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(RESEARCH ARTICLE)

Assessment of environmental compliance of the mining rehabilitation plan of "NASEGA RESSOURCES SARL" in Yakassé-Attobrou (Côte d'Ivoire)

Kinanpara KONE [1, 2, *], Zilé Alex KOUADIO [1], Jean Renaud ALLOUKO [2], Kouamé Edmond YAO [1] and Kotchi Yves BONY [2]

[1] *Department of Environment, Laboratory of Environmental Sciences and Technologies, University Jean Lorougnon Guédé, BP 150 Daloa, Côte d'Ivoire.*
[2] *Department of Environment, Laboratory of Biodiversity and Tropical Ecology, University Jean Lorougnon Guédé, BP 150 Daloa, Côte d'Ivoire.*

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Abstract

This study is part of a critical assessment of the conformity of the environmental rehabilitation plan applied in the context of a semi-industrial gold mining operation. The study aims to assess the relevance and effectiveness of the actions implemented with regard to the Ivorian mining code of 2014, interministerial decree n° 0026/MINEDD/MMG/2019 as well as international standards. The methodology adopted combines field observation, local survey, semi-structured interviews, regulatory analyses and GIS processing. The analysis is structured around three axes: the initial state of the site, the impacts of mining activities and the technical quality of the rehabilitation measures. The results reveal that only 32% of pits are properly backfilled, with signs of erosion, partial revegetation of the soil, and poorly recycled waste. Deficits in environmental monitoring and the low involvement of authorities constitute major limitations. This work proposes technical and institutional recommendations for better post-exploitation ecological governance. It is part of a dynamic of continuous, practical and rigorous strengthening of the regulatory, normative, operational, scientific, environmental, socio-economic and cultural framework of contemporary, inclusive and truly sustainable semi-industrial gold mining in Côte d'Ivoire.

Keywords: Environmental rehabilitation; Semi-industrial exploitation; Regulatory compliance; Mining station management; Côte d'Ivoire

1. Introduction

Mining is a major economic activity in many parts of the world, particularly in sub-Saharan Africa, where abundant exploitable mineral deposits offer significant development opportunities. In Côte d'Ivoire, gold represents a strategic resource, both for diversifying export revenues and for boosting local economies. Over the past decade, the growth of semi-industrial and artisanal mining has contributed to strengthening this dynamic. However, these often poorly regulated forms of mining are the source of widespread environmental degradation and social tensions. The Yakassé-Attobrou department, located in the southeast of the country, is particularly affected by this issue due to the presence of gold deposits exploited by companies such as NASEGA RESSOURCES SARL. This company operates in a semi-industrial setting, with technical resources intermediate between artisanal and heavy industry. While this activity provides employment and income for some local communities, it also poses significant challenges in terms of environmental management and the restoration of degraded areas. Indeed, according to **[1]** and **[2]**, small-scale mining contributes to deforestation, soil degradation, and water pollution, particularly through the uncontrolled use of toxic substances such as mercury and cyanide. **[3]** confirm that mining activity is now one of the main drivers of biodiversity

* Corresponding author: KONE Kinanpara

loss in tropical areas. These facts necessitate the implementation of rigorous ecological rehabilitation strategies to restore ecosystem functions after site closures. Mining site rehabilitation is an essential step in the life cycle of responsible mining. It aims not only to restore the ecological integrity of affected areas, but also to prevent the risks of long-term contamination and enable the productive reuse of land. However, in Côte d'Ivoire, the implementation of rehabilitation plans often remains limited due to a constantly evolving regulatory framework, limited technical resources, and a lack of systematic monitoring [4]. Numerous studies have demonstrated the harmful effects of small-scale gold mining, particularly in West Africa [5]. However, few studies have focused on designing rehabilitation plans adapted to the specific socio-environmental conditions of local areas in Côte d'Ivoire, and even fewer in the Yakassé-Attobrou region. This study aims to fill this gap by developing a methodological framework to assess impacts, examine existing standards, and propose concrete and contextualized measures. The overall objective of this study is to evaluate the environmental compliance of the rehabilitation plan implemented by NASEGA RESSOURCE SARL for its semi-industrial gold mining operation in the Yakassé-Attobrou department.

2. Material and Methods

2.1. Study area

The NASEGA mining area, owned by KASSA GOLD S.A., is located in the Yakassé-Attobrou department, Mé region, in southeastern Côte d'Ivoire. The mining area covers 25 square kilometers and is delimited by the following approximate geographical coordinates: 6°00' - 6°05' North latitude and 3°45' - 3°50' West longitude, according to the Directorate General of Mines and Geology. The area is accessible via the A1 national highway linking Abidjan to Abengourou, and then by a 35-kilometer departmental road leading to Yakassé-Attobrou. A network of secondary tracks serves the various mining sites within the area, sometimes making access difficult during the rainy season [6] (Figure 1).

2.2. Methodology

The methodology applied is based on a combination of rigorously planned and executed qualitative and quantitative approaches over a period of twelve (12) weeks, from March 20 to June 12, 2025. The study was carried out through field visits for data collection and a phase of analysis of the collected data.

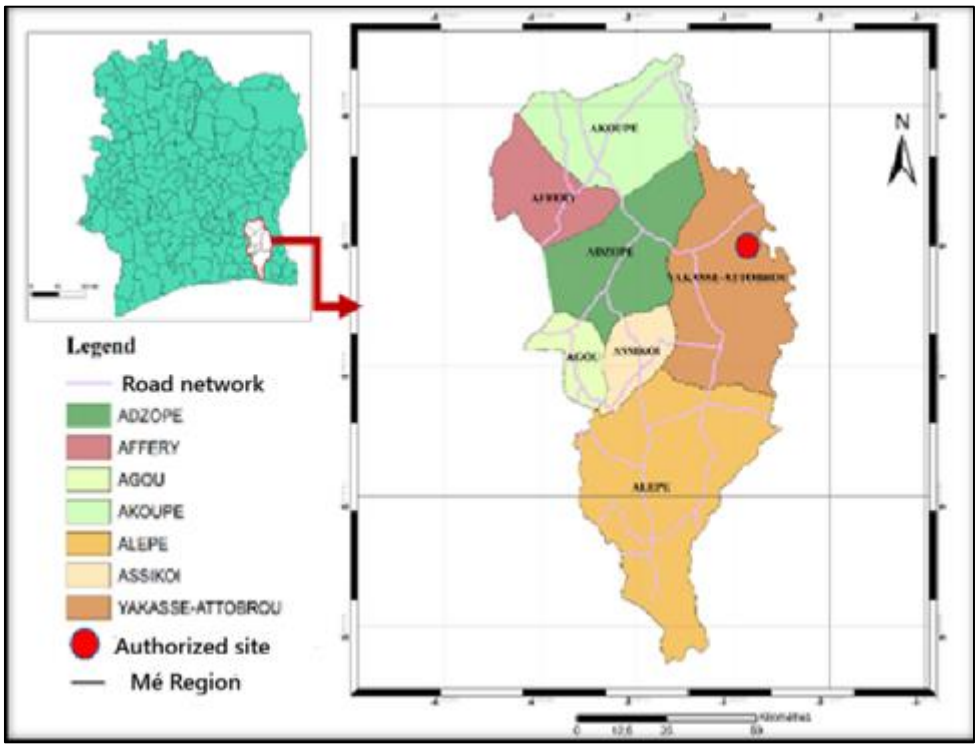

Figure 1 Location of study areas

2.2.1. Direct Observation and Georeferenced Surveys

This method consisted of systematic visual observations and spatial surveys to identify and locate the environmental impacts caused by semi-industrial gold mining.

Field visits

Regular visits were conducted to the main mining sites: extraction areas, storage areas, processing areas, and surrounding aquatic environments. The objective was to identify and describe the observed degradation (deforestation, erosion, water pollution, etc.).

Data collection

Observations were recorded in a field notebook and on standardized observation forms, including a description of the impact, its estimated intensity, explanatory factors, and illustrative photographs.

GPS Surveys

Each observation was georeferenced using a handheld GPS device (e.g., Garmin eTrex). The coordinates made it possible to precisely locate the impacted areas and to prepare thematic maps.

2.2.2. Regulatory document analysis

This method aimed to assess the compliance of mining activities with applicable regulatory and normative requirements. The different stages of this analysis were as follows:

Collection and consultation of regulatory texts and reference guides, including the Mining Code of Côte d'Ivoire and the ANDE (National Environment Agency) Guide relating to environmental impact assessments and the rehabilitation of mining sites;

Extraction of specific requirements applicable to environmental rehabilitation and protection (e.g., soil remediation, water protection, waste management, vegetation restoration);

Development of a structured compliance grid across several impact areas, such as soil, water, and waste management, biodiversity conservation, and occupational health and safety;

Scoring by impact area. For each requirement, a rating system was applied using a scale (e.g., 0 = non-compliant, 1 = partially compliant, 2 = compliant) to assess the level of compliance with regulatory obligations;

Gap analysis and recommendations. The scores obtained were analyzed to identify key shortcomings and formulate corrective or preventive actions to improve environmental compliance.

2.2.3. Structured questionnaire survey

This quantitative approach allowed for the collection of objective data on the perceptions and expectations of local residents regarding the mining operation and the planned rehabilitation activities. Data collection took place from March to May 2025. A purposive sample of 600 adults was selected from six localities in the immediate vicinity of the site. The selection process considered age, gender, and geographic location to ensure adequate representativeness. A structured questionnaire, including Likert scales, closed-ended questions, and dichotomous questions, was administered face-to-face using tablets and Kobo-Collect software, guaranteeing the reliability and security of the data collected. The data were checked by a double check (automatic comparison and manual review), then exported to Excel and SPSS for descriptive statistical processing (frequencies, means, standard deviations), allowing the major perceptual trends to be identified.

2.2.4. Semi-structured interviews and focus groups

This qualitative approach aimed to better understand the perceptions, concerns, and expectations of stakeholders. Individual interviews were conducted with community leaders, representatives of local associations, mining operators, and administrative authorities. Six focus groups were also organized, each with 8 to 12 participants, including women and young people, to diversify perspectives. The interview guides were pre-tested and structured around four main themes:

- Knowledge of environmental impacts;
- Expectations regarding rehabilitation;
- Perception of community involvement;
- Level of trust in the mining operator.

The interviews and discussions were audio-recorded (with informed consent) and then fully transcribed. The transcripts were reviewed by two team members to ensure data reliability. Thematic coding **[7]** was used to classify the comments according to recurring themes and to identify convergences and divergences. Analysis of the verbatim transcripts provided qualitative insight into the observed quantitative trends.

2.2.5. Data triangulation

To strengthen the robustness of the findings, a methodical triangulation was carried out by cross-referencing direct field observations, the results of the questionnaire survey, and the perceptions expressed during interviews and focus groups. This approach, inspired by the recommendations of **[8]**, aimed to distinguish perceptions confirmed by the facts from more subjective representations. The triangulation made it possible to verify the consistency of the information and to propose recommendations supported by a convergence of sources.

2.2.6. In-depth documentary analysis of the rehabilitation plan

This method involved conducting a systematic and comparative study of the content of the rehabilitation plan developed by the mining operator. The analysis was carried out in several stages:

- Collection of reference documents: official rehabilitation plan, national regulations, and relevant international standards;
- Development of a compliance checklist: a comparative table was created to verify, point by point, legal obligations and good environmental practices (soil management, habitat restoration, water treatment, site security, implementation schedule, etc.);
- Assignment of a compliance score: each action proposed in the plan received a score (compliant, partially compliant, non-compliant), allowing for the calculation of an overall compliance score and the identification of deficiencies;
- Summaries and recommendations: the identified discrepancies were presented in tabular and analytical text format, accompanied by corrective suggestions.

3. Results

3.1. Environmental assessment of semi-industrial gold mining

In this study, 34 points distributed across the entire mining site were inspected. These inspections aimed to demonstrate the impact of gold mining on the environment. They allowed for the identification of the main types of visible environmental degradation and their location and frequency (Figures 2 and 3).

Figure 2 Types of environmental degradation

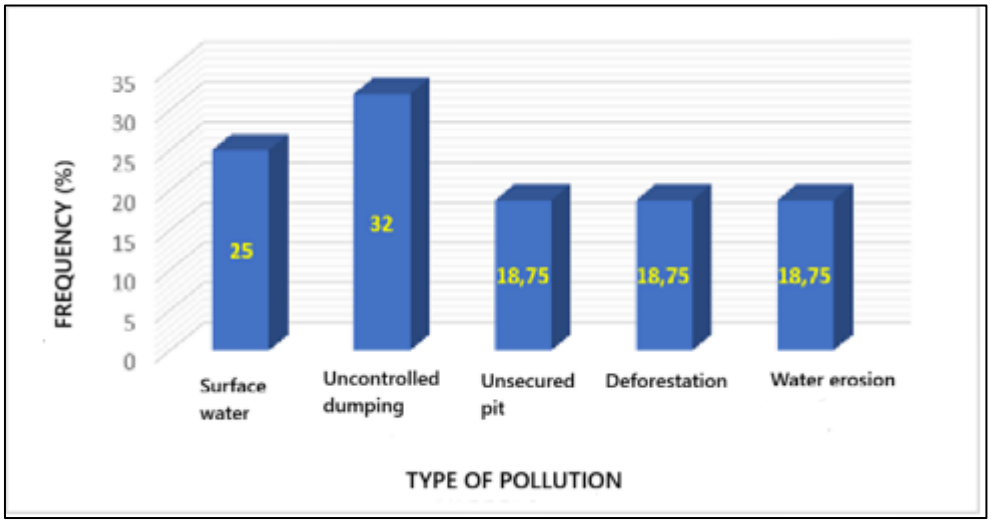

Figure 3 Frequencies of environmental degradation

3.2. Socio-demographic characteristics of the population

The interviews allowed us to define the socio-demographic profile of the residents (Table I).

Table 1 Simulated socio-demographic characteristics of the residents

Localities	Modeled workforce (%)	Men (%)	Women (%)	18-35 years (%)	36-60 years (%)	≥ 60 years (%)
Yakassé Attobrou	20	56	44	52	38	10
Abradine 1	16,7	53	47	48	41	11
Abradine 2	15	58	52	45	43	12
Gbato	15,8	50	50	60	30	10
Montezo	16,7	54	46	55	35	10
Yadio	15,8	49	51	50	40	10
Total	100	53,3	46,7	51,7	37,8	10,5

The table above shows that the local population is predominantly young adults (18-35 years old) at 51.7%. There is a slight male predominance (53.3%) due to mining activities being traditionally male-dominated. Yakassé-Attobrou is the most represented locality (20%) in the modeled population and is located in the immediate vicinity of mining areas. This data allows us to identify the social categories most sensitive to the impacts and to plan targeted actions based on age, sex, and area of exposure. The modeling shows an overall moderate perception (average approximately 3) of environmental impacts. Noise pollution and air pollution are the most frequently felt impacts (Table II).

Analysis of community expectations, simulated based on field observations of 600 people, reveals strong support for rehabilitation measures. The priorities expressed are soil restoration (82%), reforestation (77%), water sanitation (69%), and safe waste management (65%). Community participation is also considered essential (60%) (Figure 4).

Table 2 Perception of environmental impacts

Impact	Note 1 (%)	Note 2 (%)	Note 3 (%)	Note 4 (%)	Note 5 (%)	Average	Standard deviation
Deforestation	21,2	18,5	18	22,3	20,2	3,02	1,44
Water Pollution	21,3	20,3	20	17,7	20,7	2,96	1,44
Soil degradation	20	19,8	20	19,7	20,5	3,01	1,42
Air pollution	19,3	21,7	17	20,7	21,7	3,04	1,44
Loss of biodiversity	21,2	17	20	23	19,2	3,02	1,42
Noise pollution	19,3	18,3	21	21	20,7	3,05	1,41

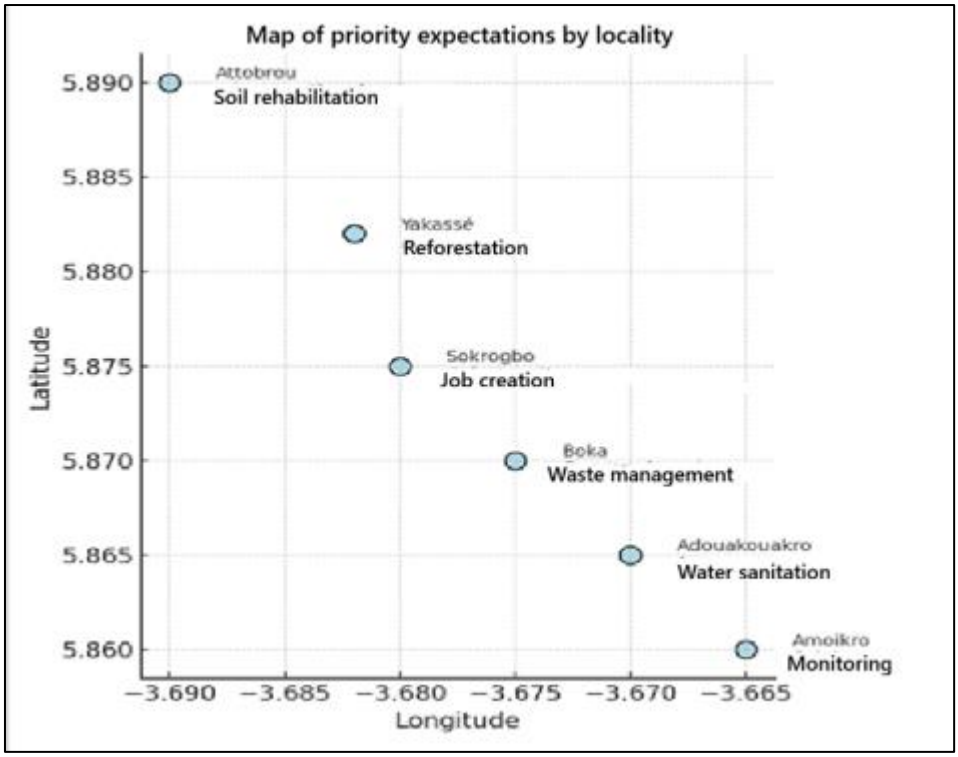

Figure 4 Priority expectations of the population

3.3. Synthesis of the themes of representations and expectations of local stakeholders

The analysis of semi-structured interviews conducted with traditional authorities, association leaders, farmers, and local youth, as well as the focus group composed of a representative sample of the community, highlights several key themes. These representations reveal a keen awareness of the impacts of mining, but also very clear expectations regarding environmental rehabilitation. Three main themes emerge.

3.3.1. Ecological degradation perceived as irreversible without intervention

Interviewees reported a profound disruption of the natural environment, including the disappearance of vegetation cover, pollution of waterways, and the transformation of arable land into barren wasteland. The impact is considered not only visible but also long-lasting if serious corrective measures are not taken.

3.3.2. Rehabilitation expected as a right, not a favor

The expectations expressed are not simply a desire for improvement, but rather a civic demand. There is a demand for effective land redevelopment, soil restoration, slope stabilization, and reforestation with useful local species (shea, teak, iroko). The utilitarian approach prevails: rehabilitation must generate a collective benefit.

3.3.3. Insufficient or even nonexistent top-down communication

Respondents denounced insufficient or even nonexistent top-down communication between the company and the communities. A feeling of exclusion from decision-making processes is pervasive, reinforcing a climate of mistrust towards measures announced but not implemented. Community participation is seen as an essential condition for any credible rehabilitation effort.

The cross-analysis of these statements reveals a contrasting picture, highlighting both strong cohesion around certain values and strategic divergences in expectations (Table III).

Table 3 Summary analysis of convergence and divergence

Major convergences	Notable divergences
Shared environmental diagnosis	Timeframe of expectations
Value of involvement	Expected function of rehabilitated land
Expectation of a paradigm shift	Nature of co-inhabited participation

3.4. Regulatory document analysis

The document analysis was conducted using the legislative and regulatory texts governing mining activity and environmental rehabilitation in Côte d'Ivoire. This assessment was based on national laws (Mining Code, Environmental Code), implementing decrees (in particular Decree No. 2015-454 relating to environmental assessment), National Environment Agency technical guides, as well as international standards of good practice (in particular the IFC Performance Standards, especially Standard 6 on biodiversity) (Table IV).

Table 4 Compliance rating grid for rehabilitation actions

Domain	Score (on 5)	Justification for the score
Soil	3	Backfill present, no post-restoration monitoring measures
Water	1	No provisions regarding effluents or water quality
Biodiversity	2	Reforestation planned but without reference to local ecology
Waste	1	No management plan, failure to comply with minimum standards
Safety/risks	2	Lack of a clear post-closure safety plan

3.5. Operational recommendations for compliance

The recommendations are primarily regulatory:

- Revise the plan according to the requirements of Article 22 of Decree No. 2015-454, incorporating measurable environmental performance indicators;
- Include a regulatory annex listing, article by article, the legal obligations and the adopted means of achieving compliance.

They are also specific technical recommendations, developed based on deficiencies identified on-site, with the aim of ensuring a compliant, sustainable, and operational environmental remediation of the site (Table V).

Table 5 Proposed technical actions for remediation

Domain	Recommanded actions	Responsibles
Soil	Development of a geotechnical soil stabilization plan + agronomic monitoring	Geological Engineer
Water	Implementation of treatment plants + quarterly water quality monitoring	Hydrogeologist / Environmental Agency
Biodiversity	Differentiated reforestation with local species + refuge area for sensitive species	Ecologist
Waste	Development of a comprehensive mining waste management plan	Environnementalist
Security	Post-mining risk mapping + fencing + signage	Hygiene, Safety, Environment

3.6. Analysis of the rehabilitation plan

This analysis is based on a regulatory framework structured by area (soil, water, biodiversity, waste, safety) and aims to identify major discrepancies, technical shortcomings, and regulatory failures (Tables VI and VII). It constitutes a critical evaluation of the rehabilitation plan submitted by NASEGA RESSOURCES SARL, comparing it to Ivorian regulatory requirements and international performance standards.

Table 6 Comparison between rehabilitation plan and regulatory requierements

Theme	Regulatory or normative reference	Contents of NASEGA plan	Non-conformity or deviation identified
Soil	Art. 83 Mining code ; ANDE guide (2018)	Backfilling mentioned without any method, compaction, or drainage	No stabilization protocol or monitoring indicators
Water	Art. 41 Environmental code ; decree 2015-454	No wastewater treatment measures or hydrogeological monitoring	Violation of the obligation for continuous environmental monitoring
Biodiversity	Norme SFI PS6 ; ANDE Guide	Generic reforestation with eucalyptus, without prior ecological assessment	Choice of non-native species unsuited to the local environment
Waste	Art. 85 Mining code ; Law n°2014-138	No sorting, storage, or recycling provisions	Serious breach of hazardous waste management obligations
Security	Art. 47 Environmental code ; Norme ISO 45001	Simple mention of signage; no barriers or fencing	Incomplete post-closure risk management plan

Table 7 Plan compliance score by area

Domain	Score (on 5)	Justification
Soil	2	Backfilling announced, without a geotechnical study or post-intervention indicators
Water	1	No technical measures or monitoring campaigns defined
Biodiversity	2	Non-native species, no ecological assessment, and no refuge area
Waste	1	No management or storage system identified, despite legal requirements
Security	2	Vague mention of safety measures, no structured measures, and no risk mapping

3.6.1. Enhanced Critical Synthesis

The evaluation of the rehabilitation plan reveals serious shortcomings in legal, technical, and environmental terms. The plan does not meet the minimum requirements stipulated by Decree No. 2015-454 concerning environmental assessment, nor the standards of the Mining Code. None of the proposed actions are based on a measurable operational framework. Biodiversity is poorly addressed, water resources are not monitored, and waste management is entirely absent. The average score of 1.6/5 across all areas demonstrates a critical level of inadequacy. As it stands, this plan cannot be validated by the National Environment Agency or the relevant stakeholders and could jeopardize the project's social acceptability in the study area.

3.6.2. Operational recommendations by area

These recommendations, recorded in Table VIII below, outline by strategic area the operational actions to be implemented to guarantee effective, multi-sectoral environmental rehabilitation in accordance with regulatory requirements.

Table 8 Operational recommendations by domain

Domain	Actions	Responsibles	Recommended deadline
Soil	Geotechnical study + post-filling monitoring	Geologist + Engineering firm	3 months
Water	Quality campaign + mobile treatment plant	Hydrogéologist + Environmental Agency	6 months
Biodiversity	Ecological inventory + targeted restoration plan	Ecologist + local NGO	4 months
Waste	Development of a comprehensive waste management plan + secure storage	Certified environmentalist	2 months
Security	Risk mapping + marking + fencing	Hygiene, Safety, Environment manager + local company	3 months

3.7. Triangulation and cross-validation of results

Methodological triangulation is an essential step to ensure the reliability and robustness of the results obtained in the environmental assessment of the rehabilitation plan for the semi-industrial gold mining area of NASEGA Ressources SARL. It allows for the cross-referencing of data from quantitative analyses (satellite imagery, field statistics), qualitative analyses (semi-structured interviews, focus groups), and direct observations made in the field (Table IX). This table shows the relationships between the main variables identified from the three data sources used.

Table 9 Summary Cross-Referencing of data

Key variables	Quantitative data (GIS, statistics)	Qualitative data (interviews, focus groups)	Direct field observations
Degraded areas to be rehabilitated	24,6 ha identified (SPOT 6 imaging, NDVI < 0,2)	Local residents point to the former processing and extraction areas	Visible presence of bare soil, absence of plant regeneration
Prioritizing critical areas	Classification by high Ecological Disturbance Index (EPI). Its median is 69.10	Local residents are identifying areas near their homes as urgent	Severe erosion and intense gullying on unstable slopes
Reforestation and revegetation	No trace detected in 92% of areas in 2023	Strong preference expressed for fast-growing species	Lack of sowing, arid zone, presence of runoff
Effectiveness of security fences	Only 3.2% of the perimeter fenced according to GPS measurements	Concerns expressed about access for children and animals	Fences partially collapsed or non-existent
Condition of mine pits and drainage works	17 pits identified (depth > 1.5 m) not filled, with 35% and 30% stagnant water	Major fear of accident risks expressed in 75% of comments	Stagnant water, mosquito proliferation, visible waste

4. Discussion

This study aims to assess the environmental compliance of the rehabilitation plan implemented by NASEGA RESSOURCE SARL for its semi-industrial gold mining operation in the Yakassé-Attobrou department. Data from field surveys, interviews, and document analysis revealed a low level of compliance with environmental requirements. The radar chart clearly illustrates these deficiencies: the average compliance score does not exceed 4/10 for all key indicators (vegetation, backfilling, water management, social acceptability, and pit safety). The rehabilitated pits remain partially open, exposing local residents and livestock to the risks of accidents and contamination. These results corroborate the

findings of [9], which highlight the lack of a rigorous protocol for closing semi-industrial mining sites in Côte d'Ivoire. The NASEGA case is therefore no exception to this national trend. At the African level, the practices observed at Yakassé-Attobrou are comparable to the weaknesses documented in Ghana [10] or Burkina Faso [11], where rehabilitation is often perceived as a post-exploitation formality, rarely followed by tangible actions. In contrast, countries like South Africa require rehabilitation plans to be validated before the mine opens [12]. Internationally, Australia [13] requires operators to conduct periodic environmental audits, submit a restoration plan certified by independent geo-ecologists, and establish a rehabilitation trust fund. The gap is therefore clear: the NASEGA site suffers from a partial, or even non-existent, application of these robust standards. This mismatch between local practices and international standards raises questions about the urgent need to reform the Ivorian regulatory framework. Three major points stand out:

- Lack of systematic backfilling of pits: The failure to return excavated materials promotes the formation of acidic lakes, erosion zones, and the loss of agricultural land;
- Superficial revegetation: Some plantings are visible, but without ecological monitoring or soil restoration (topsoil, organic amendment);
- Virtually nonexistent community participation: No village environmental monitoring committee has been established, creating a sense of abandonment among the local communities.

These findings align with those of [14], which emphasize that mine rehabilitation in Côte d'Ivoire remains dominated by a logic of administrative compliance rather than genuine socio-ecological commitment. This work highlights new data on a poorly documented site, with GIS mapping of active, rehabilitated, and abandoned pits, as well as a cross-analysis of environmental performance. Unlike existing studies, which often remain descriptive, this research offers a structured assessment based on measurable indicators, making the diagnosis more robust and reproducible. The results call for the implementation of a participatory, certified, and georeferenced rehabilitation plan, based on three pillars:

- A digital environmental cadastre of exploited and rehabilitated areas;
- The requirement for an environmental guarantee fund to be paid before the site opens;
- The creation of village monitoring units trained in ecological practices.

This approach advocates for mining governance based on transparency, citizen participation, and environmental accountability. Despite its rigor, this work has certain methodological limitations. On the one hand, the lack of quantitative data from physicochemical analyses of the soil or water limits the depth of the environmental assessment. On the other hand, the absence of a broader panel of stakeholders in the interviews (local authorities, displaced populations, etc.) restricts the socio-political scope of the results. These limitations do not invalidate the conclusions but call for further, multidisciplinary research. The results undeniably demonstrate that the environmental rehabilitation carried out by NASEGA RESSOURCES SARL does not meet the requirements of the Ivorian mining code, nor African or international standards. This weakness is not isolated but symptomatic of an extractive model that shows little regard for the ecosystem and local communities.

5. Conclusion

The results of this research reveal a clear mismatch between the environmental rehabilitation plan of NASEGA RESSOURCES SARL in Yakassé-Attobrou and current national and international regulatory requirements. Field observations (poorly filled pits, lack of monitoring of revegetation) and marginalization of local communities reflect a rehabilitation conceived as an administrative formality rather than a lever for environmental governance. This study presents a critical approach based on the paradigm of strong sustainability, according to which rehabilitation cannot be reduced to minimal technical measures. It must integrate a strategic, proactive vision framed by binding mechanisms. The gap with international standards underscores the urgent need to strengthen the Ivorian regulatory framework, establish fiduciary guarantees, and implement truly operational monitoring mechanisms.

One of the major contributions of this work lies in the proposal of an inclusive rehabilitation model, based on: geospatial mapping of rehabilitated and abandoned sites; the institutionalized involvement of communities through village monitoring units; and the establishment of an environmental guarantee fund payable before exploitation. Despite certain limitations, notably the absence of physicochemical analyses, the postponement of spatial modeling, and the restricted panel of participants, the robustness of the qualitative and spatial methods used strengthens the validity of the conclusions. These constraints underscore the need for transdisciplinary approaches combining environmental expertise, mining law, geomatics, and social sciences. Yakassé-Attobrou is not an isolated case. It reflects the structural tensions of an African extractive model with weak local roots and low accountability. Rehabilitation must no longer be an end-of-cycle task, but a central pillar of mining planning. This study, both critical and forward-looking, is part of a

dynamic of transformation, promoting ethical, participatory, and scientifically grounded governance of mining activities in Côte d'Ivoire, in line with the Sustainable Development Goals.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there are no conflicts of interest that is relevant to the content of this article.

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