INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ORIGINAL ARTICLE

OPEN ACCESS

Received: 14/04/2025

Accepted: 06/06/2025

Published: 29/06/2025

Mining-related Pollution of Water Resources and Local Perceptions of Effects on Natural Ecosystems in the Pô-Nazinga-Sissili Ecological Complex in Burkina Faso

Zonata Ramdé[1]*, **Oumar Kaboré**[2]

1 Ph.D. Geo. Student, Natural Resources Management, Joseph KI-ZERBO University, Ouagadougou, Burkina Faso
2 INERA. CNRST. LDES, Geography, Joseph KI-ZERBO University, Ouagadougou, Burkina Faso

Abstract

Objectives: The aim of this research is to analyze the effects of mining activities, in particular the dispersion of mining pollutants in the water resources. In Burkina Faso, the Pô-Nazinga-Sissili (PONASI) ecological complex, the country's second largest wildlife continuum, covering some 327,000 hectares in the country, is subject to several intrusions from neighboring communities, including mining operators. Therefore, it has become important to study the effects of mining activities on water resources within the complex, in order to mitigate their negative impacts on aquatic ecosystems, and thus contribute to the conservation of biodiversity. **Methods:** The methodological approach combines tools and techniques for data collection, processing and analysis. A total of 18 water samples, carefully collected downstream of minor riverbeds and based on proximity to mining sites, were analyzed in the laboratory to study the presence of mining pollutants, particularly cyanide and mercury. In addition, surveys of 384 heads of families, mainly farmers, stockbreeders and mining operators, enabled us to collect qualitative and quantitative data on the use of mining pollutants, and their impact on water resources. **Findings:** The results of laboratory analysis of water samples revealed contamination by cyanide and mercury, although concentrations remain below the WHO/Burkina Faso standard for safe human consumption and cultivation, which is 70 μg/L for cyanide, and 6 μg/L for mercury. Furthermore, survey results showed that 39% of mining operators discharge mining pollutants from gold extraction processes into pits dug near mining sites, while 11% of them discharge them into the riverbeds supplying the area, despite the fact that 80% of mining operators are aware of the impacts of these mining pollutants on water resources in the study area. **Novelty:** Nevertheless, the mining activities represent a serious threat to the biodiversity conservation of the complex. Taking these impacts into account in preservation objectives seems necessary.

Keywords: Mining activities; Water pollution; Degradation of aquatic ecosystems; Loss of biodiversity; PONASI ecological complex

Citation: Ramdé Z, Kaboré O (2025) Mining-related Pollution of Water Resources and Local Perceptions of Effects on Natural Ecosystems in the Pô-Nazinga-Sissili Ecological Complex in Burkina Faso. Indian Journal of Science and Technology 18(24): 1972-1984. https://doi.org/10.17485/IJST/v18i24.708

* **Corresponding author**.

ramdzonata.22@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

1 Introduction

Mining-related water pollution has been a current issue and a major concern in natural resource management worldwide since the early 19th century(1). This issue arises when extractive activities lead to soil and landscape degradation in mining areas in general(2). Indeed, degradation affects various aspects of environment, such as climate, biodiversity and natural ecosystems through water resources, air, and soils [3-6]. Human behavior in this context is, therefore, very important in reducing exposure to mining-related toxic substances(3).

It should be noted that environmental awareness in the extractive sector has been ”late” in Africa and other countries of the South. The denunciations of the environmental risks linked to mining in poor countries are said to have begun with the cyanide scandal in Peru in western South America. They began in Africa in the late 1990s and early 2000s, a period that corresponds to the early stages of the mining boom. In Burkina Faso, a country located in the heart of West Africa, the mining sector occupies an important place in the national economy, with massive exploitation of gold and other minerals(4). The government regulates this industry through mining codes, contracts with mining companies and revenue collection mechanisms. However, mining, whether industrial or artisanal, has disastrous consequences not only for human health, but also for the conservation of natural ecosystems through the use of toxic substances such as cyanide and mercury [9, 10]. Gold exploitation emerges as a key issue in the context of sustainable natural resource management(5). The accelerated growth of this activity and current mining methods, characterized by the misuse of toxic chemicals and explosives, raise enormous sustainability issues, particularly for the agro-sylvo-pastoral sector(6). Indeed, mining activities constitute an environmental hazard through the use of chemicals during gold processing. Cyanide and mercury are the most commonly used chemicals in gold mining around the PONASI complex(7). Mercury is used during the amalgamation phase, while cyanide is used during the cyanidation phase. During these phases, over 24 kg of mercury or cyanide pellets are poured into rectangular basins and mixed with around 200 L of water(8). After processing, the resulting toxic water with very high concentrations of cyanide or mercury is discharged into the environment through the nearest watercourses. These toxic substances are carried by rainwater into natural ecosystems, leading to biodiversity loss.

Concerned about preserving its environment, Burkina Faso has ratified several environmental agreements and international conventions, including the Minamata Convention on Mercury in Japan, against the greatest threats to human health and environment caused by anthropogenic emissions and the release of mercury and mercury compounds into the nature. Despite the ratification of these international environmental agreements, the use of mercury and cyanide still persists in mining activities in Burkina Faso, leading to serious health problems for populations living near the mining sites and the contamination of their water resources with heavy metals(9). The issue of formalizing these activities has become more urgent, with the goal of achieving more effective regulation and management(10). Unfortunately, the PONASI ecosystem is no exception to this trend. This protected area, a vast ecological space of 327,000 hectares with high wildlife potential, has been confronted with serious degradation problems, including those related to mining activities in recent decades(11). Currently, there are at least five mining sites around the PONASI complex [12, 17], with gradual impacts on the quality of water resources in this area. In Burkina Faso, many scientific studies have focused on the effects of mining at the scale of watersheds such as that of Tuy. These effects have also been related to the dynamics of plant formations, land use and the quality of the environment through water, air and soil at various sites. In the PONASI complex, the work of(12) focused mainly on aspects of the governance of this complex, which is increasingly influenced by artisanal mining. However, the effects of artisanal mining in this complex are still very little known despite the threat they represent, hence the interest of this article.

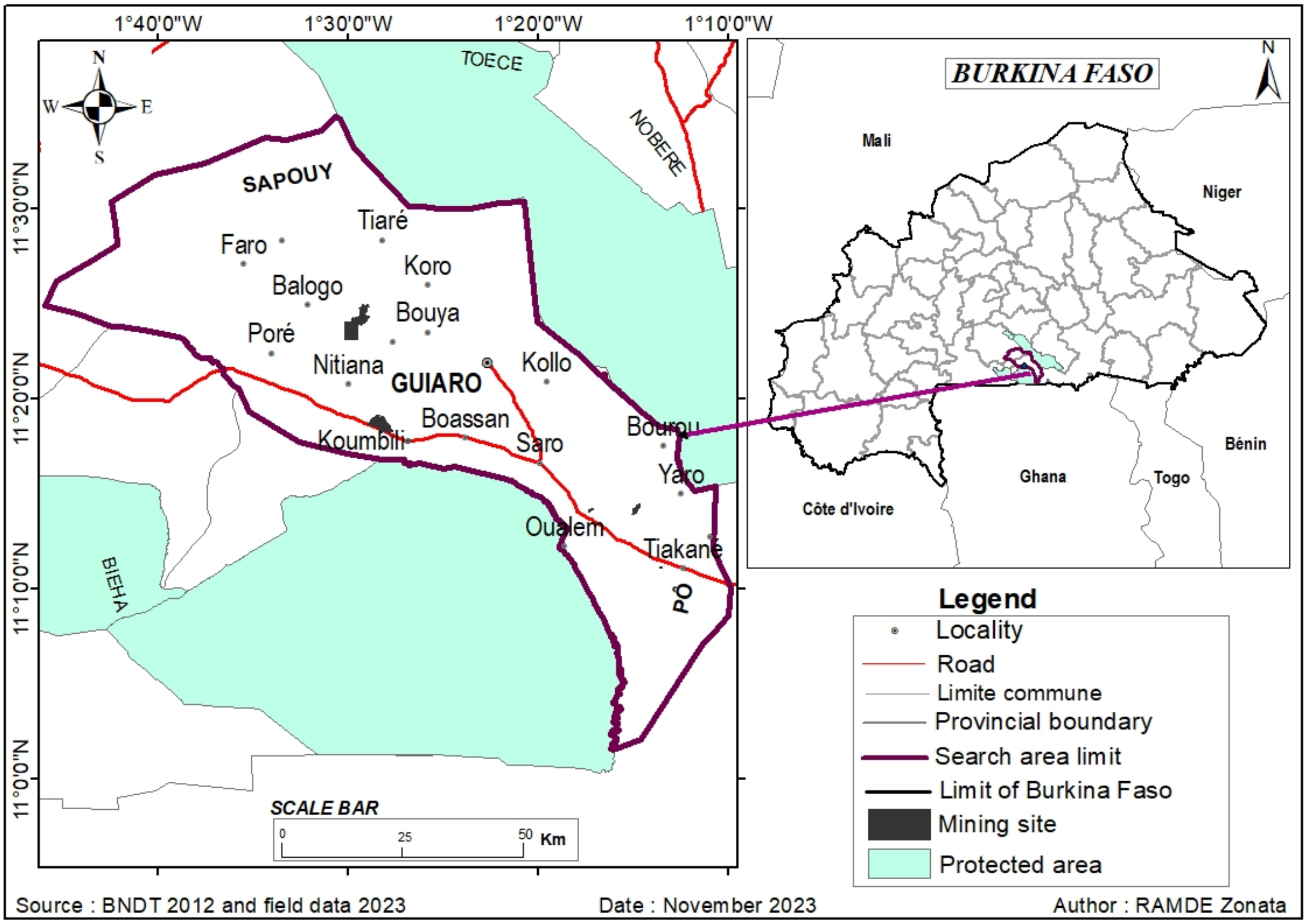
2 Methodology

2.1 Location of study area

The PONASI ecological complex is the second largest ecological continuum in Burkina Faso, with a significant presence of protected areas. It is located between 11°0’00” and 11°30’0” North Latitude and 1° 10’0” and 1° 40’0” West Longitude in southern Burkina Faso, along the border with Ghana. It spans over the Centre-Sud and Centre-Ouest regions (Figure 1). The municipalities of Pô, Guiaro and Sapouy located at the center of the complex are potential areas for a massive influx of agro-pastoralists, stockbreeders and mining operators from a variety of backgrounds in search of land(11), some for farming and others for gold mining. The recognized importance this entity contrasts, however, with the practices detrimental to its conservation and sustainable development, including those of agro-herder and forager populations, and recently a mining company (Nétiana Mining SA) established within its boundaries(7). The combination of these factors threatens the biodiversity of this area. This is what justify the choice of this zone, where the exacerbation of pressures on the natural ecosystems of the complex is worsened by the introduction of the mining activities.

The mixed method was therefore adopted in this study, as it combines quantitative and qualitative data. The communes of Pô, Guiaro (Central-south region) and Sapouy (Central-west region) were covered by the study. A total of 16 villages, selected on the basis of their proximity to the mining sites and protected areas, were chosen for the field investigations. Thus 384 heads of households selected in a reasoned manner were surveyed.

Primary data collection techniques included field observations, interviews and focus groups in the target villages. The KoboCollect platform was used to process and analyze survey data, and R, Python and Excel were used to cross-reference survey variables.



Source : BNDT 2012 and field data 2023 Date : November 2023 Author : RAMDE Zonata

Fig 1. Geographical location of the PONASI ecological complex

2.2 The relief of the study area

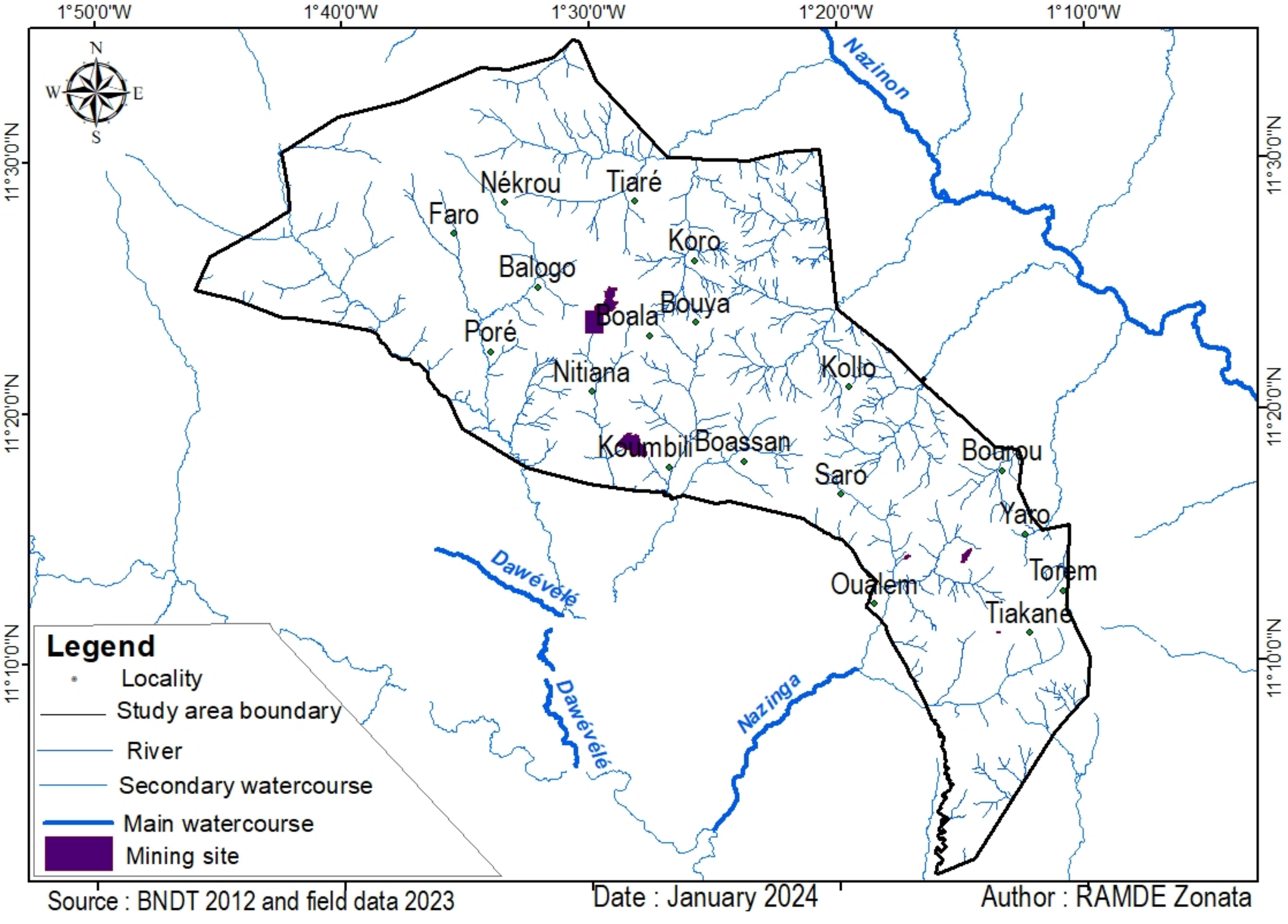
The PONASI ecological complex features a rugged relief, characterized by hills and inselbergs[7]. The highest altitudes are found in the northern part of the area, particularly in the villages of Boala, Balogho and Koro, where volcanic rocks are concentrated. In contrast, the lowest altitudes are found in the southern part, in the villages of Oualem and Koumbili on the edge of the Nazinga game ranch. Analysis of the distribution of slope classes around the PONASI complex shows flat and gently sloping areas (very gentle to flat and gentle slopes) dominate the landscape, occupying around 70% of the area. They are located mainly in the central and southern parts of the area. However, more rugged areas (steep and very steep slopes) are found on the periphery of the area, particularly in the north, west and east. They account for around 30% of the area.

The distribution of slope classes has a major influence on land use and the spatial distribution of socio-economic activities around the complex. Flat and gently sloping areas are favorable to agriculture and livestock farming. They are also more densely populated, whereas the more rugged areas are less favorable to agriculture and are often covered with forest or savannah. They are less densely populated and can be suitable for hunting or forestry activities. Slopes play a crucial role in the dispersion of mining pollutants around the complex. They determine the direction in which mining pollutants spread through the area.

2.3 Climate and hydrographic network of the study area

The climate of the PONASI complex is similar to that of the municipality of Pô and is classified as Sudanian. It characterized by an annual rainfall of approximatively 1000 millimeters(11), making it one of the most watered regions in the country. The Sudanian climate is often associated with a rainy season followed by a dry season. The region generally receives moderate precipitation throughout the year, which can influence environmental conditions, vegetation status, water availability, and agricultural activities.

The hydrographic network of the PONASI ecological complex is very dense. The Nazinon river and its secondary tributaries, including the Sissili, Dawevélé and Nazinga rivers, flow through the complex in a northwest-southeast direction. Water flow becomes regular starting in June, with peak discharge reaching 35 m^3 per second in September(12). As soon as the dry season begins, the river's flow diminishes, breaking up along its course into a chain of ponds. These watercourses form the basis of the hydrographic network of the complex. Additionally, there are eleven water reservoirs within the Nazinga Game Ranch. The flow regime of these watercourses is irregular, with active water flow occurring from July to October. Figure 2 shows the hydrographic network draining the study area.



Source : BNDT 2012 and field data 2023 Date : January 2024 Author : RAMDE Zonata

Fig 2. Hydrographic network in the study area

The availability of surface water is a key factor in the survival of wildlife within ecosystems during the dry season. In the study area, water reservoirs are very inadequate and unevenly distributed among villages. They consist of boreholes, human-powered pumps and public fountains in some places (Tiakané). Most of these facilities are provided by non-governmental organizations. These few pumps must supply drinking water for both animals and humans, while simultaneously supporting their daily activities. During the rainy season, water scarcity is not an issue, as there is still water in the lowlands. In contrast, during the dry season, water scarcity becomes acute due to competing demands of farmers, herders and miners for the same water sources. Faced with this situation, some natives assert their rights to the water sources and charge migrants with additional fees to have access to the facilities. Around the mining sites, motor-driven pumps are used to pump water from local watercourses to the ore processing sites. Some gold miners have also dug water reservoirs near mining sites to store water for use during mineral processing. Such equipment and facilities are commonly used to optimize the gold extraction and processing process in the study area**.** According to surveys, gold miners deal with toxic water from ore processing in a variety of ways. The majority of miners acknowledge discharging it into watercourses, while some release it in protected areas and others dispose of it in holes or pits dug to bury it in the ground.

Gold miners dig pits to bury toxic water from mineral processing, in order to prevent its spreading into protected areas. They are committed to ensuring that these pits are covered with topsoil once they are no longer needed, in order to mitigate their impact on the environment of the target areas.

Water discharged into local watercourses runs off to join other tributaries through rainwater, which carries it from the upper slopes upstream to the lowlands downstream, in the protected areas of the ecological complex. This represents a potential risk of contamination of the overall hydrographic network, with negative consequences for the natural ecosystems of the ecological complex.

2.4 Water sampling method and Sample collection

In order to assess the level of contamination of water resources by mining effluents in the study area, a research study was carried out. To this end, water samples were taken to assess the level of cyanide and mercury pollution. A total of 18 water samples (surface and groundwater) were collected on and around the mining sites, throughout the entire study area. The 18 samples (EO1, EO2, EO3, EO4, EO5, EO6, EO7, E08, EO9, EO10, E011, EO12, EO13, EO14, EO15, EO16, EO17, EOT) were collected primarily from highly sensitive areas (depending on the slope and the water flow direction) likely to provide the most useful information on the dispersion of pollutants in the environment. The samples were collected from pits, boreholes and stagnant water around the sites and near forests, in order to take into account surface water as well as underground infusions. Moreover, the samples were collected from 7:00 a.m. to 9:00 a.m., to ensure ionic stabilization of the water. Each of the sample was stored in 1-liter sealed and sterilized containers, conditioned to a temperature of 25°C, and transported to the laboratory. The geographical coordinates of the sampling sites were taken using a GPS device for spatial analysis purposes. Figure 3 shows the locations where water samples were collected.

This technique enabled us to simultaneously monitor the dispersion of chemical pollutants on the sites and on specific locations deemed sensitive.

Water samples were analyzed at the Office of Mines and Geology (BUMIGEB) in Ouagadougou. The parameters investigated were concentrations of free cyanide (CN^-) and mercury (Hg^+). Pollutants were determined by atomic absorption, spectrophotometry (AAS), Flow Injection Atomic Spectrometric (FIAS), while the analysis was conducted using ion chromatography.

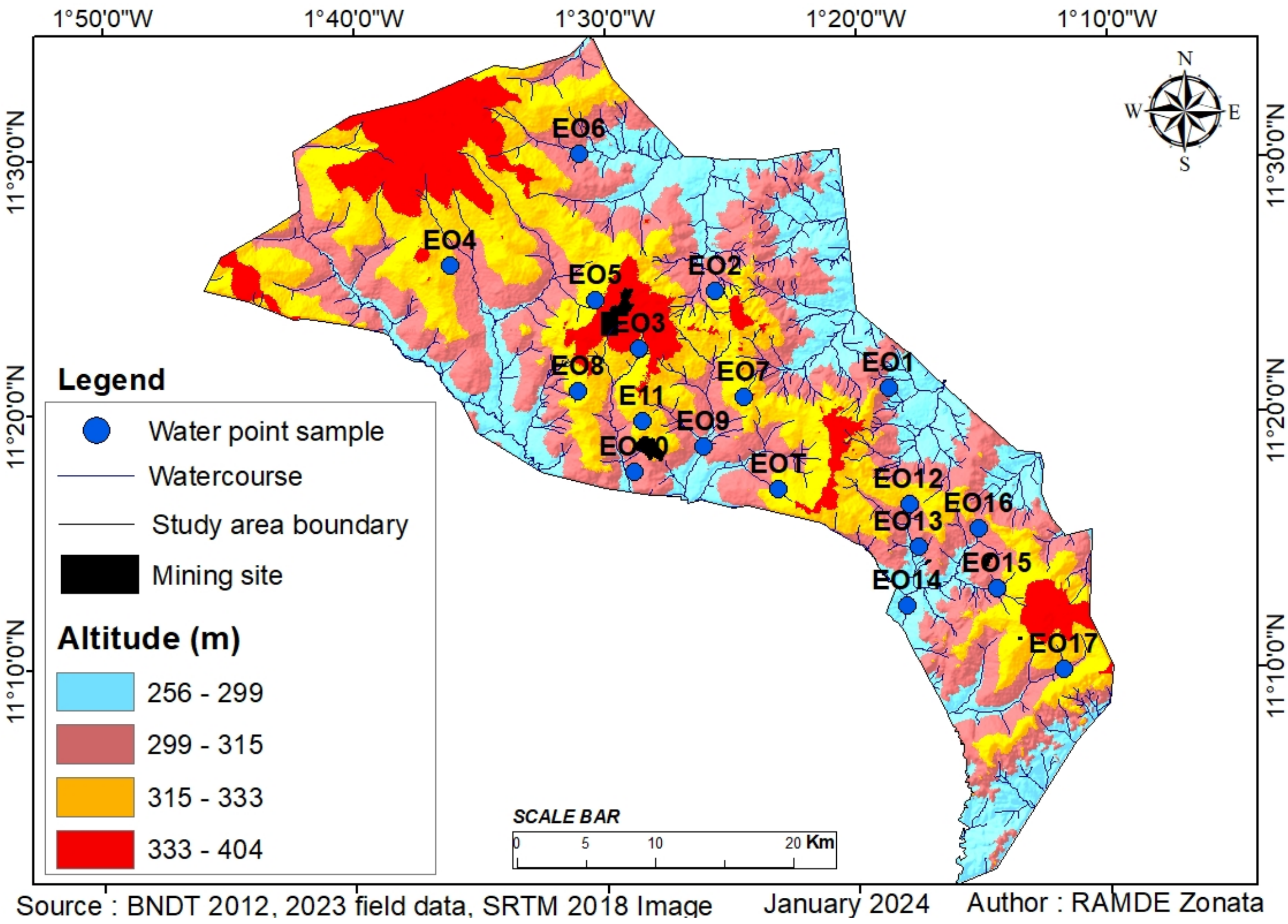
The results obtained from laboratory analyses were used to determine the spatial the dispersion of mining pollutants in the study area.

3 Results and Discussion

3.1 Assessment of cyanide dispersion in water resources in the study area

Figure 4 shows the dispersion of cyanide in water samples analyzed by the laboratory of Office of Mines and Geology (BUMIGEB) in Burkina Faso. Analysis revealed that all water samples collected (EO1...EO18) downstream of the mining sites contained cyanide concentration below the WHO/Burkina standard (>70 μg/L). However, concentrations varied according to proximity or distance from the mining sites, allowing for a classification of pollution levels. All samples show concentrations below the detection limit of 0.5μg/L, except for samples EO13 and EO15, where concentrations of 5.64 μg/L and 6.33 μg/L were observed respectively.

Observation of the map indicates that high concentrations of cyanide were found in the southeastern part of the study area, precisely around the villages of Tiakané, Yaro, and Oualem, which are villages bordering corridor no. 1 of the PONASI complex. In contrast, medium and low concentrations were observed in the western and north-western parts of the area. The observation of high cyanide concentrations in the south-eastern part of the zone indicated that cyanide was used extensively in these areas. In fact, this part of the zone is home to numerous artisanal mining sites in operation, where ore processing is carried out. Field



Source : BNDT 2012, 2023 field data, SRTM 2018 Image January 2024 Author : RAMDE Zonata

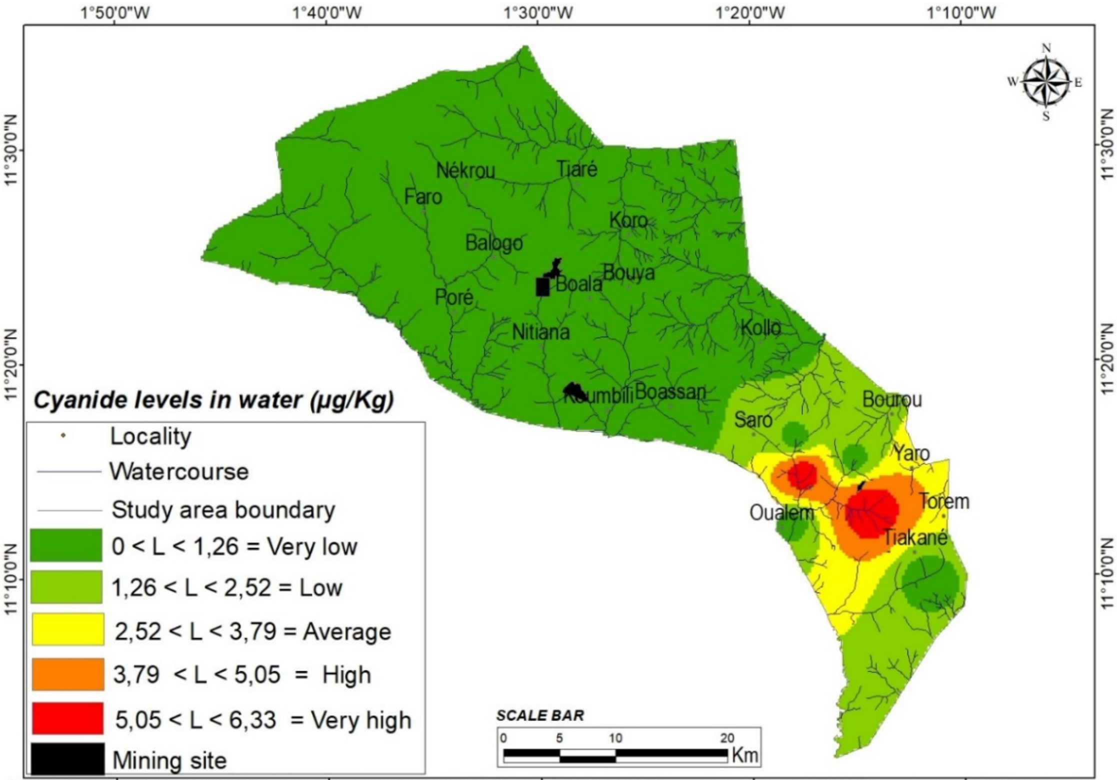
Fig 3. Locations of water samples collection sites for laboratory analysis

surveys indicated that water sources were sometimes located close to processing sites. This explains the infiltration of cyanide into the water.

The low levels observed in the western and north-western parts of the zone could be explained, on the one hand, by the fact that when cyanide was carried by rainwater, undulations on the slopes and infiltrations in the soil likely slowed down cyanide runoff, thus preventing its massive accumulation downstream. On the other hand, this could be explained by the fact that the abundance of organic matter contained in the soil likely reduced cyanide runoff downstream through absorption and biodegradation processes. Cyanide is a highly toxic chemical for human health. The Life Cycle Assessment (LCA) of cyanide used in mining activity makes it possible to assess its impacts at each stage of its use, particularly in ecologically sensitive areas such as those around the PONASI complex. Its production, from ammonia and methane, generates significant greenhouse gas emissions. Its transport to often isolated sites increase the risk of accidents and the carbon footprint. In the field, cyanide is used to extract gold from ore, which leads to heavy soil and water pollution, acute toxicity to fauna, flora and populations, as well as poor management of cyanide waste. At the end of the cycle, the lack of rehabilitation measures in artisanal gold panning leaves dangerous residues in the environment, causing lasting contamination of ecosystems and chronic effects on human health. Overall, the use of cyanide generates environmental impacts (deforestation, water pollution, loss of biodiversity), social impacts (conflicts over water use, diseases) and economic impacts (high costs of remediation, loss of natural resources), which far exceed the short-term benefits of gold mining.

3.2 Assessment of mercury dispersion in water resources in the research area

Figure 5 shows the dispersion of mercury in water samples analyzed by the laboratory of Office of Mines and Geology (BUMIGEB) in Burkina (BUMIGEB). Analysis of these samples showed that all water samples collected (EO1...EO18)



Sources : BNDT 2012, BUMIGEB Laboratory analysis results 2024, and data field 2023. Date : December 2024 Author : RAMDE Zonata

Fig 4. Dispersion of cyanide in watercourses around the complex PONASI

downstream of the mining sites contained mercury concentrations below the WHO/Burkina standard (>6 μg/L). However, concentrations varied according to proximity or distance to the mining sites, allowing for classification of pollution levels. All samples were below the detection limit of 0.5μg/L, except for EO2, EO5 and EO11, where concentrations of 0.57μg/L, 2.45μg/L and 0.85μg/L were observed respectively (Figure 5).

High mercury concentrations were found in the western and north-western parts of the study area, precisely around the villages of Balogho, Boala, Nitiana, Koro and Tiaré. In contrast, low concentrations were found in the eastern and south-eastern parts of the area, particularly around the villages of Tiakané, Oualem and Yaro. The high mercury levels observed in the north-western and western parts of the area could be explained by the presence of numerous artisanal mining sites and also the existence of an abandoned industrial mining site in this part of the area. The use of mercury in mining activities has therefore led to its discharge into the surrounding water sources.

Field surveys indicated that contaminated water sources are close to ore processing sites. This explains the infiltration of mercury into the water. However, the low mercury concentrations found in the south-eastern parts of the area could be explained by the limited use of mercury this part of the area. Mercury is a more volatile chemical compound in ambient air. Its massive dispersion into the atmosphere could lead to contamination of protected forests and poisoning of the wildlife within the complex. This could lead to a migration of animal species to other, more suitable areas. In addition, the accumulation of mercury in the natural ecosystems of the complex could lead to the poisoning of aquatic ecosystems, particularly in the Nazinga game ranch where there are many aquaculture dams. Mercury is a very dangerous chemical compound for human consumption. The Life Cycle Assessment (LCA) of mercury used in mining activities highlights heavy environmental, health and economic impacts, particularly in sensitive areas such as the PONASI ecological complex. Mercury is extracted from ores or by-products of industrial processes, a step that is already polluting and energy intensive. Its transport to mine sites increases the risk of leaks and accidental contamination. During on-site use, gold miners mix mercury with the ore to amalgamate the gold, and then heat it to separate the two metals, releasing toxic vapors into the air. This practice leads to severe pollution of soil, water and air, directly affecting ecosystems and the health of local populations. Mercury accumulates in aquatic food chains (bioaccumulation), causing serious neurological effects, especially in children and pregnant women. If the absence of rehabilitation, mercury residues remain in the environment, generating long-term contamination.

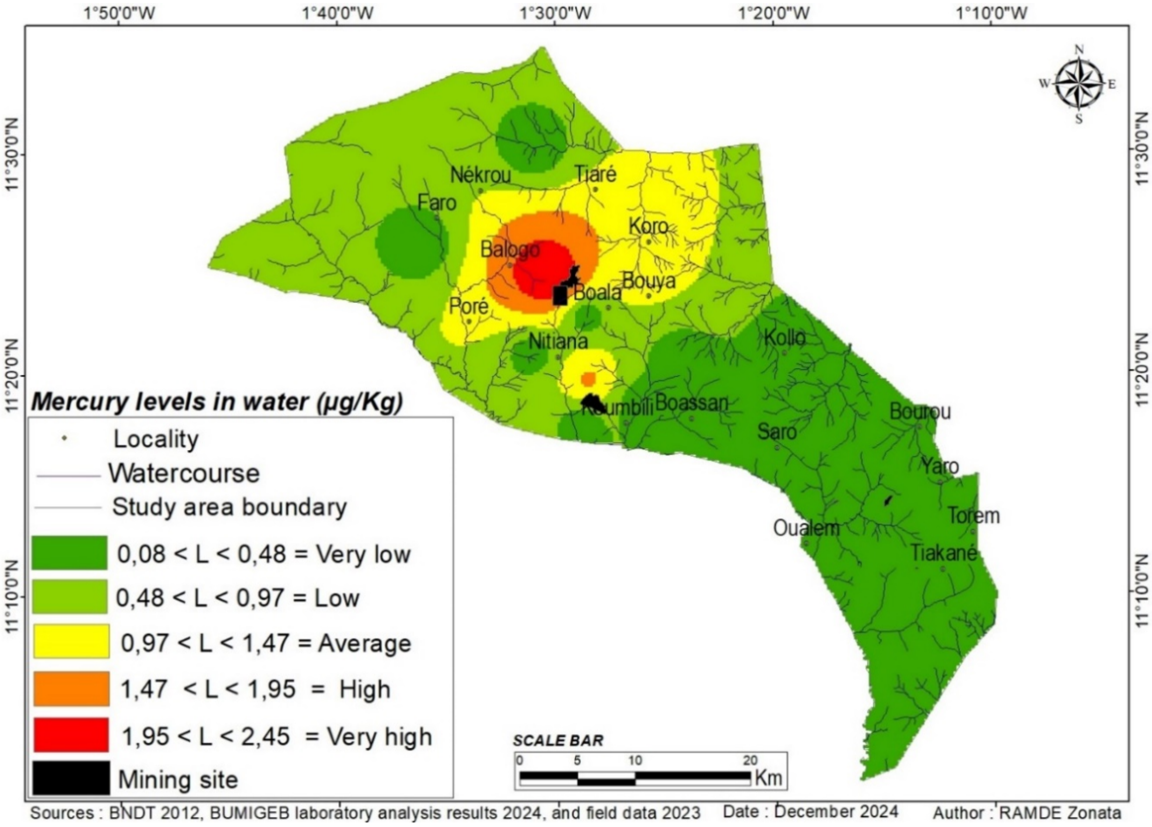


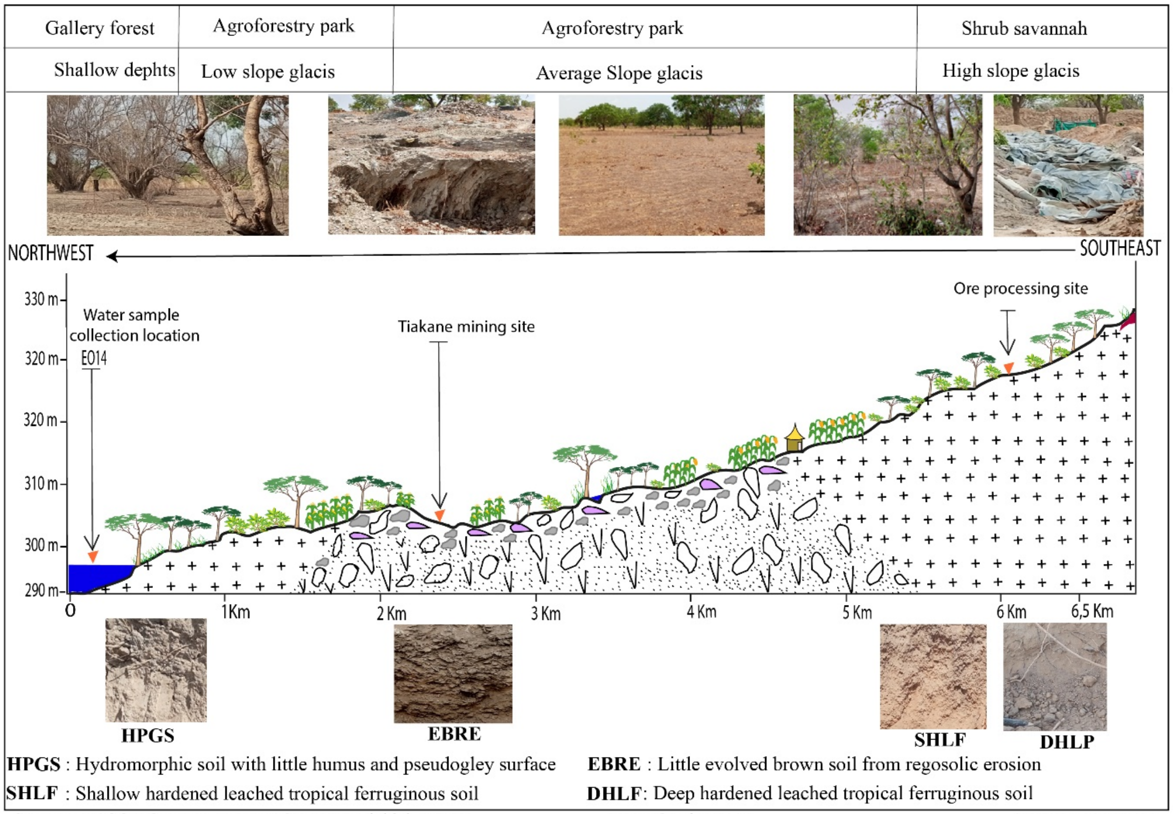
Fig 5. Dispersion of mercury in watercourses around the complex PONASI

3.3 Assessing the hydrographic network contamination risks

Figure 6 shows an initial toposequence carried out around the PONASI complex. It crosses the mining site in the village of Tiakané, located in the municipality of Pô in the southeastern of the study area. This toposequence spans over a distance of approximatively 7 km, with an average slope of 0.57%. Its altitude varies from 330 m upstream to 290 m downstream (corresponding to the minor riverbed), with a south-east (SE) and north-west (NW) orientation. The average altitude is 310 m. At the top of the toposequence, the landscape photographs show the mainland use units such as gallery forest, agroforestry parkland and shrub savannah, spread out along the slope variation (lower middle, and upper slopes).

Given the variation in slope, the position of the mining processing sites at the top of the slope, and the position of the lowland at the bottom of the middle slope, there is a potential risk of contamination of the lowland water by mining effluents. Although the results of laboratory physicochemical analysis of the water samples collected showed cyanide concentrations below the WHO standard, the analysis of the topographic profiles showed that it is highly likely that mining effluents located upstream of the profile on the upper slope flow down the slope, contaminating the land-use units along the transect, and reaching the lowland areas downstream. Indeed, the analysis of the toposequence showed a steep slope, with a significant elevation drop, culminating in the Nazinga protected forests. As the Tiakané mining site and ore processing area are located upstream of the watercourses, the risk of mining pollutants running off into the hydrographic network of the complex seems very high. Traces of mercury detected in the lowland areas indicate that mercury transport from the mining sites was attenuated through absorption and biodegradation along the transect, then leached into these areas. These mining effluents, highly dangerous for local populations, their livestock and their environment, could reach the entire hydrographic network.

Figure 7 also shows a second toposequence conducted around the PONASI complex to determine the direction of dispersion of mining pollutants. It crosses the Balogho artisanal mining sites to the north-west of the study area and spans over a distance of approximatively 8.5 km, with two average slopes of 2.3% and 1.9% and an inselberg-shaped hilltop. The altitude of the first slope varies from 400 m upstream to 330 m downstream (the minor riverbed) with a south-southeast (SSE) and north-northwest (NNW) orientation, while the second slope varies from 400 m upstream to 295 m downstream (the minor riverbed) with a south-east (S-E) north-east (NE) orientation. The average altitude of the first slope is 365 m, while that of the second slope is



Source : NASOILOF 2001, Image ASTER 30, Field data 2023 **Date** : October 2023 **Author** : RAMDE Z.

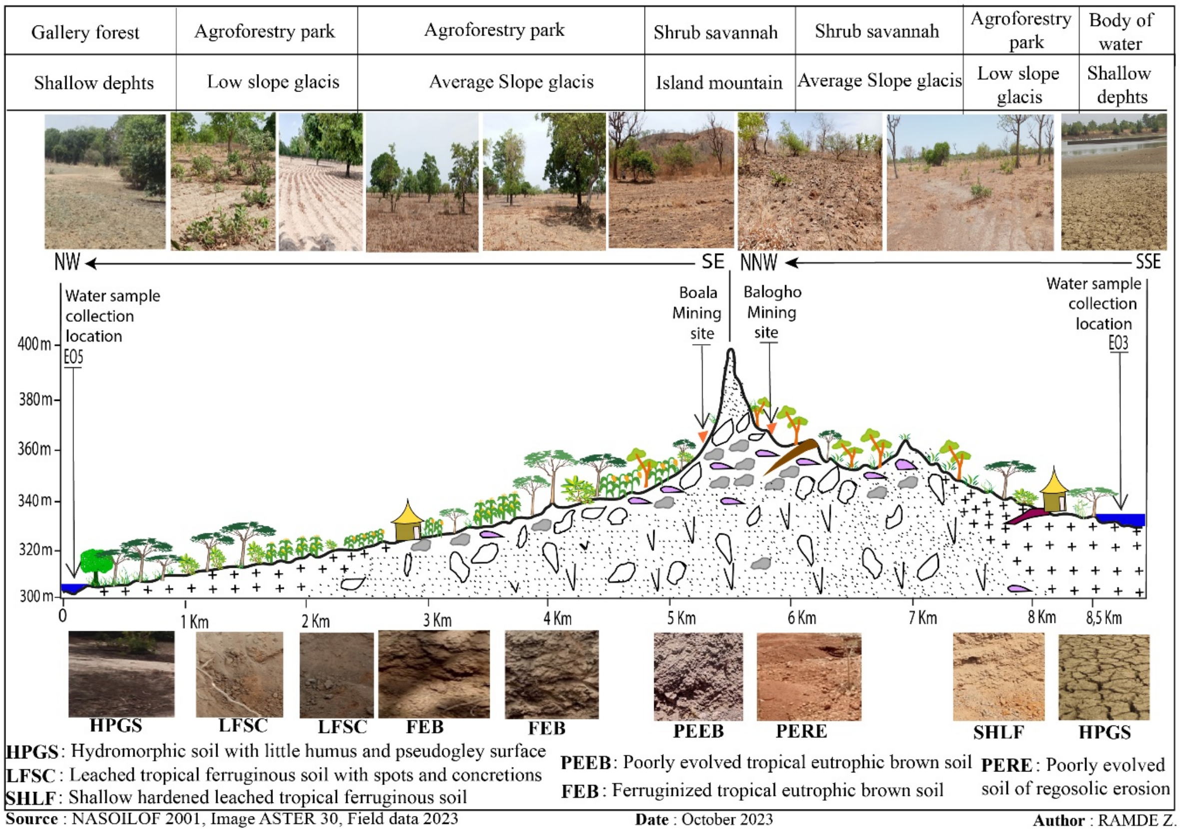
Fig 6. Toposequence no.1 crossing the mine site of Tiakané

348 m. At the top of the figure, photographs show the different landscape types across the toposequence, such as gallery forest, agroforestry parkland, shrub savannah, and water.

Analysis of this toposequence revealed an area with two juxtaposed slopes, separated by a sharp-crested inselberg (hill). The first slope, running from south-southeast to north-northwest, is less steep than the second slope, running from southeast to northwest, where the slope is steep and very steep. Both slopes descend into lowland areas and then into the entire hydrographic network of the complex. The mining sites are located on the hill slopes upstream and spread out on either side of the upper slopes. There is therefore a risk of mercury contamination of the land-use units through runoff along the transect, reaching the lowlands located downstream. Despite the results of analyses of water samples collected in the lowlands, showing mercury concentrations below the WHO standard, there is a risk of mercury contamination of the central watercourses, including the Nazinga, Delwindé and Nazinon rivers, which supplies the surrounding environment of the complex. This could have serious consequences for the health of local populations, aquatic ecosystems and wildlife, regularly drinking from these contaminated watercourses. The entire hydrographic network is threatened, as the toposequence line flows into the Nazinga and PNKT protected areas, where several aquaculture dams are found. A single episode of flooding, triggered by heavy rainfall, could carry these mining pollutants along the slopes to contaminate all water resources within the complex.

Mining practices reveal excessive use of cyanide and mercury, with amounts ranging from 300 to 2000 grams per ton of ore processed, well above the 0,3 to 0,5 grams needed for efficient extraction. This overconsumption leads to significant pollution of water resources. However, the cost of cleaning up water contaminated by these substances is estimated at between $12 and $228.42 per cubic meter. For example, for an affected area of 10000 m^3, treatment costs would be between $114215 and $2284320.

A national study estimated the cost of health impacts related to the uncontrolled use of these chemicals in mining activity in Burkina Faso at approximately $24,2 million per year. In addition, environmental contamination by these substances has a strong impact on aquatic biodiversity. It leads to the degradation of essential ecosystem services, such as fisheries and access to drinking water. The loss of these services can be estimated at between $1142 and $11424,5 per hectare per year.



Source : NASOILOF 2001, Image ASTER 30, Field data 2023 **Date** : October 2023 **Author** : RAMDE Z.

Fig 7. Toposequence no. 2 crossing the artisanal mining site of Balogho/Boala

3.4 Local perceptions of the effects of mining activities on natural ecosystems around the PONASI ecological complex

The analysis in Figure 8 shows the locations where toxic water is discharged after ore has been treated with mining pollutants such as cyanide and mercury. Knowledge of these locations helps to understand the dispersion of mining pollutants in the research area**.**

Figure 8 shows six different dumping sites. Dumping takes place in watercourses (11%), gutters (39%), are conditioned and discharged far from the village (26%), in open air (42 operators), and within protected areas (19 operators). According to the surveys, majority of gold miners discharge toxic wastewater from ore processing into pits dug near the sites, which they refer to as gutters. In fact, the gutters mentioned by the respondents are holes dug by the gold miners to bury the toxic wastewater, expecting that the toxic effect of these effluents will be destroyed over time. Watercourses are also a major dumping place. This practice has a direct impact on water quality through the poisoning of water and aquatic biodiversity. Dumping polluted water in protected areas is illegal and extremely damaging to fragile ecosystems. The other categories of dumping (open air, conditioned/discharged far away, etc.) reflect a diversity of practices, ranging from disposal into the natural environment to more or less effective waste management practices. This situation underscores the urgent need to implement effective measures to reduce pollution and protect aquatic ecosystems and public health.

The analysis of the crossover table relating mining pollutant discharge locations to the perceived impact of mining activities on water resources (Table 1) revealed that only 2.3% of mining operators believe that mining activities have no impact on water resources, whereas 97.7% acknowledge that they negatively affect the water resources within the complex. This significant difference in percentages indicates a broad awareness of the environmental impacts associated with mining activities around the complex, particularly in terms of water quality pollution and the availability of drinking water, which are very critical issues for the health of natural ecosystems and local communities.

Approximatively 52% of those surveyed said that mining activities lead to the proliferation of water-borne diseases, while 26% of operators said they lead to the degradation of aquatic ecosystems. These perceptions highlight the urgent need to take

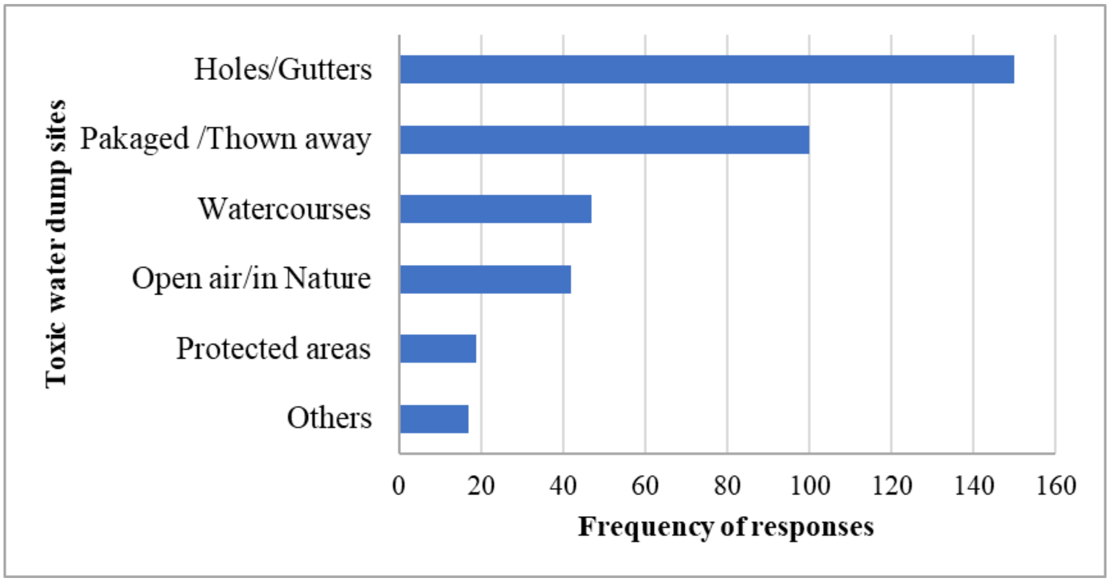


Fig 8. Locations of toxic water discharges from mining effluents in the research area

Table 1. Crossover tableau between mining pollutant discharge locations and their consequences on water resources

Characteristics	**No** N = 9[1]	**Yes** N = 375[1]	**Overall** N = 384[1]
Use of cyanide and mercury			
No	2 (25%)	146 (39%)	148 (38%)
Yes	6 (75%)	233 (61%)	239 (62%)
Discharge into the open air			
No	5 (83%)	186 (83%)	191 (83%)
Yes	1 (17%)	39 (17%)	40 (17%)
Discharge in protected areas			
No	6 (100%)	209 (93%)	215 (93%)
Yes	0 (0%)	16 (7.1%)	16 (6.9%)
Package and thrown away			
No	2 (33%)	143 (64%)	145 (63%)
Yes	4 (67%)	82 (36%)	86 (37%)
Discharge in watercourses			
No	6 (100%)	185 (82%)	191 (83%)
Yes	0 (0%)	40 (18%)	40 (17%)
Discharge in other places			
No	5 (83%)	212 (94%)	217 (94%)
Yes	1 (17%)	13 (5.8%)	14 (6.1%)

strict measures to regulate mining practices around the complex, to adopt less polluting mining technologies, and to implement sustainable water resource management systems, in order to preserve water quality, as well as the health of aquatic ecosystems.

The analysis of the crossover relating mining pollutant discharge locations to the impact on the protected areas of the complex highlighted the serious concerns about the consequences of mining pollutant discharges in protected areas. Indeed, 93% of those surveyed acknowledged that these discharges have significant negative effects on the natural ecosystems present in these protected areas. On the contrary, only 13% of respondents felt that these discharges had no effect on the ecosystems concerned, a relatively small proportion which suggests either a minority of dissenting opinions, or perhaps a lack of awareness regarding the environmental impacts of mining pollutants on water resources. However, the dumping of mining waste in these areas has disastrous consequences for these ecosystems, and the 93% of respondents who acknowledged this reality underscored the scale of these impacts.

3.5 Discussion

The analysis of the contamination around the PONASI complex highlights localized pollution by cyanide and mercury, linked to mining activities. In the south-eastern part of the zone, abnormally high concentrations of cyanide were detected (5.64 μg/L and 6.33 μg/L in two samples). This pollution is mainly due to the direct discharge of wastewater from mineral processing into waterways by 11% of local operators. At the same time, in the western and northwestern parts, mercury concentrations above the detection limit were recorded (up to 2.45 μg/L). These levels of contamination can be explained by the intensive use of mercury in artisanal gold panning, with 39% of operators discharging mercury-laden water into gutters or pits dug for this purpose. These practices lead to a differentiated dispersion of pollutants in the sense that cyanide mainly affects surface waters, while mercury infiltrates into groundwater. The use of cyanide and mercury in mining operations leads to chemical pollution of water resources in the study area. These pollutants, transported from the mining sites, flow down the slopes into the local drainage system, thereby contaminating the aquatic ecosystems of the complex. These findings are consistent with those reported by other researchers. For instance, observed similar results in the municipality of Bomboré, where gold mining has contributed to the pollution of groundwater with cyanide and mercury. This author warns that this pollution could reach the groundwater if no corrective measures are taken to reverse the trend of degradation linked to the negative impacts of mining activities in the municipality. Likewise, research findings by(13) identified mercury as a source of emissions, toxicity and contamination of the aquatic environment in Benin. According to this author, the formation of methylmercury in the aquatic environment, under the influence of various factors, and its bioaccumulation are mainly responsible for the toxic effects on humans.

The results of the study by(14) in the Bounkani region of Côte d'Ivoire indicated that the impacts of artisanal gold mining on water resources are mainly depletion of water resources, through the massive use of water in the extraction process and water discharges during shaft sinking, pollution of surface water and/or groundwater, and destruction of riverbeds. This leads to eutrophication of the aquatic environment, resulting from the increased concentration of suspended solids (including dyes) in the watercourses receiving the treatment sludge.

The pollution of water resources by mining is related, on the one hand, to archaic gold mining techniques, and on the other hand to the lack of supervision of mining activities(10) in the area hosting mining sites. The results of this study therefore confirm those of(12), in the sense that governance of the PONASI ecological complex cannot be achieved without comprehensive consideration of its peripheral area. Indeed, anthropogenic actions such as the clearing of forests for agricultural expansion, deforestation, and the use of chemical fertilizers in the fields(11) were already present in this area. However, it appeared that this environmental pressure has intensified with the introduction of mining activities, which constitutes a major factor in the degradation of the natural ecosystems within the complex. Mining operations emerge as the significant threat to the complex, due to the use of toxic mining pollutants. Field surveys showed that, following gold extraction, 11% of mining operators have reported discharging toxic water directly into watercourses. Rainwater could carry this polluted water into the hydrographic network supplying the entire ecological complex, putting the entire area at risk of pollution. Water contamination may lead to the death of humans and animals, relying on these sources for drinking water, while other species may migrate to neighboring countries (particularly in Ghana) where survival conditions are more favorable(7). According to studies by(8), the use of mercury and cyanide in the mining sector is driven by their ability to enhance the efficiency and profitability of gold extraction. This explains why their use continues despite the fact that the majority (80%) of mining operators are aware of the negative impacts of these mining pollutants on water resources. Though legal frameworks and protective environmental measures established, artisanal gold activities persist and intensify, often showing less concern for environmental protection(14).

4 Conclusion

This study revealed that mining operations have significant impacts on water resources in the PONASI ecological complex. This is reflected in water pollution by mining effluents such as cyanide and mercury, used in ore processing. Such pollution could have serious consequences for the health of local populations, their livestock, and for the sustainable preservation of the aquatic ecosystems within the complex. The use of cyanide and mercury in mining activities around the PONASI complex results in significant environmental and health costs, estimated at between \$27.8 million and \$31 million per year. These costs far outweigh the direct economic benefits of artisanal gold panning. Given the dichotomous realities (positive and negative aspects) of by mining activities around the complex, local stakeholders such as mining operators, traditional authorities, the scientific community, decentralized state entities, and the local community must get involved in the rigorous and collaborative management of mining activities. This is essential to prevent mining pollutants from flowing into watercourses and to mitigate their impact on the aquatic ecosystems of the complex. Achieving this requires the adoption and dissemination of good mining techniques and practices, that eliminate the use of cyanide and mercury in gold extraction processes around the ecological complex. In addition, the political authorities must invest in the closure of certain mining sites because of their proximity to protected areas.

5 Acknowledgement

The research was conducted with authors' own funds and no external funding support availed. The laboratory analysis costs were covered by the Ministry of Higher Education, Research and Innovation (MESRI) of Burkina Faso.

References

1) Judet P. Exploitation, abandonment and nationalization of Savoyard mines from 1750 to the present day. An introduction to a long and contrasting history. 17. 2019. Available from: https://edytem.osug.fr/collection-edytem.
2) Deshaies M. Mining and the Environment in the Americas: The Paradoxes of Mining. *IdeAs*. 2016;(8). Available from: http://journals.openedition.org/ideas/1639. https://doi.org/10.4000/ideas.1639.
3) Hubert M, Debra P, Luis R, Jorge C. Mining pollution: an integrated methodology from spatial analysis. *International Congress Geo Tunis, 5th edition*. 2020;p. 25. https://doi.org/10.3406/edyte.2014.1273.
4) Bohbot J. The Manufacture of Standards in Gold Panning: Between Attempts at State Formalization and Self-Regulation of the Sector, Case Study of the Gold Miners of Vihiga and Kakamega, Western Kenya. *Afrique contemporaines*. 2024;(277):9–51. https://doi.org/10.3917/afco1.277.0029.
5) Forest Inventory Program (PIF) report. Artisanal gold mining and sustainable agriculture in Burkina Faso. *Partnership for Action on a Green Economy (PAGE) initiative managed by the United Nations Environment Programme, (UNEP)*. 2019;p. 64. Available from: https://www.un-page.org/news/artisanal-gold-mining-and-sustainable-agriculture/.
6) UNEP Report. Highlights of the organization's work in tackling the triple global crisis of climate change, loss of nature and biodiversity, and pollution and waste. *UN Environment Program UNEP 2020*. 2020. Available from: https://www.unep.org/fr/resources/unepannual-report.
7) Zonata R. Direct effects of mining activities on land resources around the Pô Nazinga Sissili ecological complex in Burkina Faso. *International Journal of Natural Resource Ecology and Management*. 2025;10(1):42–58. https://doi.org/10.11648/j.ijnrem.20251001.14.
8) Digbeu MP. Monitoring of environmental pollution by cyanide and study of its dynamics on gold panning sites in Burkina Faso: the case of the zougnazagmiline and galgouli sites. *Thesis for the obtaining of the master in Water and Environmental Engineering (2IE)*. 2017;p. 65.
9) Lasne G, Fernandez JM, Laugier T, Letourneur Y, Payri EC. Guide to monitoring the quality of the marine environment in New Caledonia. Nickel and its Environment;vol. 2. 2022. https://doi.org/10.34928/dr77-sz84.
10) Sawadogo E, Da DEC. Enjeux de la mutation des techniques artisanales sur la formalisation de l'exploitation de l'or au Burkina Faso. *Open Edition Journals EchoGéo 58/2021 Varia*. 2021. Available from: https://journals.openedition.org/echogeo/22710.
11) Sama A, Ramdé Z, Ouédraogo PC, Sikuzani YU, Salomon W, Dipama JM, et al. Anthropogenic Actions and Land Use Dynamics around Corridor No. 1 of the Pô-Nazinga-Sissili Ecological Complex in Burkina Faso. *Tropicultura*. 2023. Available from: https://popups.uliege.be/2295-8010/index.php?id=2200.
12) Zougmoré WDA. Challenges and limits of the governance of the PONASI ecological complex: perspectives for a better conservation of forest resources in Burkina Faso in the context of decentralization. *PhD thesis in geography, option: natural resource management LERMIT Laboratory, Joseph KI ZERBO University*. 2022;p. 261.
13) Degila WH, Azon NBN, Adounkpe JG, Akowanou OV, Aïna MP. Mercury: sources of emission, toxicity, contamination of the aquatic environment and particularity of Benin republic. *Int J Biol Chem Sci*. 2019;13(7):3429–3448.
14) Affessi AA, Koffi KGJC, Sangaré M. Social and Environmental Impacts of Gold Panning on the Populations of the Bounkani Region (Ivory Coast). *European Scientific Journal*. 2016;12(26). https://doi.org/10.19044/esj.2016.v12n26p288.