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Perceived Environmental and Socio-Health Impacts of Artisanal Gold Mining in the Banalia/Bangba Sector, Banalia Territory, Democratic Republic of the Congo

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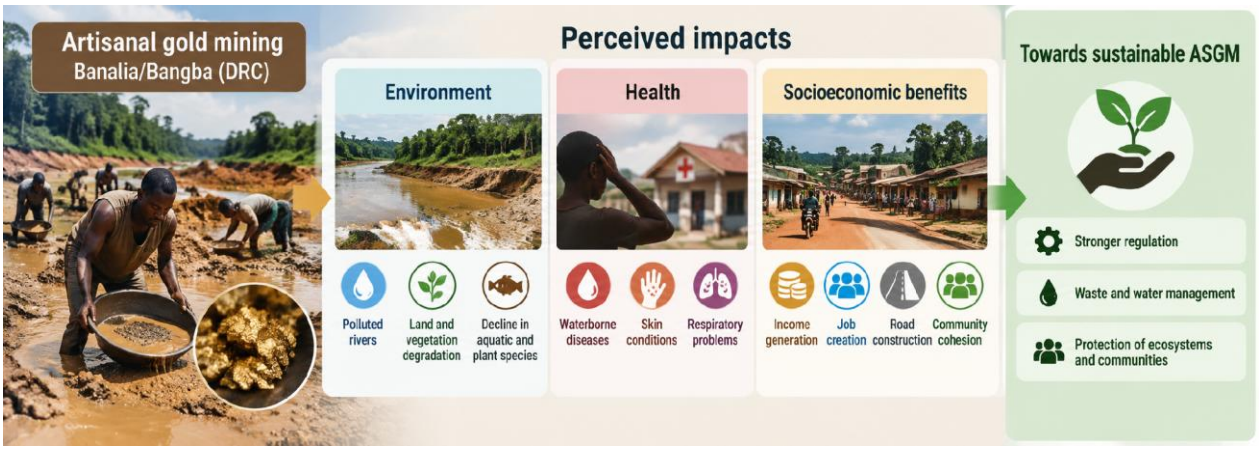
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Graphical Abstract

Artisanal mining is an important source of income for rural populations in the Democratic Republic of the Congo, but may also affect the environment and health. This study describes the perceived environmental and socio-health impacts of artisanal gold mining in the Banalia/Bangba sector, particularly river pollution, waste accumulation, degradation of soils and vegetation cover, and water-related diseases. As these findings are based on reported perceptions rather than analytical or clinical measurements, further investigations and strengthened environmental and health oversight are needed.



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Abstract: Artisanal mining is a source of income for many rural populations in the Democratic Republic of the Congo, but may affect the environment and health. This study describes the perceived environmental and socio-health impacts of artisanal gold mining in the Banalia/Bangba sector. A descriptive cross-sectional survey was conducted in 2021 among 100 key informants. Respondents mainly reported river pollution, waste accumulation, degradation of soils and vegetation cover, as well as water-related diseases. In the absence of analytical or clinical measurements, these observations do not allow a causal relationship to be established. Strengthened environmental and health oversight, together with further investigations, is therefore needed.

Keywords: *Artisanal gold mining, Environmental impacts, Health*

Introduction

Artisanal and small-scale gold mining (ASGM) constitutes an important economic activity in many developing countries. Worldwide, it provides livelihoods for several million people and supports various related activities, including trade, transport, catering and services [1].

The economic importance of this activity has increased over recent decades, particularly as a result of global demand for gold, changes in its price and the lack of formal employment opportunities in many rural areas. Artisanal gold mining can exert considerable pressure on the environment and population health.

The extraction and processing techniques used by artisanal miners are often poorly mechanized and insufficiently regulated in technical, environmental and health respects. They can lead to deforestation, soil degradation and erosion, siltation of watercourses, habitat destruction and, depending on the processes used, contamination of soils and water resources. Mining activities can also alter the living conditions of local populations.

The economic attractiveness of mining areas can lead to population movements and the arrival of workers, traders and other economic actors. This population growth may increase pressure on natural resources, health infrastructure and available social services.

In mining communities, inadequate sanitation infrastructure, overcrowding, limited access to safe drinking water and exposure to occupational hazards may contribute to public health problems [2].

The environmental consequences of artisanal mining can be pronounced in tropical forest regions, including destruction of forest cover, disturbance of watercourses, degradation of agricultural land, dust emissions and, in some contexts, chemical pollution of soils and water. The use of mercury (Hg) for gold amalgamation is, in particular, a major environmental and health concern [3].

In the Democratic Republic of the Congo, artisanal mining expanded significantly from the 1980s onwards, in the context of economic liberalization policies and changes in the regulation of the mining sector. The north-eastern and central-eastern provinces of the country, which contain substantial gold resources, are particularly affected. In these regions, artisanal gold mining represents an essential economic activity for many families and constitutes an important source of income in rural areas. It therefore contributes to local economic dynamics alongside agriculture, livestock farming and trade [4]. Banalia Territory, located in Tshopo Province, is among the areas characterized by substantial artisanal gold-mining activity. In the Banalia/Bangba Sector, this

activity contributes to the livelihoods of local populations, but is also accompanied by significant changes to the natural environment.

The use of mercury in gold ore processing constitutes, in particular, an environmental and health concern. Prolonged exposure to mercury, combined with deforestation, soil disturbance and the destruction of alluvial terraces, may contribute to the contamination of soils and watercourse sediments and alter aquatic and terrestrial habitats. In the longer term, these changes may affect the ecological functioning of ecosystems and increase the risks of exposure among local populations [5,6].

Although several studies have documented the environmental effects of artisanal mining in different regions of the DRC, data specifically addressing the environmental and socio-health consequences of artisanal gold mining in the Banalia/Bangba Sector remain limited. In particular, the available local data do not allow an integrated characterization of community perceptions concerning water, waste, biodiversity and health problems associated with mining sites.

This is an important gap because ASGM constitutes a priority sector in development and poverty-reduction policies in the DRC. It also has direct links with several Sustainable Development Goals (SDGs), particularly those relating to poverty eradication, health, access to safe drinking water, ecosystem protection and the promotion of sustainable communities [7,8].

In this context, the present study aims to describe the perceived environmental and socio-health impacts of ASGM in the Banalia/Bangba Sector, Banalia Territory. More specifically, it seeks to document the forms of environmental degradation reported by local stakeholders, the health problems reported, and the perceived socio-economic benefits of ASGM activities.

Materials and Methods

Study Area

The study was conducted in 2021 in the Banalia/Bangba Sector, located in Banalia Territory, Tshopo Province, Democratic Republic of the Congo. This area is characterized by ASGM activities that constitute an important source of income for part of the local population. Artisanal mining takes place within a rural environment where populations also depend on natural resources for agriculture, fishing, hunting, forestry and other subsistence activities. This coexistence of mining and rural activities makes the analysis of these interactions particularly important. Figure 1 below shows the different sites within the study area.

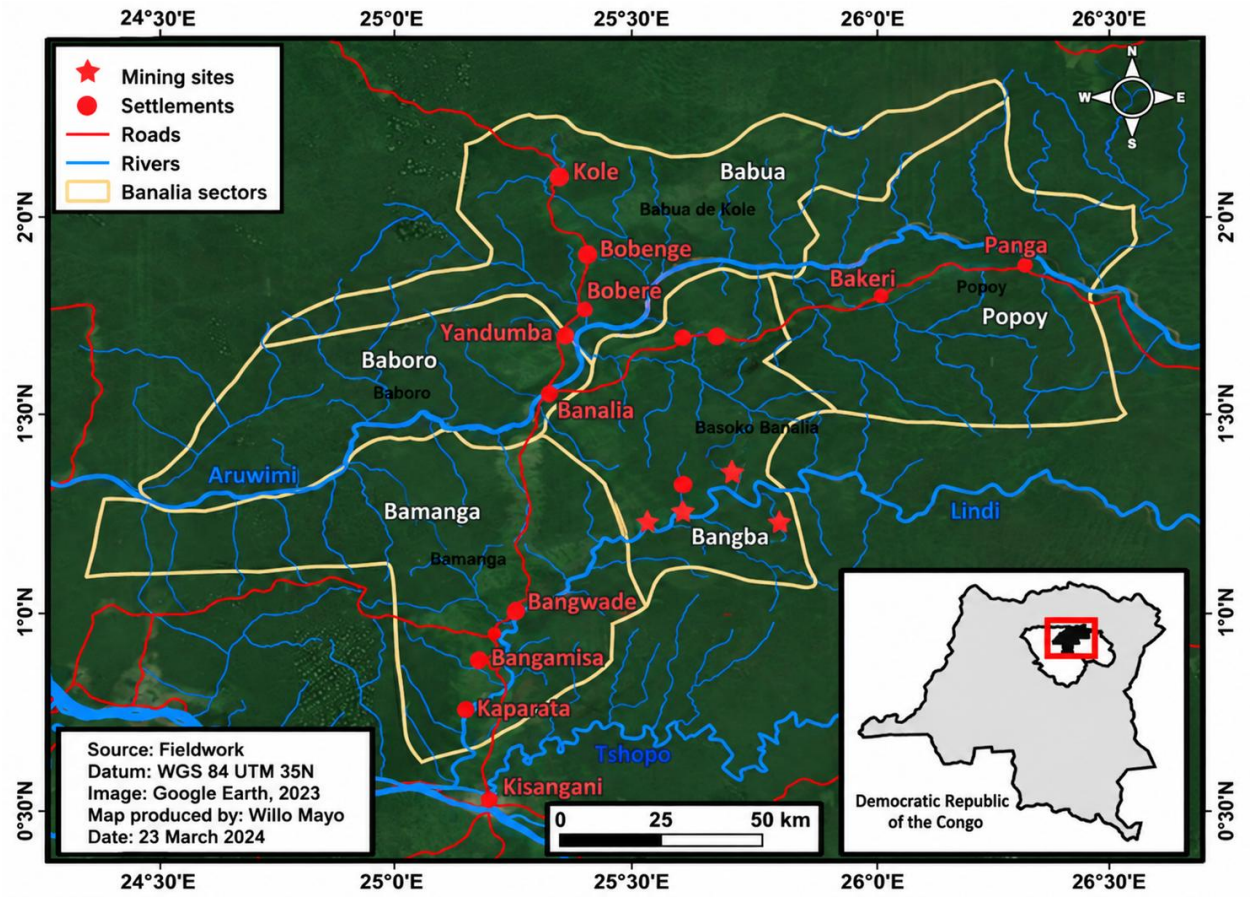


Figure 1. Map of the study area showing mining sites and settlements in the Banalia–Bangba sector

Methodological Approach and Data Analysis

This was a descriptive cross-sectional purposive survey with qualitative and quantitative components, conducted in 2021. Semi-structured interviews were used to collect the perceptions, experiences and observations of stakeholders familiar with the realities of artisanal mining in the Banalia/Bangba sector. These interviews yielded data which the research team examined to study environmental changes, sanitation conditions, reported health problems and the perceived socio-economic impacts of mining activities.

The sample comprised **100 participants**, selected on the basis of their knowledge of the local context, experience of mining activities or involvement in community life. The source version specifies neither the source population nor the formal inclusion and non-inclusion criteria, the detailed recruitment procedure, or a sample size calculation. Consequently, this non-probability

sample does not allow the statistical representativeness of the sector's entire population to be estimated. The interviews addressed gold-mining practices, observed environmental changes, water resources, waste management, reported health problems and the perceived socio-economic impacts of mining activities.

Following data collection, open-ended responses were grouped into thematic categories using content analysis. Categorical variables derived from the coding were entered into Excel and summarized using frequencies and proportions. Chi-square goodness-of-fit tests were used to assess whether the observed frequencies differed significantly from an equal distribution across response categories. The null hypothesis assumed equal expected frequencies among categories. Statistical significance was set at $p < 0.05$.

Results and Discussion

The results concern the composition of the sample, waste and sanitation, river pollution as perceived by respondents, areas of sites reported as degraded, aquatic and plant species reported as having become rarer, reported health problems, and the perceived socio-economic impacts of mining activities.

Environmental Impacts

The 100 participants represented six socio-professional categories, as shown in Table 1.

Table 1. Socioprofessional categories of the study participants

No.	Participant category	n	%
1	Artisanal miners	30	30
2	Local residents	20	20
3	Local authorities	20	20
4	Gold traders	15	15
5	Mine operators	10	10
6	Others	5	5
Total		**100**	**100**

The distribution of respondents differed significantly among the six professional categories ($\chi^2 = 23.00$, df = 5, $p < 0.001$). Artisanal miners were the most represented category (30%), followed by local residents and local authorities (20% each), then mine operators and other participants represented 10% and 5%, respectively.

Waste was frequently cited as a source of deterioration of living conditions at the mining sites (Table 2). The accumulation of solid waste and wastewater, combined with inadequate waste collection and disposal systems, was reported as an environmental and public health concern. These data are based on participants' reports, not direct environmental measurements.

Table 2. Participants' perceptions of waste as a factor contributing to environmental degradation at mining sites

No.	Response	n	%
1	Source of insanitary conditions	28	56
2	Perceived health hazard	14	28
3	Source of unpleasant odours	8	16
Total		**50**	**100**

The distribution of responses concerning the main nuisances differed significantly among the three categories ($\chi^2 = 14.08$, df = 2, $p < 0.001$). Sources of insanitary conditions were the most frequently reported nuisance (56%), followed by perceived health hazards (28%) and unpleasant odours (16%).

Regarding the question on the condition of the rivers presented in Table 3, respondents associated this situation with the washing of gold-bearing sands and the absence of sanitation facilities in some camps. These results reflect a perception of pollution.

Table 3. Participants' perceptions of the pollution status of rivers

No.	Response	n	%
1	River reported as polluted	75	75
2	River reported as not polluted	25	25
Total		**100**	**100**

The perception of river pollution differed significantly between the two response categories (χ^2 = 25.00, df = 1, $p < 0.001$). Overall, 75% of respondents reported the river as polluted, but 25% reported it as not polluted.

For the four sites presented in Table 4, the areas reported as degraded totalled **13 ha in 2021**.

Table 4. Number of artisanal miners and areas reported as degraded at each mining site

No.	Mining site	Number of artisanal miners	Reported degraded area (ha)
1	Lolima	40	7
2	Guma	25	3
3	Bogbolo	20	2
4	Mavi Tshopo	15	1
Total		**100**	**13**

The analysis of the relationship between the number of artisanal miners and the area reported as degraded revealed a **very strong positive linear correlation** (r = 0.997; p = 0.0026). This association was statistically significant at the 5% level. Across the four sites, higher numbers of artisanal miners were associated with larger reported degraded areas. Given the small number of sites and the reported nature of the degraded-area estimates, this association should be interpreted cautiously.

Table 5. Aquatic species reported as having become rare or locally disappeared

No.	Vernacular name	Scientific name	n	%
1	Sulu	*Labeo longipinnis*	15	15
2	Foka	*Chrysichthys nigrodigitatus*	10	10
3	Ndakalla (sardines)	*Stolothrissa tanganicae*	12	12
4	Mbenga	*Hydrocynus goliath*	14	14
5	Sela	*Labeo degeni*	8	8
6	Mboto	*Distichodus sexfasciatus*	13	13
7	Ngolo (catfish)	*Clarias gariepinus*	15	15
8	Apili (oysters)	*Ostrea metazoa*	13	13
Total			**100**	**100**

The distribution of the reported aquatic species did not differ significantly from an equal distribution ($\chi^2 = 3.36$, df = 7, p = 0.850). Frequencies ranged from 8% for *Labeo degeni* to 15% for *Labeo longipinnis* and *Clarias gariepinus*.

Regarding the flora, participants notably cited *Gilbertiodendron dewevrei*, *Pericopsis elata*, *Vernonia amygdalina* and *Entandrophragma cylindricum* as species that had become locally rarer

Table 6. Plant species reported as having become rare or locally disappeared

No.	Vernacular name	Scientific name	n	%
1	Limbalu	*Gilbertiodendron dewevrei*	30	30
2	Mogoya	*Pericopsis elata*	25	25
3	Botuma	*Vernonia amygdalina*	30	30
4	Liboyo	*Entandrophragma cylindricum*	15	15
Total			**100**	**100**

The distribution of the reported plant species did not differ significantly from an equal distribution ($\chi^2 = 6.00$, df = 3, p = 0.112). *Gilbertiodendron dewevrei* and *Vernonia amygdalina* were the most frequently reported species (30% each), followed by *Pericopsis elata* (25%) and *Entandrophragma cylindricum* (15%).

Socio-health Impacts

Table 7. Health problems reported by participants

No.	Reported health problem	n	%
1	Reported skin conditions	30	30
2	Reported waterborne diseases	50	50
3	Reported respiratory problems	20	20
Total		**100**	**100**

The distribution of reported health problems differed significantly among the three categories ($\chi^2 = 14.00$, df = 2, $p < 0.001$). Waterborne diseases were the most frequently reported health problem (50%), followed by skin conditions (30%) and respiratory problems (20%).

The distribution of perceived socio-economic benefits differed significantly among the five categories ($\chi^2 = 77.50$, df = 4, $p < 0.0001$). Wealth creation was the main social value identified by respondents, accounting for 50% of responses, followed by job creation (30%) and road construction (10%). Coexistence among communities and a reduction in banditry each accounted for 5% of responses.

These results show that economic benefits, particularly wealth and job creation, occupy a predominant place in respondents' perceptions of the social benefits of the activities studied.

Table 8. Summary of chi-square goodness-of-fit tests for the variables investigated

Variable	χ^2	df	*p*-value	Statistical significance
Professional category	23.00	5	< 0.001	Significant
Insanitary conditions/nuisances	14.08	2	< 0.001	Significant
River perceived as polluted/not polluted	25.00	1	< 0.001	Significant
Aquatic species	3.36	7	0.850	Not significant
Plant species	6.00	3	0.112	Not significant
Reported health consequences	14.00	2	< 0.001	Significant
Perceived socio-economic benefits	77.50	4	< 0.0001	Significant

Note: χ^2 = chi-square statistic; df = degrees of freedom.

Discussion

The study was based on a descriptive cross-sectional purposive survey conducted using semi-structured interviews and content analysis, supplemented by frequencies and proportions. Given the nature of the sampling and the absence of direct environmental or clinical measurements, the discussion should focus on perceived impacts rather than on causally demonstrated effects.

The sample comprised 100 participants belonging to several stakeholder categories: artisanal miners, local residents, local authorities, traders, mine operators and other resource persons.

The composition of the sample was as follows: artisanal miners, 30%; local residents, 20%; local authorities, 20%; traders, 15%; mine operators, 10%; and other categories, 5%. These proportions correspond to Table 1.

The results highlight the perceived duality of artisanal and small-scale gold mining (ASGM): the activity is associated with local economic benefits, and is also described by participants as a source of environmental and socio-health pressures.

The high representation of artisanal miners (30%) reflects the study's strategy for selecting resource persons. Owing to the non-probability sampling approach, however, this proportion cannot be used to estimate their actual representation within the population of the sector.

Table 4 shows a strong positive correlation between the number of artisanal miners and the reported degraded area across the four mining sites ($r = 0.997$, $p = 0.0026$). This result should be interpreted

cautiously because it is based on only four sites and the method used to estimate the degraded areas was not documented. The observed association therefore does not establish a causal relationship between the number of artisanal miners and land degradation.

The perceived environmental impacts concerned several environmental components: water, soils, sanitation and biodiversity [9]. But, the study did not include instrumental measurements to quantify water quality, chemical contamination, air quality or changes in biodiversity.

Regarding water and waste, 75% of respondents reported that the rivers were polluted, and waste was described as a source of insanitary conditions, health risks and unpleasant odours. These findings are consistent with a local perception of deterioration in living conditions, but they should be distinguished from an analytical demonstration of pollution.

Environmental degradation and deterioration of water quality have also been documented in artisanal gold-mining areas elsewhere in sub-Saharan Africa [10]. Unlike those analytical studies, the present findings represent respondents' perceptions and were not confirmed by physicochemical measurements.

Tables 5 and 6 list aquatic and plant species reported as having become rarer or having disappeared locally. These observations are particularly relevant in the forest context of Tshopo Province, which supports substantial biological diversity and forms part of the wider Congo Basin forest ecosystem [11,12]. In the absence of standardized inventories, comparable historical data and control sites, it is not possible to attribute these changes to mining activities or to conclude that there has been a 'collapse' in biodiversity. Rather, these findings represent ecological signals that should be investigated through dedicated field studies.

Waterborne diseases (50%), skin conditions (30%) and respiratory problems (20%) were the main reported health categories. Their coexistence with sanitation problems and perceived river pollution is a matter of concern, but the study does not allow a causal relationship to be established. In other African artisanal gold-mining contexts, mercury exposure has been investigated through both fish contamination and human exposure assessments [15]. Such evidence cannot be extrapolated directly to Banalia/Bangba, but it supports the need for targeted biomonitoring and environmental analyses in the study area.

The perceived positive impacts were mainly economic: wealth creation (50%) and job creation (30%). These perceived benefits should also be considered within the broader socio-economic and

institutional dynamics of artisanal gold production in the DRC, including the informal production and trading arrangements [11]. Other responses concerned road construction (10%), coexistence among communities (5%) and a reduction in banditry (5%). These data illustrate the socio-economic importance attributed to artisanal gold mining by respondents, but they do not allow the actual distribution of income or public and private investment to be assessed, owing to the absence of dedicated economic data.

Overall, the findings describe a local trade-off between perceived economic benefits and reported environmental and health pressures. They support the relevance of regulating ASGM through measures that integrate waste management, access to water and sanitation, reduction of chemical exposures, and ecosystem protection. Mercury use nevertheless remains a major concern in Congolese artisanal gold mining, where local perceptions of exposure and environmental risk have previously been documented [13-15]. But, any recommendation concerning the cessation or substitution of mercury use at the Banalia/Bangba sites should be based on confirmation of its actual use and on a characterization of local processes.

Conclusion

This descriptive cross-sectional survey, conducted in 2021 among 100 resource persons, highlights several perceived environmental and socio-health impacts of artisanal gold mining in the Banalia/Bangba sector. Respondents mainly reported river pollution, waste-management problems, degradation of land and vegetation cover, the local decline of certain species, and health problems dominated by reported waterborne diseases. At the same time, they highlighted economic benefits, particularly wealth and job creation. Owing to the purposive sampling approach and the absence of direct environmental, biological or clinical measurements, these findings should be interpreted as reported perceptions and observations. They are not a causal demonstration of the effects of artisanal gold mining. Similar interactions between artisanal mining, rural livelihoods, employment and local socio-economic transformations have been documented in other West African mining contexts.

It is recommended that environmental and health oversight of mining sites be strengthened, together with waste and wastewater management, protection of water sources, and prevention of occupational and chemical exposures. The presence of mercury and the ways in which it is used at the sites studied should be documented before quantifying or attributing any specific risk to this metal.

Further studies are needed to assess the reported observations objectively, including physicochemical and microbiological analyses of water, soil and sediment analyses, standardized ecological inventories, and epidemiological studies with explicit definitions of exposures and health outcomes. Such investigations would make it possible to estimate potential contamination levels and assess associations between mining-related exposures and health without drawing conclusions beyond what the data support.

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