard *et al*. (2015) and Soma *et al*. (2021), in their study areas.

All these risky behaviours are sources of disease for both gold miners and the local population. These include diseases arising directly from gold panning, diseases linked to living conditions, and behavioural diseases. However, there is no occupational health and safety system in the mining sites and miners are exposed to numerous risks inherent in artisanal gold mining activity, as indicated by Obase *et al*. (2018) in Cameroon.

In terms of the perception of the gold rush, the study reveals that the stakeholders, particularly the gold miners, are unanimous in their view that it is a "necessary evil". All in all, responsibility seems to be shared for the rational exploitation and management of natural resources in the Mouhoun River sub-basin. The authorities seem to blame the gold miners for environmental degradation, while the latter feel they have no support or guidance from the technical services to help them carry out their activities. This observation is in line with the analysis by Soma *et al*. (2021) and Somé (2004), who believe that the social and technical exclusion of gold miners offers little chance of raising awareness and taking collective action against environmental degradation.

In conclusion, the discussion shows that the gold rush and illegal mining activities have significant adverse impacts on society, the economy and the environment directly and indirectly. As a result, it is better for the mining actor and Government to develop strategies to mitigate harmful environmental and health impacts, as suggested also by authors such as Mencho *et al*. (2022) and Ofori *et al*. (2024).

In addition, this study encountered difficulties due to the reluctance of these people to answer the questions, on the one hand, and the poor security situation in the country, especially at the gold-mining sites, on the other. This affected data collection and analysis. Also, the study's methodological approach had its limitations. Indeed, for the analysis of health risks, laboratory analyses of soil, vegetation and water contamination were not carried out, as some authors, such as Cordora-Tovar *et al*. (2023) and Vergara-Murillo *et al*. (2022), have done, to further investigate the results of the study. The study did not also look at conflicts between gold miners and the autochthon population, or between gold miners and farmers. These difficulties and limitations could be capitalised on for future research in the field of illegal mining.

5 CONCLUSION

The study addressed a global issue linked to concerns about the rational exploitation and management of mining resources, particularly gold. It attempted to highlight the contribution of research to the field of sustainability by looking at the illegal exploitation of gold in an anthropised sub-basin.

The mining sector, particularly gold mining, has become an increasingly important part of all countries, particularly Burkina Faso's economy in recent years. Gold miners see it as a “necessary evil”, given the negative and positive effects it generates. However, the negative effects are greater, particularly on the environment and people's health.

Faced with these dichotomous realities (positive and negative aspects) of the gold rush in the Bougouriba River sub-watershed, the potential stakeholders - the gold miners, the municipal authorities, the decentralized technical services of the Government and the local population must work to organize this activity properly to mitigate and prevent the harmful effects on people and the environment leading to an ecological crisis. It is better for the Government to take the lead in developing strategies to mitigate harmful environmental and health impacts. Current national regulations through Law N°036 2015/CNT on the mining code of Burkina Faso of October 29, 2015, provide for gold panning sites to be supervised by national operators who are issued artisanal mining permits by the mining administration. However, there are shortcomings in the application of these regulations. The beneficial effects of mining activity must not lead to lose sight of the serious consequences of such an activity in a vision of sustainable development of the resources of the river's sub-catchment area, which extends beyond the borders of Burkina Faso through the implementation of Sustainable Development Objectives (SDO). So, Gold miners must be made aware of and responsible for the cost of restoring the environment destroyed by gold mining. Capitalizing a methodological approach that is much more focused on the determinants of the gold rush, the responsibility of gold miners and in-depth analysis of the diseases caused by gold panning and related conflicts, are different fields of research to be explored in future studies.

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