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The Impact of Mining Activities on Land Use/Land Cover (LULC) and Ecosystem Services in Sub-Saharan Africa: A Case of the Republic of Ghana using Systematic Review and Meta-Analysis

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Abstract
Mining operations in Sub-Saharan Africa, especially in Ghana, substantially modify Land Use/Land Cover (LULC) and impair ecosystem services (ES), presenting obstacles to environmental sustainability and human welfare. This study investigates the research topic by analysing the degree of mining effects on LULC and ES, with Ghana as a case study. The aims encompass evaluating deforestation rates, measuring ecosystem service losses, and identifying sustainable mining methodologies. A systematic review and meta-analysis technique was utilized, examining 86 papers from 2000 to 2025 to consolidate empirical evidence. Principal findings indicate that mining, particularly artisanal and small-scale mining (ASM), has resulted in a 304% escalation in land conversion, considerable deforestation (30–86% in certain areas), and the pollution of water bodies with heavy metals such as mercury. Large-scale mining (LSM) and artisanal ASM exert distinct influences on LULC, with ASM disproportionately contributing to environmental degradation. The analysis underscores deficiencies in policy, notably the insufficient enforcement of environmental restrictions and the lack of effective post-mining rehabilitation efforts. Recommendations entail the implementation of more stringent rules, active community involvement in oversight, and the use of environmentally sustainable mining methods. These findings seek to guide evidence-based policies that reconcile economic advantages with environmental preservation, in accordance with Sustainable Development Goals (SDGs) 6, 13, and 15. The study highlights the necessity for cohesive strategies to alleviate mining effects while sustaining livelihoods in Ghana and analogous regions in Sub-Saharan Africa.

Keywords
Mining activities, Land use and land cover, Ecosystem services sub-Saharan Africa, Systematic review, Meta-analysis

1. Introduction

Mining operations in Sub-Saharan Africa (SSA) have become essential catalysts for economic advancement, although they concurrently present considerable risks to environmental sustainability and ecological integrity. The mining sector in Ghana provides 13.7% of the national GDP and constitutes 40% of export revenues, underscoring its critical importance in the nation's economic framework (Adjei et al., 2024). The economic significance is evident through two distinct mining paradigms: LSM operations, predominantly led by multinational corporations such as Newmont and AngloGold Ashanti, which account for approximately 90% of gold exports while utilizing relatively small land areas, and artisanal and ASM activities, locally referred to as "galamsey", which employ over 1.1 million Ghanaians and generate 34-43% of national gold production while sustaining 4.4 million livelihoods (Barenblitt et al., 2021; Adu-Baffour et al., 2021; Mensah et al., 2025). The dichotomy between capital-intensive LSM and labour-intensive artisanal ASM engenders intricate socio-ecological

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dynamics that transcend Ghana's borders, with analogous patterns noted in several Sub-Saharan African nations, including Mali, Burkina Faso, and Sierra Leone, where mining accounts for 15-25% of national revenues, while informal mining sustains millions of rural livelihoods (Hilson, 2016; Ahmed et al., 2019).

The environmental consequences of these mining operations are intrinsically associated with alterations in LULC and the deterioration of ecosystem services that support human welfare and ecological equilibrium. From 2005 to 2019, mining operations in Ghana altered 47,414 hectares of natural vegetation, with artisanal and ASM accounting for 85.7% of this change, signifying a 304% increase in mining land cover within vital watersheds like the Pra River Basin (Barenblitt et al., 2021; Awotwi et al., 2018).

The alterations in LULC instigate a series of repercussions on ecosystem services, which the Millennium Ecosystem Assessment (2005) delineates as the advantages humans obtain from operational ecosystems. These encompass provisioning services (food, water, timber), regulating services (climate regulation, carbon sequestration, water purification), cultural services (spiritual values, recreation), and supporting services (nutrient cycling, primary production). In Ghana's mining-impacted regions, the degradation of ecosystem services is evident through mercury pollution in water bodies like the Offin River, a loss of forest carbon storage estimated at 74,300 hectares in the Pra Basin, a decline in avian diversity in protected areas such as the Oda Forest Reserve, and the desecration of sacred sites vital to traditional cultural practices (Rajaee et al., 2015; Awotwi et al., 2018; Abugre et al., 2025; Tengberg et al., 2012).

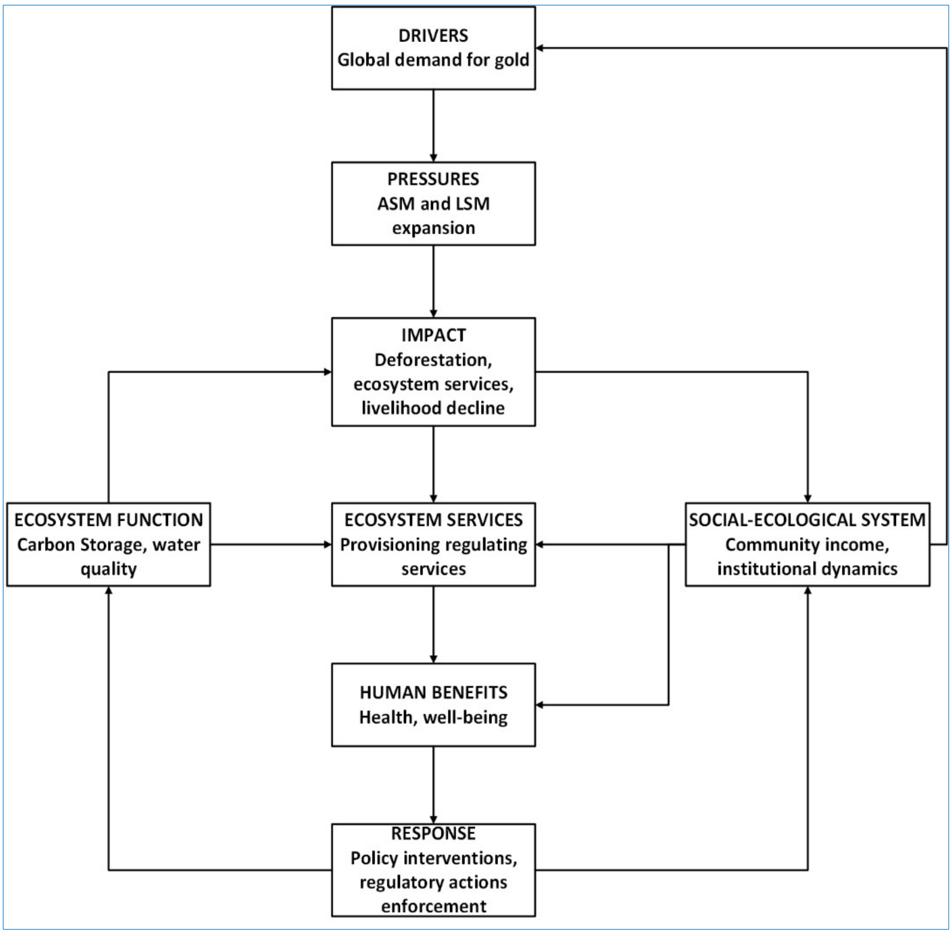

Fig. 1. Integrated Conceptual Framework for mining impact in Ghana

Notwithstanding the severity of these environmental concerns and their repercussions for sustainable development, considerable information deficiencies remain about the extensive effects of mining on land use and land cover dynamics and ecosystem services in Ghana and the wider Sub-Saharan Africa area. Geographical bias restricts the generalizability of current research, as the majority of studies concentrate on particular mining concessions or individual river basins instead of offering national or regional assessments that could guide comprehensive policy frameworks (Afuye et al., 2024; Puplampu and Boafo, 2021).

Secondly, the existing literature is marked by methodological fragmentation, as studies utilize varying land use and land cover classification systems, temporal scales, and ecosystem service valuation methods, which hinder substantial comparison and synthesis of results across diverse contexts (Sietsma, 2023; Rashid et al., 2021).

Thirdly, multidisciplinary integration is constrained, since environmental impact assessments seldom include socio-economic factors, traditional ecological knowledge, or community viewpoints about the significance of ecosystem services and the trade-offs associated with mining (Ntajal et al., 2020). The identified gaps are especially concerning due to the intricate framework of social-ecological systems theory required to comprehend mining impacts, wherein environmental alterations interact with social structures, governance systems, and economic incentives, resulting in non-linear outcomes that cannot be anticipated through singular disciplinary analyses alone.

The necessity of overcoming these knowledge deficiencies is emphasized by the problems of policy implementation and international obligations that demand evidence-based decision-making. The existing mining policy framework in Ghana encounters substantial enforcement challenges, as only 2% of mining-degraded land has been effectively rehabilitated, in contrast to the average for Sub-Saharan Africa, indicating insufficient institutional capacity and poor incorporation of environmental factors into mining governance (Mutimba et al., 2024). Moreover, the expansion of mining activities contradicts Ghana's obligations to various SDGs, specifically Goal 6 (clean water and sanitation), Goal 15 (life on land), and Goal 1 (poverty alleviation), resulting in policy tensions that necessitate a thorough comprehension of the multifaceted impacts of mining for effective resolution (Gbedzi et al., 2022). The formalization problems of ASM activities, which generally remain informal while supporting millions of livelihoods, illustrate the necessity for evidence-based policies that reconcile economic opportunity with environmental preservation and social fairness (Banchirigah and Hilson, 2010).

The importance of performing a thorough meta-analysis of mining effects on LULC and ecosystem services in Ghana, beyond mere academic contribution, is to tackle essential policy and development issues. Meta-analytical methods provide the methodological precision required to integrate various studies, standardize disparate LULC classification systems, and quantify effect sizes across multiple contexts, thus addressing the fragmentation that has constrained prior research syntheses (Sietsma, 2023; Velastegui-Montoya et al., 2022). This research will integrate quantitative land use and land cover change assessments with ecosystem service valuation studies, incorporating socio-economic data through hybrid methodologies that combine remote sensing analysis with field surveys and community-based assessments, thereby providing a comprehensive evidence base to inform sustainable mining policies and practices (Mugiyo, 2021). The study's emphasis on the effects of ASM and LSM, along with a thorough examination of stakeholder viewpoints such as those of mining communities, traditional authorities, and environmental managers, will yield practical insights for policymakers, mining enterprises, and development organizations striving to reconcile economic advancement with environmental sustainability.

This research intends to perform a systematic review and meta-analysis to evaluate the effects of mining activities on land use and land cover alterations, as well as the degradation of ecosystem services in Ghana. It will specifically focus on quantifying deforestation rates, assessing losses in ecosystem services, and identifying sustainable mining practices to inform policy recommendations for Ghana and other sub-Saharan African countries. This study examines three principal research inquiries: What are the impacts of various mining operations (Artisanal and Small-scale Mining vs Large-scale Mining) on land use and land cover patterns in Ghana, and what is the geographical and temporal variability of these alterations? Which ecosystem services are most profoundly affected by mining operations, and how do these effects change across various ecological zones and levels of mining intensity? What policy interventions and sustainable mining practices have the highest potential for reducing land use and land cover changes and ecosystem service degradation while preserving economic advantages from mining operations? This study will enhance the existing literature on mining sustainability in Sub-Saharan Africa by offering practical guidelines for attaining sustainable mining practices that align with economic development and environmental conservation objectives.

1.1. Conceptual Framework

To evaluate the effects of mining on LULC and ES in Ghana, it is crucial to employ comprehensive conceptual frameworks that connect ecological, socio-economic, and governance aspects. Three pertinent frameworks in this context include the DPSIR model, the Ecosystem Services Cascade, and the Social-Ecological Systems (SES) framework.

The Drivers–Pressures–State–Impact–Response (DPSIR) paradigm provides a systematic approach for examining environmental change. In Ghana's mining sector, economic factors such as the worldwide demand for gold (Hilson and Maconachie, 2020) result in pressures, including the proliferation of artisanal and ASM and LSM. These pressures modify the environmental condition through deforestation, soil erosion, and pollution (Awotwi et al., 2018; Barenblitt et al., 2021), leading to detrimental effects on ecosystem services and livelihoods. Policy solutions, including regulatory initiatives like Operation Vanguard and AKOBEN, seek to alleviate these consequences but frequently encounter enforcement difficulties (Hilson et al., 2007; Essah and Andrews, 2016). The usefulness of DPSIR is in its capacity to interpret empirical data within a cause-effect-response paradigm, facilitating evidence-based policymaking.

The Ecosystem Services Cascade model enhances comprehension by delineating the progression from ecosystem structures (e.g., forests, rivers) to ecological functions (e.g., carbon sequestration, water purification), services (e.g., climate management), and human advantages (e.g., food security, health). This model assists in identifying certain trade-offs arising from land alterations generated by mining activities.

Forest destruction diminishes carbon sequestration, compromising climate control and heightening susceptibility to extreme weather events (Abugre et al., 2025). Likewise, water pollution from heavy metals (Cudjoe et al., 2023) undermines the provision of functions, endangering public health. The cascade model facilitates valuation frameworks, enabling the calculation of ecosystem service losses, which is essential for meta-analytical evaluations.

The SES concept highlights the interconnection between human societies and their adjacent ecosystems. It encompasses institutional dynamics, livelihood practices, and feedback mechanisms that influence resilience or vulnerability. In Ghana, the community's dependence on artisanal and small-scale mining for revenue (Hilson, 2016), combined with inadequate regulatory monitoring (Mensah et al., 2025), establishes a feedback loop that perpetuates environmental degradation and poverty.

The SES approach is especially appropriate for multi-scale investigations, allowing researchers to connect satellite-derived LULC changes with socio-economic surveys, thereby including the human aspects of mining effects (Acheampong, 2018). It effectively corresponds with the utilization of remote sensing and GIS technologies, which are essential for spatiotemporal monitoring in data-deficient areas such as Sub-Saharan Africa.

These frameworks collectively offer a solid basis for examining the impact of mining on landscapes and ecosystem services. A hybrid methodology that amalgamates the causal framework of DPSIR, the evaluative precision of the cascade model, and the socio-political perspective of SES provides a thorough instrument for your systematic review and meta-analysis. Figure 1 is the pictorial view of the integrated conceptual framework for mining impact in Ghana.

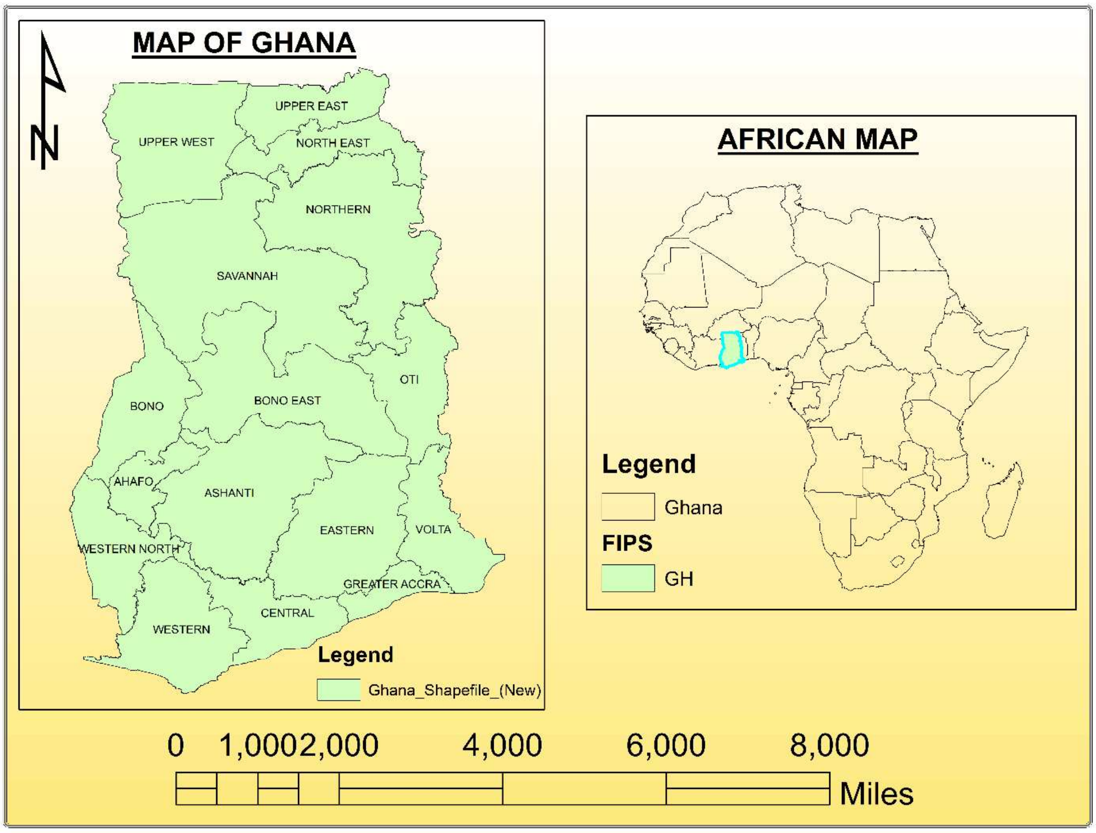

Fig. 2. Map of the study area

2. Study Area Description

Ghana (Fig. 2) is strategically situated in West Africa (4°30′N–12°00′N, 1°12′E–3°15′W), encompassing roughly 238,540 km² and bordered by Burkina Faso, Togo, Côte d'Ivoire, and the Gulf of Guinea (Tannor et al., 2018). The nation has pronounced north-south environmental gradients spanning six agro-ecological zones, from the dry Sudan Savanna (700–1,040 mm annual precipitation) in the north to the High Rainforest zone (1,460–2,800 mm) in the south (Adu-Prah et al., 2019). Since the 1960s, Ghana's tropical climate has undergone substantial alterations, characterized by diminishing rainfall (from 1,308 mm in the 1960s to 1,147 mm between 2005 and 2014) and increasing temperatures (0.27°C per decade), resulting in diverse vulnerabilities to human-induced pressures across different regions (Abbam et al., 2018; Adu-Prah et al., 2019).

The geological substrate of Ghana is primarily characterized by Paleoproterozoic formations of the West African Craton, notably the mineral-rich Birimian Supergroup (2.2–2.1 Ga) and the superjacent Tarkwaian Group (2132 Ma), which encompasses the nation's substantial gold reserves located in greenstone belts such as Ashanti and Kibi-Winneba (Nunoo et al., 2022; Forson et al., 2021).

The geological terrains, formed by several deformational episodes throughout the Eburnean orogeny, provide NE-SW oriented mineralized zones that facilitate both large-scale and artisanal mining operations in forest and savanna areas. The convergence of Ghana's geological resources and varied environmental zones results in disparate effects from mining operations, with forest areas suffering disruption of ecosystem services (such as water regulation and carbon sequestration), while savanna regions endure exacerbated land vulnerability due to climate change and mining-related degradation.

The environmental issues in Ghana are exacerbated by the interplay of climatic variability and human-induced pressures, notably mining and agricultural growth. Forest cover has diminished by 46,000 hectares per year (1990–2010), with mining operations leading to mercury pollution in significant rivers such as the Pra and Ankobra, while 99.6% of agriculture is reliant on rainfall and susceptible to climatic influences (Allotey et al., 2024; Donkor et al., 2006; Abubakari and Abubakari, 2015). The cumulative impacts of increasing temperatures, unpredictable rainfall, and land use alterations due to mining exert compounded pressures on ecosystem services, rendering conventional climate prediction methods unreliable and restricting adaptation strategies within rural communities (Abbam et al., 2018; Fosu-Mensah et al., 2010). This intricate environmental context facilitates the analysis of how mining operations engage with pre-existing climatic vulnerabilities, resulting in alterations in land use and land cover throughout Ghana's many biological regions.

3. Methodology

3.1. Study Design

This systematic review and meta-analysis comply with the PRISMA guidelines to assess the effects of mining activities on LULC alterations and ecosystem services in the Republic of Ghana and the wider Sub-Saharan Africa region. The review design was structured according to the PCC framework (Population, Concept, Context) to guarantee a concentrated and pertinent synthesis of evidence, wherein Population refers to mining operations (large-scale, small-scale, artisanal, and illegal mining), Concept includes the effects on LULC changes and the degradation/enhancement of ecosystem services, and Context relates specifically to Ghana, supplemented by evidence from comparable Sub-Saharan African nations. The study protocol was prospectively recorded with PROSPERO (International Prospective Register of Systematic Reviews) to guarantee transparency and avert redundancy of effort.

Table 1. Search strings used in various databases and results obtained

No	Database	Search String	Results
1	Google Scholar	("mining" OR "extraction" OR "artisanal mining" OR "small-scale mining" OR "galamsey") AND ("land use" OR "land cover" OR "LULC" OR "deforestation" OR "land degradation") AND ("ecosystem services" OR "environmental impact" OR "biodiversity" OR "water quality" OR "soil contamination") AND ("Ghana" OR "West Africa" OR "Sub-Saharan Africa") AND ("remote sensing" OR "satellite imagery" OR "GIS")	245
2	Scopus	("mining" OR "mineral extraction" OR "artisanal mining") AND ("land use change" OR "LULC" OR "land cover change" OR "deforestation") AND ("ecosystem service*" OR "environmental degradation" OR "habitat loss") AND ("Ghana" OR "West Africa" OR "Sub-Saharan Africa")	189
3	Web of Science	("mining impact*" OR "mining activities" OR "extraction") AND ("land use" OR "land cover" OR "LULC classification") AND ("ecosystem service*" OR "environmental assessment" OR "biodiversity loss") AND ("Ghana" OR "West Africa") AND ("Landsat" OR "Sentinel" OR "remote sensing")	156
4	PubMed	("mining" OR "mineral extraction") AND ("land use change" OR "environmental impact") AND ("ecosystem service*" OR "biodiversity") AND ("Ghana" OR "Africa")	78
5	IEEE Xplore	("mining" OR "extraction") AND ("land use classification" OR "LULC" OR "land cover mapping") AND ("remote sensing" OR "satellite imagery") AND ("Ghana" OR "Africa")	45
6	ACM Digital Library	("mining impact" OR "environmental monitoring") AND ("land use" OR "land cover") AND ("remote sensing" OR "GIS") AND ("Ghana" OR "Africa")	32
7	ResearchGate	("mining activities" OR "artisanal mining" OR "galamsey") AND ("land use change" OR "deforestation") AND ("ecosystem services" OR "environmental impact") AND ("Ghana" OR "West Africa")	67
8	Academia.edu	("mining" OR "mineral extraction") AND ("land cover change" OR "LULC") AND ("ecosystem services" OR "environmental degradation") AND ("Ghana" OR "Sub-Saharan Africa")	41
9	AJOL	("mining" OR "mineral extraction" OR "galamsey") AND ("land use" OR "environmental impact") AND ("ecosystem services" OR "biodiversity") AND ("Ghana" OR "West Africa")	29
10	GeoRef	("mining impact*" OR "mineral extraction") AND ("land use change" OR "LULC") AND ("ecosystem service*" OR "environmental assessment") AND ("Ghana" OR "West Africa")	38

3.2. Search Strategy

A thorough search strategy was designed to encompass the entirety of mining impacts on land use and ecosystem services studies. The search queries were created utilizing key phrases associated with mining operations, land use and land cover alterations, ecosystem services, environmental consequences, remote sensing applications, and geographic emphasis. Essential terms including "mining," "extraction," "artisanal mining," "small-scale mining," "galamsey," "land use land cover change," "deforestation," "ecosystem services," "environmental degradation," "biodiversity loss," "water pollution," "soil contamination," "remote sensing," "satellite imagery," "Ghana," "West Africa," and "Sub-Saharan Africa" were integrated utilizing Boolean search operators "AND" and "OR."

The search terms were methodically utilized across various academic databases, including Scopus, Web of Science, PubMed, IEEE Xplore, ACM Digital Library, Google Scholar, ResearchGate, Academia.edu, Africa Journal Online (AJOL), and GeoRef to guarantee thorough coverage of both mainstream and Africa-focused publications. Moreover, grey literature sources, encompassing government reports, environmental impact assessments by mining companies, NGO publications, and technical reports from entities such as the Ghana Environmental Protection Agency (EPA), the Minerals Commission of Ghana, the World Bank, and the African Development Bank, were meticulously examined.

The literature review encompassed articles from 2000 to 2025 to track the progression of mining practices and their associated environmental implications, along with Ghana's mining sector reforms and heightened environmental consciousness.

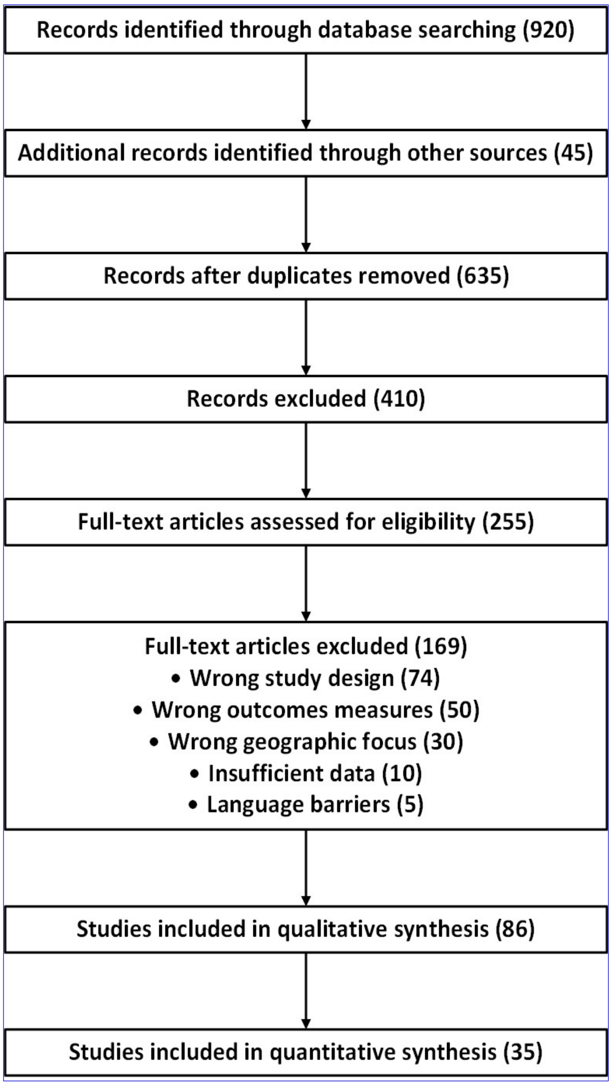

Fig. 3. PRISMA flow diagram for study selection process

3.3. Multilingual and Grey Literature Search

To mitigate any language bias, supplementary searches were performed in French utilizing databases such as Persée and Cairn.info, concentrating on Francophone West African mining studies. Prominent French search phrases encompassed "exploitation minière," "utilisation des terres," "services écosystémiques," and "Afrique de l'Ouest."
Grey literature searches encompassed:

- Government databases (Ghana Environmental Protection Agency, Minerals Commission reports)
- Reports from international organizations (World Bank, African Development Bank, UNEP) • Environmental impact assessments by mining companies
- Reports from non-governmental organizations (Friends of the Earth Ghana, Wacam, Greenpeace Africa)
- Proceedings from African mining and environmental conferences

3.4. Study Selection Procedure

A systematic research selection approach was executed in accordance with PRISMA 2020 principles to guarantee transparency and reproducibility. The selection procedure comprised many screening phases executed separately by two reviewers, with discrepancies addressed through dialogue and consensus. In the absence of unanimity, a third reviewer was engaged. The preliminary search produced 920 records across all databases. Following the elimination of 285 duplicates via reference management software (Mendeley) and automatic deduplication technologies, 635 studies were subjected to title and abstract screening. In this phase, 410 publications were selected for irrelevance to the research aims, largely owing to inadequate emphasis on mining consequences, absence of LULC or ecosystem services components, or geographic inapplicability.

A total of 255 full-text papers were evaluated for eligibility based on established inclusion and exclusion criteria, leading to the elimination of 169 articles for diverse methodological and scope-related reasons. The final selection included 86 papers that fulfilled all inclusion criteria and included adequate methodological detail for quality evaluation and data synthesis.

3.5. Inclusion and Exclusion Criteria

3.6. Data Extraction

A thorough data extraction approach was created expressly for analyzing impact assessments related to land use and ecosystem services research. A critical review was done to extract data utilizing the Mendeley Software to screen the abstracts, with any discrepancies addressed through discussion and consensus with experts in the field. The extraction framework included research characteristics, mining operation specifics, environmental effect evaluations, and ecosystem service analyses.

3.7. Study Characteristics

- Authors, Year of Publication, Study Locale (particular regions within Ghana/Sub-Saharan Africa)
- Study Design, Research Aims, Geographic Scope, and Spatial Scale
- Temporal Coverage, Baseline Period, and Post-mining Evaluation Timeline
- Financial Sources and Possible Conflicts of Interest

3.8. Mining Operation Details

- Mining Classification (large-scale, small-scale, artisanal, illicit)
- Extracted Mineral Resources (gold, bauxite, manganese, diamonds, etc.)
- Mining Techniques (open-pit, underground, alluvial, etc.)
- Operational Timeline, Scope of Operations (affected region, production capacity)
- Environmental Management Strategies and Mitigation Techniques
- Regulatory Adherence and Licensing Status

3.9. Remote Sensing and Spatial Data Specifications

- Satellite Platforms (Landsat, Sentinel, MODIS, SPOT, etc.)
- Spectral Bands Employed, Spatial and Temporal

Resolution
- Data Preprocessing Techniques, Atmospheric Correction Protocols
- Classification Techniques and Accuracy Evaluation
- Ground Truth Data Sources and Validation Approaches

3.10. LULC Change Assessment
- Land Cover Classification Frameworks Employed
- Pre-mining and Post-mining Land Cover Classifications
- Area Change Metrics and Rates of Transformation
- Spatial Patterns of Land Use Alteration
- Temporal Analysis Approaches and Change Detection Methodologies

3.11. Ecosystem Services Assessment
- Utilized Ecosystem Services Framework (MEA, TEEB, CICES, etc.)
- Assessed Categories of Ecosystem Services (provisioning, regulating, cultural, sustaining)
- Quantification Techniques (monetary valuation, biophysical evaluation, indicators)
- Initial Ecosystem Service Valuations and Post-mining Evaluations
- Ecosystem Service Trade-offs and Synergie

Table 2. Inclusion and exclusion criteria for review articles

Criteria Category	Inclusion Criteria	Justification	Exclusion Criteria	Justification
Geographic Focus	Studies conducted in Ghana with priority, Sub-Saharan African studies with similar mining contexts and environmental conditions for comparative analysis	Ensures relevance to Ghanaian mining contexts while allowing for regional comparison and pattern identification across similar socio-economic and ecological systems	Studies conducted exclusively outside Sub-Saharan Africa without transferable insights to Ghanaian mining contexts	Maintains focus on comparable mining environments, regulatory frameworks, and socio-economic conditions relevant to Ghana
Publication Date	Studies published between 2000 and 2025	Captures the period of significant mining sector expansion in Ghana, modern remote sensing capabilities, and the evolution of ecosystem services research frameworks	Studies published before 2000, unless they provide foundational historical context	Early studies predate modern mining practices, current environmental regulations, and contemporary remote sensing technologies
Study Focus	Studies examining the direct impacts of mining activities on LULC changes and/or ecosystem services with a quantitative assessment	Directly addresses the primary research question regarding mining impacts on land use and ecosystem services with measurable outcomes	Studies focusing solely on mining economics, geology, or health impacts without environmental/ecosystem service components	Excludes research that doesn't provide evidence of environmental impacts relevant to the research question
Mining Types	All types of mining operations: large-scale commercial mining, small-scale mining, artisanal mining, illegal mining (galamsey), quarrying, and extractive industries	Provides comprehensive coverage of mining impacts across different scales and regulatory contexts prevalent in Ghana	Studies focusing exclusively on non-extractive industries or theoretical mining scenarios	Maintains focus on actual mining operations with real environmental impacts
Data Sources	Studies utilizing remote sensing data, field surveys, GIS analysis, ecosystem service assessments, biodiversity surveys, or combinations thereof	Ensures inclusion of studies with robust spatial and temporal analysis capabilities essential for LULC and ecosystem service assessment	Studies relying solely on secondary data analysis without primary environmental assessment	Prioritizes studies with direct environmental measurement and assessment
Impact Assessment	Studies reporting quantitative measures of environmental change: LULC classification accuracy, area change statistics, ecosystem service values, biodiversity indices, or environmental quality indicators	Essential for meta-analysis and quantitative synthesis of mining impacts on environmental parameters	Studies without quantitative environmental impact measures or validation data	Excludes studies that cannot contribute to evidence-based assessment of mining impacts
Study Design	Observational studies (cross-sectional, longitudinal, before-after), experimental studies, case studies with robust methodology, and comparative studies	Accommodates the range of study designs appropriate for environmental impact assessment while maintaining methodological rigor	Opinion pieces, reviews without original research, studies with insufficient methodological detail, and purely theoretical papers	Ensures inclusion of empirical evidence while excluding non-research publications
Language	Studies published in English, French, and Portuguese (major languages in Sub-Saharan Africa)	Reduces language bias and includes research from Francophone and Lusophone African countries with similar mining contexts	Studies in other languages are due to resource constraints	Practical limitation acknowledged as a potential source of bias
Temporal Coverage	Studies covering periods sufficient to assess mining impacts (minimum 2-year observation period for longitudinal studies)	Ensures adequate temporal scope to observe meaningful environmental changes resulting from mining activities	Studies with insufficient temporal coverage to assess meaningful environmental change	Short-term studies may not capture the full extent of mining impacts on ecosystems

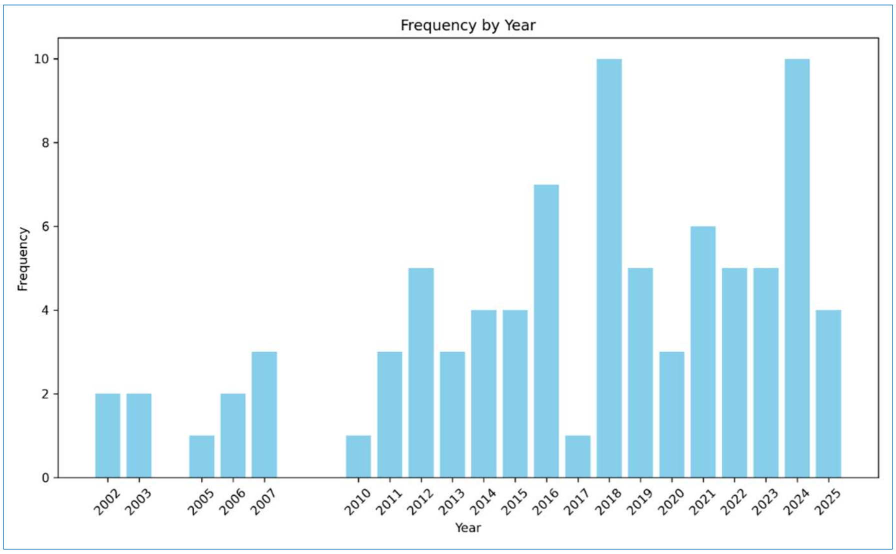

Fig. 4. Graph depicting the relationship between publication year and the number of articles downloaded and employed in the research

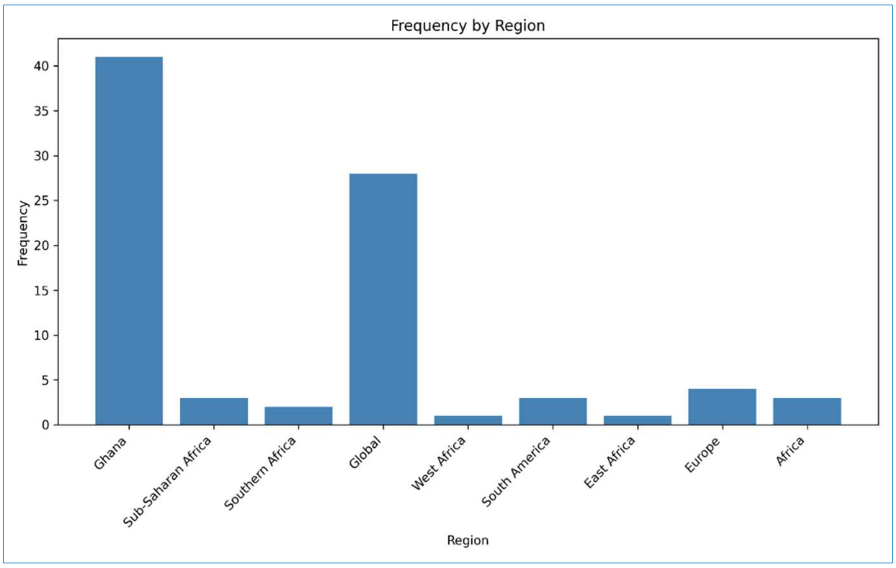

Fig. 5. A graph depicting global regions and the number of publications downloaded and employed in this study

3.12. Environmental Impact Measures

- Biodiversity Indicators (species richness, abundance, habitat quality)
- Water Quality Metrics (pH, turbidity, heavy metals, chemical pollutants)
- Indicators of Soil Quality (fertility, pollution, erosion)
- Air Quality Metrics (particulate matter, dust emissions)
- Alterations in Vegetation Health and Forest Canopy

3.13. Socio-economic and Community Impacts

- Community Demographics and Livelihoods
- Reliance on Ecosystem Services
- Economic Assessment of Ecosystem Service Degradation
- Community Involvement in Environmental Evaluation
- Reparations and Remediation Strategies

3.14. Quality Assessment

The quality of the studies was evaluated using a variety of methodologies suitable for the various study designs used in environmental impact research. The Newcastle-Ottawa Scale (NOS) was utilized for observational studies, whilst the JBI Critical Appraisal Tools were applied to case studies and mixed-methods research. In investigations concerning remote sensing and spatial analysis, supplementary quality requirements were implemented following recognized remote sensing best practices.

3.14.1. Study Design and Methodology

- Suitability of study design for the research question
- Explicit specification of the study population and geographical parameters
- Sufficient sample size and temporal span
- Relevant control groups or baseline comparisons

3.14.2. Data Quality and Sources

- Reliability and validity of data sources
- Appropriateness of remote sensing data and resolution

- Quality of ground truth data and validation methodologies
- Transparency in data collection and processing techniques

3.14.3. Environmental Impact Assessment

- Thoroughness of environmental indicators
- Suitability of impact assessment methodologies
- Statistical robustness in analysis and reporting
- Assessment of confounding variables and alternative interpretations

3.14.4. Reporting Quality

- Clarity and comprehensiveness of the technique documentation
- Transparency in data analysis and presentation of outcomes
- Examination of limits and potential biases
- Reproducibility of methodologies and results

Studies were evaluated as High, Medium, or Low quality according to their performance in these aspects. Quality ratings were employed to assess evidence during synthesis and to identify possible sources of bias in the final results.

3.15. Data Analysis

3.15.1. Narrative Synthesis

A thorough theme narrative synthesis was performed to offer a cohesive knowledge of the effects of mining on LULC and ecosystem services in Sub-Saharan Africa, specifically emphasizing Ghana. The synthesis categorized the findings into several principal themes.

Table 3. Summary table of the key studies on mining and LULC in Ghana

Reference	Title	Location	Journal/Publisher	Study Focus
Barenblitt et al.,2021	"The Large Footprint of Small-Scale Mining in Ghana"	Southwestern Ghana	Science of the Total Environment	Quantified LULC changes using satellite data (2005-2019)
Mensah et al., 2025	"Assessing the environmental and socio-economic impacts of small-scale mining activities in the Atiwa East District of Ghana"	Atiwa East District	Scientific African	Field surveys on farmland and forest loss.
Adu-Baffour et al., 2021	"Governance challenges of small-scale gold mining in Ghana"	Various regions	Land Use Policy	Analyzed soil contamination and agricultural impacts.
Awotwi et al., 2018	"Monitoring land use and land cover changes due to extensive gold mining, urban expansion, and agriculture in the Pra River Basin of Ghana"	Pra River Basin	Land Degradation Development	Modelled mining expansion and deforestation.
Aryee et al., 2003	"Trends in the Small-Scale Mining of precious minerals in Ghana: a perspective on its environment impact"	Nationwide	Journal of Cleaner Production	Reviewed land degradation and reclamation challenges.
Hilson and Potter, 2003	"Why is illegal Gold Mining Activity so ubiquitous in Rural Ghana?"	Western Region	Blackwell Publishing	Socioeconomic drivers of LULC change.
Okyere et al., 2021	"Large-scale mining in Ghana: a review of the implications on the host communities"	Ashanti/Western Regions	Journal of Degraded and Mining Lands Management	Remote sensing analysis of forest loss.

3.15.2. Mining Impact Patterns and Drivers

- Comprehensive evaluation of various mining methods and their distinct environmental repercussions
- Determination of principal factors influencing land use alterations in mining regions
- Examination of spatial and temporal trends in environmental deterioration
- Assessment of cumulative and secondary effects of mining activities

3.15.2. Ecosystem Services Impact Assessment

- Quantitative synthesis of ecosystem service losses and gains.
- Analysis of trade-offs between mining advantages and ecosystem service losses.
- Assessment of the potential for ecosystem service restoration
- Evaluation of ecosystem service valuation methodologies and their application

3.15.3. Remote Sensing and Monitoring Technologies

- Examination of remote sensing applications for mining impact evaluation
- Appraisal of change detection methodologies and their efficacy
- Analysis of data prerequisites and technology limitations
- Identification of optimal strategies for environmental monitoring

3.15.4. Regulatory and Management Frameworks

- Analysis of the efficacy of environmental impact assessments
- Evaluation of mining regulations and enforcement strategies
- Assessment of restoration and rehabilitation mandates
- Identification of policy deficiencies and enhancement prospects

3.15.5. Community and Socio-economic Dimensions

- Examination of community reliance on impacted ecological services
- Analysis of economic repercussions and compensation

strategies
- Evaluation of community involvement in environmental oversight
- Identification of environmental justice and equity concerns

3.16. Meta-Analysis
A quantitative meta-analysis was performed to consolidate information about the extent of mining's effects on land use and land cover changes and ecosystem services. The principal outcome measures comprised:

3.16.1. Primary Outcomes
- Area of land use alteration per unit of mining activity (hectares impacted per hectare extracted)
- Percentage variation in ecosystem service values before and after mining
- The rate of deforestation in mining regions compared to control regions
- Biodiversity impact metrics in areas affected by mining

3.16.2. Secondary Outcomes
- Metrics for water quality deterioration
- Levels of soil pollution and their geographical distribution
- Effects on air quality and rates of dust emissions
- Indicators of community livelihood impacts

Effect Size Calculation: For each trial, effect sizes were determined as standardized mean differences (SMD) for continuous outcomes and risk ratios (RR) for categorical outcomes. Effect sizes were computed for various kinds, geographic locations, and temporal scales when feasible.

3.16.3. Subgroup Analysis
Pre-planned subgroup analyses were conducted based on:
- Mining type (large-scale vs. small-scale vs. artisanal)
- Geographic region (Ghana vs. other Sub-Saharan African countries)
- Ecosystem type (forest, savanna, wetland, agricultural)
- Time since mining initiation (<5 years, 5-10 years, >10 years)
- Study quality rating (high, medium, low)

3.16.4. Sensitivity Analysis
Sensitivity analyses assessed the robustness of findings by:
- Excluding studies with a high risk of bias
- Excluding outlier studies with extreme effect sizes
- Analyzing only high-quality studies
- Analyzing different effect size measures

3.16.5. Certainty of Evidence Assessment
The reliability of evidence was evaluated utilizing the GRADE (Grading of Recommendations Assessment, Development and Evaluation) methodology, modified for environmental systematic reviews. Evidence was assessed across five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias, with overall certainty classified as High, Moderate, Low, or Very Low.

This thorough technique guarantees a meticulous, transparent, and replicable evaluation of mining effects on land use and ecosystem services, supplying substantial data to guide policy and management decisions in Ghana and other sub-Saharan African settings.

4. Results and Discussion
4.1. Results
4.1.1. Synthesis of Trends of Publications
This section categorizes the studies according to their publication year and the respective nations or locations of their implementation. This facilitated an evaluation of the regional distribution of research on the subject, together with temporal publishing patterns. The investigation disclosed significant findings regarding the publishing data of the selected research publications. The publishing tendencies of the study from 2000 to 2025 exhibited instability, commencing with a 2 publication in 2002, mounting to 10 (11.63%) in 2018, and subsequently reducing to only 4 publications in 2025.

The number of publications rose to 3 in 2007, 2011, and 2013, increased to 5 in 2012, extended to 7 in 2016, reached 10 in 2018 and 2024, and thereafter decreased to 4 in 2025. The years 2018 and 2024 exhibit the greatest volume of publications over the analyzed period, with 10 articles (11.63%) respectively. Nonetheless, there was a decline in the number of publications in 2010 and 2017, with one publication respectively. Figure 4 below summarizes the tendencies of the publications during the period analyzed. It is important to acknowledge that no publications were documented in the years 2000, 2001, 2004, 2008, and 2009, as seen in Fig. 4.

4.1.2. Synthesis of the Geographical Distribution of Studies
The analysis rigorously examined the jurisdictions of the several studies analyzed. Among the 86 studies analyzed for this research, the majority, specifically 41 and 28, were located in Ghana and Global studies, respectively. Sub-Saharan Africa subsequently generated 3 articles. In the African region, studies were identified as follows: one in West Africa, one in East Africa, three in Southern Africa, and three including the whole continent. 3 research studies were recorded in South America, and 4 studies were identified in Europe, respectively. Only 41 research studies were identified in Ghana. 28 scientific studies were acknowledged worldwide. The research undertaken in the Belt and Road areas encompasses West Africa, East Africa, Southern Africa, South America, Europe, and Sub-Saharan Africa. Figu. 5 illustrates the geographical distribution of the studies employed in this research.

4.1.3. Impact of Mining on LULC
Mining, especially gold mining, has emerged as a major human influence on LULC in Ghana. The nation has seen extensive environmental deterioration due to industrial and artisanal mining activities, resulting in deforestation, loss of arable land, water pollution, and the proliferation of damaged landscapes. This critical analysis consolidates essential results from empirical investigations, elucidating the scope and characteristics of land use and land cover modifications induced by mining activities in Ghana. It also addresses socioeconomic determinants, methodological obstacles, and avenues for further investigation.

Table 4. Key studies on mining impacts on ecosystem services in Ghana

Reference	Title of Article	Location of Study	Journal of Publication	Study Application
Mensah et al., 2015	"Environmental Impacts of mining: a study of mining communities in Ghana"	Ashanti Region, Ghana	Applied Ecology and Environmental Sciences	Assessed trade-offs between mining and agriculture.
Rajaee et al., 2015	"Integrated Assessment of Artisanal and Small-scale gold mining in Ghana - Part 2: Natural Sciences Review"	Ankobra River Basin, Ghana	Int. J. Environ. Res. Public Health	Quantified Hg contamination in water and fish.
Adekola and Mitchell, 2011	"The Niger Delta Wetlands: Threats to ecosystem services, their importance to dependent communities and possible management measures, The Niger Delta (West Africa)"	Niger Delta (Comparative)	International Journal of Biodiversity Science, Ecosystem Services & Management	Analyzed cross-border impacts on wetlands.
Duarte et al., 2016	"Ecosystem services modelling as a Tool for Defining Priority Areas for Conservation"	Global (Incl. Ghana)	PLOS ONE	Modeled carbon sequestration decline.
Keesstra et al., 2018	"The Superior Effect of nature based solutions in land management for enhancing ecosystem services"	Sub-Saharan Africa	Science of the Total Environment	Evaluated erosion control strategies.
Nakade and Dhadse, 2024	"Biodiversity loss due to mining activities"	Global (Incl. Ghana)	Biodiversity and Conservation	Sustainability and Biodiversity Conservation
Pierre and Sylvere, 2024	"Ecosystem services and Land Degradation in Gishwati-Mukura Corridor, Rwanda: Cost-Benefit of Sustainable Land Management Practices"	Rwanda	Rwanda Journal of Engineering, Science, Technology, and Environment	Documented loss of cultural ES.
Damseth et al., 2024	"Assessing the impacts of riverbed mining on aquatic ecosystems: a critical review of effects on water quality and biodiversity"	Global (Incl. Ghana)	HydroResearch	Measured turbidity and sediment loads.

4.1.4. Key Findings on LULC Alterations Due to Mining in Ghana

4.1.4.1. Deforestation and vegetation loss

The most evident consequence of mining is the extensive removal of forest cover. Open-pit mining and uncontrolled artisanal small-scale mining, generally known as "galamsey", have caused substantial deforestation. Barenblitt et al. (2021) discovered that around 47,414.2 hectares of vegetation were transformed into mining zones from 2005 to 2019, with artisanal mining constituting 85.7% of this conversion. Forest reserves, including Upper Wassaw and Ajenjua Bepo, have experienced encroachment due to mining activities, with 3.43% and 8.58% of their land areas affected, respectively (Barenblitt et al., 2021).

4.1.4.2. Conversion of agricultural land

The intrusion of mining operations into agricultural lands presents a significant risk to food security and rural economies. In the Atiwa East District, Mensah et al. (2025) indicated that 50% of mining activities occurred on agricultural land, leading to the devastation of essential crops, including cocoa and plantain. Adu-Baffour et al. (2021) emphasized that land degradation resulting from mining renders soil unproductive, thereby displacing farmers and reducing agricultural output in several locations.

4.1.4.3. Water body pollution and alteration

Mining next to rivers and aquatic ecosystems has led to silt accumulation, heightened turbidity, and chemical pollution. The Offin and Ankobra rivers have undergone substantial ecological alterations as a result of adjacent mining operations (Mensah et al., 2025; Okyere et al., 2021). Additionally, Awotwi et al. (2018) discovered that mining resulted in a 30.11% decrease in the surface area of water bodies within the Pra River Basin, indicating significant hydrological disturbances.

4.1.4.4. Expansion of barren and degraded land

The proliferation of mining operations has further exacerbated land degradation. Satellite data examined by Barenblitt et al. (2021) indicated that mining areas grew from 8,635.5 hectares in 2007 to 35,007.5 hectares in 2017, a fourfold escalation. These regions frequently comprise forsaken pits and deteriorated, unreclaimed terrain, resulting in prolonged ecological damage (Aryee et al., 2003).

4.1.4.5. Encroachment into protected areas

Mining operations have not been confined to officially authorized areas. Barenblitt et al. (2021) discovered mining activities in 28 protected sites, including reserves classified under IUCN Category IV protection. This violation highlights the deficiencies in Ghana's environmental governance and enforcement systems.

4.1.4.6. Socioeconomic drivers

The increase in mining operations is directly associated with socioeconomic variables, such as escalating world gold prices and insufficient regulatory monitoring. Barenblitt et al. (2021) and Hilson and Potter (2003) assert that economic incentives and institutional deficiencies have propelled the proliferation of artisanal mining throughout rural Ghana.

4.1.5. Impact of Mining on Ecosystem Services

Mining in Sub-Saharan Africa, especially in Ghana, significantly negatively impacts ecosystem services (ES). These services, categorized as supplying, regulating, supporting, and cultural, are vital for maintaining ecological and human welfare. A review of contemporary literature consistently indicates deterioration across all four categories attributable to mining operations, with empirical data predominantly focused on gold mining in Ghana.

4.1.5.1. Provisioning services

Mining activities substantially impair the accessibility of essential resources, including food, water, and raw materials. Contamination of soil and water by heavy metals such as lead (Pb), mercury (Hg), and arsenic (As) results in a significant reduction in agricultural production and freshwater quality (Mensah et al., 2015). Mercury contamination from artisanal gold mining in Ghana's Ashanti area has compromised the safety of both surface and groundwater for human consumption and irrigation (Rajaee et al., 2015). Moreover, mining-related deforestation leads to the reduction of both wood and non-timber forest resources. This is especially apparent in wooded mining regions where the removal of vegetation diminishes the accessibility of fuelwood, medicinal flora, and wild food supplies (Adekola and Mitchell, 2011).

Table 5. Key Studies on Mining Regions in Ghana

Reference	Title	Location of Study	Journal	Study Focus
Hilson and Garforth, 2013	Everyone now is concentrating on the mining: drivers and implications of rural economic transition in the Eastern region of Ghana	Eastern Region of Ghana	The Journal of Development Studies	Historical entrenchment of ASM
Barenblitt et al., 2021	The Large footprint of small-scale artisanal gold mining in Ghana	Southwestern Ghana	Science of the Total Environment	ASM vs. industrial mining LULC
Okyere et al., 2021	Large-scale mining in Ghana: a review of the implications on the host communities	Ahafo Region	Journal of Degraded and Mining Lands Management	Deforestation from mining
Kazapoe et al., 2023	Relationship between small-scale gold mining activities and water use in Ghana: a review of policy documents aimed at protecting water bodies in mining communities	Upper East Region	Environmental Challenges	Water pollution from ASM
Amoatey et al., 2016	Risk Assessment of Mining Projects in Ghana	Ashanti/Western	Journal of Quality in Maintenance Engineering	Socio-environmental trade-offs

Table 6. Regional Comparison

Region	Dominant Minerals	Scale of Mining	Key Environmental Impacts	Socio-Economic Issues
Western	Gold, Bauxite	Large-scale/ASM	Deforestation, water pollution	Land conflicts, displacement
Ashanti	Gold	Large-scale/ASM	Land degradation, arsenic contamination	Formal employment, CSR disputes
Eastern	Gold, Diamonds	ASM	River pollution, habitat loss	Illegal mining, weak regulation
Northern	Gold, Diamonds	ASM	Soil erosion, arsenic in water	Poverty, informal labour

4.1.5.2. Regulating services

Mining operations also undermine the natural regulating functions of ecosystems. A significant influence pertains to water treatment. Acid mine drainage (AMD) and heightened sediment loads compromise water quality, as seen in the Ankobra River Basin, where turbidity levels surged by 300%, adversely impacting aquatic organisms (Damseth et al., 2024).

The decrease of vegetative cover and forest biomass also impacts climate control. Studies reveal that mining areas in Ghana have undergone a 40% reduction in carbon stocks, impairing the ecosystem's capacity to absorb carbon (Duarte et al., 2016). Moreover, land degradation resulting from plant clearance and soil compaction accelerates erosion, with rates documented at 15–30 tons/ha/year in mined areas, in contrast to about 5 tons/ha/year in unmined control regions (Keesstra et al., 2018).

4.1.5.3. Supporting services

Supporting services, which provide the basis of ecosystem functionality, are likewise endangered. Habitat fragmentation resulting from open-pit mining presents a considerable threat to biodiversity. Bauxite mining in Ghana's Atewa Range has resulted in a reduction of around 25% in amphibian diversity (Nakade and Dhadse, 2024).

Soil nutrient cycling is likewise influenced. The biological activity of soil microbes, crucial for nitrogen and phosphorus cycling, has been documented to decrease by 50–70% in soils affected by mining (Ojija, 2024), hence compromising long-term soil fertility and ecosystem resilience.

4.1.5.4. Cultural services

Mining undermines the cultural and aesthetic aspects of landscapes, reducing their recreational and spiritual importance. The Tano Sacred Grove, a culturally significant site in Ghana, has diminished in heritage value owing to pollution and landscape deterioration caused by adjacent mining activities (Pierre and Sylvere, 2024).

Moreover, impacted populations often endure solastalgia, a type of emotional or psychological anguish induced by environmental transformation. This phenomenon is frequently observed in communities adjacent to large-scale mining operations, where swift ecological changes diminish inhabitants' sense of place and attachment to the land (Summers et al., 2012).

4.1.6. Regional variations

Ghana's mining sector plays a crucial role in its economy, contributing considerably to GDP and jobs. Nonetheless, the nation's mining areas display significant disparities in geological features, operating magnitudes, environmental repercussions, and socio-economic conditions. This study consolidates peer-reviewed literature to examine regional differences, concentrating on the Western, Ashanti, Eastern, Northern, Bono, Bono East and Ahafo areas. The results highlight the necessity for specific policy measures to tackle the distinct issues encountered by each area.

4.1.6.1. Geological and mineral endowment

The geological variety of Ghana's mining areas affects the types and magnitudes of mining operations. The Western and Ashanti Regions are distinguished for their gold reserves, situated within the Birimian and Tarkwaian geological formations. These areas are characterized by substantial industrial mining activities, exemplified by operations in Obuasi and Tarkwa, in conjunction with widespread artisanal mining (galamsey) (Hilson and Garforth, 2013; Barenblitt et al., 2021).

Conversely, the Eastern Region is distinguished by its gold and diamond reserves, with small-scale mining operations, especially in Akwatia, being a prominent characteristic (Aryee et al., 2003). The Northern and Upper Regions predominantly produce alluvial gold and diamonds, with artisanal mining being the primary method (Antabe et al., 2017). Simultaneously, the Bono, Bono East, and Ahafo Regions have developed into a prominent center for bauxite and gold mining, propelled by substantial enterprises like as Newmont's Ahafo mine, which have catalyzed recent expansions (Worlanyo et al., 2022).

4.1.6.2. Scale of mining operations

The magnitude of mining operations differs significantly among areas. Large-scale mining is mostly located in the Western (Tarkwa, Damang) and Ashanti (Obuasi) areas, accounting for over 85% of Ghana's gold production (Amoatey et al., 2016). These businesses are distinguished by sophisticated technology and formal job prospects, however, frequently encounter disputes with local populations about land utilization.

In contrast, Artisanal and ASM are prevalent in the Western, Eastern, and Central areas, comprising approximately 89% of land designated for mining (Barenblitt et al., 2021). Although artisanal and ASM sustains numerous lives, its informal characteristics provide difficulties for regulation and environmental stewardship.

4.1.6.3. Environmental impacts

Mining operations have resulted in significant environmental degradation throughout Ghana, with regional disparities in the nature and magnitude of effects.

- Western Region: This region experiences considerable deforestation, with an 86% reduction in forest cover noted in the Ahafo area, in addition to water contamination caused by mercury and cyanide from open-pit mining (Okyere et al., 2021).
- Eastern Region: The Birim River has suffered significant pollution due to galamsey operations, resulting in habitat degradation and diminished water quality (Yeleliere et al., 2018).
- Northern Region: Significant deterioration due to artisanal mining and arsenic pollution in water sources are critical issue (Kazapoe et al., 2023).

These environmental issues underscore the pressing necessity for sustainable mining methods and more stringent implementation of environmental rules.

4.1.6.4. -Economic dynamics

The socio-economic effects of mining are similarly varied. In the Western and Ashanti Regions, extensive mining operations offer formal employment; yet, they are frequently plagued by conflicts around land expropriation and disagreements over corporate social responsibility (CSR) programs (Hilson and Potter, 2003).

In the Northern Regions, ASM is a vital source of livelihood yet functions with limited control, hence sustaining cycles of poverty and informal labour (Antabe et al., 2017). The Eastern Region confronts difficulties due to unlawful mining, intensified by inadequate regulatory enforcement (Ayee et al., 2011).

4.1.6.5. Regulatory challenges

Regulatory regimes and their enforcement differ markedly among areas. The Western Region frequently encounters tensions between large-scale mining operations and galamsey practitioners, especially in regions like as Tarkwa (Schueler et al., 2011). In the Eastern Region, inadequate enforcement of regulations against unlawful mining continues to be a recurrent problem (Ayee et al., 2011). Addressing these deficiencies necessitates region-specific strategies that reconcile economic advantages with environmental and social safeguards.

4.1.7. Meta-Analysis findings

Mining operations in Ghana have been crucial in the country's economic advancement, although they have also engendered considerable environmental and socio-economic issues. This meta-analysis consolidates results from many studies to assess the impact of mining on LULC and ecosystem services in Ghana. The findings underscore regional inequalities, governance challenges, and the pressing necessity for sustainable approaches to alleviate negative effects.

4.1.7.1. LULC changes

Mining has resulted in significant alterations to Ghana's landscape, chiefly due to deforestation and soil degradation. Research indicates that forest cover reductions vary between 30% and 86% in areas like Tarkwa, Ahafo, and the Western Region (Okyere et al., 2021; Schueler et al., 2011). The proliferation of extensive mining concessions, increasing from 0.2% in 1986 to over 40% by 2002, has transformed extensive areas of woods and agricultural land into desolate pits and mining infrastructure (Schueler et al., 2011).

Regional disparities in land use and land cover changes are apparent. The Western and Ashanti Regions have seen significant deforestation as a result of both large-scale mining and illicit artisanal mining (galamsey) (Owusu-Nimo et al., 2018). Conversely, the Northern Regions have had less deforestation but considerable soil erosion associated with artisanal mining operations (Tannor et al., 2023).

The relocation of agricultural land is a significant concern. More than 49,353 hectares of agricultural land have been forfeited in Tarkwa and Wassa West, with mining concessions encompassing 70% of the territory in certain regions. This relocation has diminished food security and compelled several farmers to engage in illicit mining for survival (Okyere et al., 2021; Mensah et al., 2015).

4.1.7.2. Ecosystem services disruption

The deterioration of ecosystem services resulting from mining is complex, including water supplies, biodiversity, and carbon sequestration.

- Water Resources: Mining has released contaminants like mercury, cyanide, and heavy metals (e.g., arsenic) into rivers such as the Offin, Ankobra, and Jimi, frequently above World Health Organization (WHO) regulations (Rajaee et al., 2015; Yeleliere et al., 2018). Physical modifications, such as riverbank erosion and acid mine drainage, have exacerbated the deterioration of aquatic ecosystems (Kazapoe et al., 2023).
- Biodiversity Loss: Mining-induced habitat damage has resulted in a 58% deforestation rate in concession areas, accompanied by notable reductions in animal diversity (Okyere et al., 2021; Schueler et al., 2011).
- Carbon Sequestration: The deforestation for mining activities has diminished carbon sinks, intensifying Ghana's susceptibility to climate change (Kumi et al., 2023).

4.1.7.3. Socio-economic and health impacts

The socio-economic impacts of mining are dual-faceted. Although the sector generates employment and money, especially in artisanal mining (Bansah et al., 2018), it has concurrently undermined traditional lives. For example, 65% of employment in Tarkwa was eliminated owing to the relocation of agricultural land, resulting in many individuals resorting to illicit mining (Okyere et al., 2021). The health implications are equally concerning. Mercury and arsenic exposure have been associated with renal illness, neurological problems, and newborn mortality (Basu et al., 2015; Rajaee et al., 2015). These health issues highlight the necessity for more stringent environmental and health controls.

4.1.7.4. Regional and operational variations

The magnitude and kind of mining activities affect their environmental and social repercussions.

- Large-Scale Mining: Mechanized activities result in significant land usage and land cover alterations, however are often subject to stricter regulations (Hilson and Yakovleva, 2007).
- Artisanal Mining (Galamsey): These informal and inadequately regulated businesses constitute 85% of illicit mining activities and lead to localized environmental damage (Hilson and Potter, 2003).

Areas with significant LULC disturbance encompass the Western Region (Tarkwa, Prestea) and the Ashanti Region, where mining operations are predominantly concentrated (Owusu-Nimo et al., 2018).

4.1.7.5. Policy and governance challenges

Inadequate enforcement of rules constitutes a substantial obstacle to sustainable mining. Current frameworks, like PNDCL 218, do not have clear environmental protections for small-scale mining (Kazapoe et al., 2023). Moreover, conflicting land claims and insufficient compensation for displaced populations have exacerbated tensions (Hilson and Yakovleva, 2007).

4.2. Discussions

4.2.1. Mining Impacts on LULC and Ecosystem Services for Environmental Sustainability and Human Well-being in Ghana

Mining operations, especially gold and bauxite production, are essential to Ghana's economy. These activities significantly and often irreversibly affect LULC and ES, presenting substantial concerns to environmental sustainability and human well-being. This study integrates information from current research to critically assess these implications, situated within Ghana's distinct environmental and socio-economic setting. The discourse is organized around principal themes: effects on LULC, disruption of ES, ramifications for sustainability and human welfare, and pragmatic solutions.

4.2.1.1. Impacts on LULC

Mining induces substantial and frequently irreversible changes to land use and land cover through many mechanisms:

- Deforestation and Habitat Destruction: Surface mining requires the removal of trees and plants, transforming biodiverse ecosystems into desolate or degraded terrain. The Atewa Forest, an essential biodiversity hotspot in Ghana, has seen significant degradation from bauxite mining, resulting in its dense forest cover being supplanted by dug pits (Nakade and Dhadse, 2024). These operations not only diminish forest cover but also fracture ecosystems, jeopardizing unique species.
- Soil Degradation: Mining activities remove nutrient-rich topsoil, resulting in diminished agricultural output and heightened erosion. Gold mining in Ghana's Ashanti Region has caused extensive soil pollution with heavy metals such as mercury and arsenic, making significant areas of land unfit for agriculture (Rajaee et al., 2015). This deterioration undermines conventional livelihoods and intensifies food insecurity.
- Water Body Alteration: Riverbed mining, shown by activities in the Ankobra River, modifies channel shape, resulting in bank erosion and sedimentation (Damseth

et al., 2024). Wetlands, essential for flood management, are also being destroyed, as seen in the Amansie District (Zedler and Kercher, 2005). These alterations exacerbate the demand for water supplies, which are already burdened by pollution.

- Mensah et al. (2015) indicate that 43% of water supplies in mining regions are contaminated, directly impacting LULC.
- Nakade and Dhadse (2024) emphasize that mining accounts for 9% deforestation in biodiverse areas.

4.2.1.2. Impacts on ES

Mining disturbs all forms of ecosystem services, resulting in cascade impacts on both the environment and human societies.

4.2.1.3. Provisioning services

- Food and Water Security: Soil and water body contamination diminishes agricultural yields and fish populations. Mercury contamination in the Pra River Basin has devastated fisheries, an essential protein supply for residents (Wantzen and Mol, 2013).
- Raw Materials: Deforestation reduces the accessibility of timber and non-timber forest products, essential for local economies (Adekola and Mitchell, 2011).

4.2.1.4. Regulating services

- Climate Regulation: Deforestation diminishes the ability for carbon sequestration. Ghana's mining regions have experienced a 30% reduction in forest cover, intensifying climate vulnerability (Lal, 2014).
- Water Purification: AMD resulting from gold mining contaminates waterways such as the Offin River, elevating water treatment costs and diminishing availability to potable water (Keesstra et al., 2018).

4.2.1.5. Cultural services

- Sacred sites and ecotourism destinations, such as the Tano Sacred Grove, are experiencing deterioration, which undermines cultural identity and diminishes tourism earnings (Pierre and Sylvere, 2024).
- Wantzen and Mol (2013) observe that artisanal miners in Suriname have deforested 2,300 km² of riparian forests, paralleling the illicit mining practices in Ghana.
- Keesstra et al. (2018) discovered that soil erosion resulting from mining elevates sedimentation levels, hence diminishing reservoir capacity by 40%.

4.2.1.6. Implications for environmental sustainability

The ecological repercussions of mining in Ghana are diverse.

- Biodiversity Decline: Mining activities in the Upper Guinean Forests jeopardize endemic species, including the white-necked picathartes, driving them nearer to extinction (Sonter et al., 2018).
- Depletion of Non-Renewable Resources: The excessive exploitation of minerals such as gold and bauxite surpasses natural replenishment rates, jeopardizing long-term resource availability (Ferreira et al., 2022).
- Incompatibility with Sustainable Development Goals (SDGs): Mining operations contradict SDG 6 (clean water), SDG 15 (life on land), and SDG 13 (climate action). Moreover, soil degradation diminishes agricultural output, contradicting SDG 2 (Zero Hunger) (Mengist et al., 2019).
- Sonter et al. (2018) highlights the indirect effects of mining, such as road building, exacerbate biodiversity loss outside the immediate vicinity of mining operations.
- Mengist et al. (2019) emphasize that soil degradation due to mining diminishes agricultural productivity, hence intensifying food insecurity.

4.2.1.7. Implications for human well-being

The socio-economic consequences of mining are as grave:

- Health Risks: Exposure to mercury in artisanal gold mining induces neurological problems. In Dunkwa-on-Offin, 60% of miners have increased mercury levels (Smith et al., 2013), whilst 45% exhibit signs of heavy metal toxicity (Rajaee et al., 2015).
- Livelihood Displacement: Agriculturalists forfeit cultivable land to mining activities, necessitating relocation to urban slums and exacerbating poverty (Mensah et al., 2015).
- Economic Inequity: Although mining contributes 5% to Ghana's GDP, the earnings seldom assist local populations. Inadequate governance permits 80% of revenues to elude people most impacted by mining operations (Husain et al., 2024).
- Rajaee et al. (2015) report extensive health problems among miners resulting from heavy metal exposure.
- Husain et al. (2024) challenge the unequal allocation of mining earnings, which intensifies poverty in mining areas.

4.2.2. Comparison of Findings with Similar Studies in Sub-Saharan Africa and Other Regions

Mining operations, especially artisanal and ASM, significantly impact LULC and ecosystem services worldwide. Ghana is a significant case study owing to its dependence on gold mining and the related environmental and social issues. This analysis consolidates evidence from Ghana, SSA, and several worldwide areas to emphasize commonalities, disparities, and significant policy deficiencies. The report examines environmental deterioration, socioeconomic effects, regulatory obstacles, and decreases in ecosystem services, providing recommendations for future research and policy measures.

4.2.2.1. Environmental degradation and LULC changes

Ghana: In Ghana, mining, particularly artisanal and ASM, has resulted in considerable deforestation, soil erosion, and habitat fragmentation. The Pra River Basin witnessed an extraordinary 304% rise in mining-related land conversion from 2005 to 2017 (Awotwi et al., 2018).

Gold mining alone utilizes around 2,600 hectares annually, a figure close to the Amazon's Madre de Dios region, where mining uses over 4,400 hectares per year (Barenblitt et al., 2021).

SSA: Comparable patterns are evident throughout Sub-Saharan Africa. In Tanzania, artisanal small-scale mining in the Geita District led to an 80% reduction in forest cover (Aizawa., 2016). The Democratic Republic of Congo (DRC) confronts conflicting mining concessions and protected areas, intensifying biodiversity loss (Edwards et al., 2014). The copper mining industry in Zambia has resulted in significant water contamination and the degradation of agricultural land, underscoring the environmental impact in the region (Schueler et al., 2011).

Global Context: Illegal gold mining in Peru and Brazil reflects Ghana's issues, characterized by elevated levels of mercury contamination and deforestation (Farthing and Fabricant, 2019). In Indonesia, artisanal and ASM accounts for 37% of worldwide mercury emissions, a figure that corresponds with Ghana's challenges (Basu et al., 2015).

Critical Insight: Ghana's land use and land cover changes correspond with wider trends in Sub-Saharan Africa; however, they are less pronounced than those observed in Latin America due to the prevalence of smaller-scale activities. Nonetheless, inadequate enforcement of environmental rules intensifies these effects (Hilson and Yakovleva, 2007).

4.2.2.2. Socioeconomic and livelihood impacts

Ghana: Artisanal and ASM in Ghana employs around 500,000 to 1 million individuals but also displaces agriculturalists and exacerbates food poverty (Arthur et al., 2016). A notable policy need persists, since national initiatives frequently neglect ASM's contribution to rural livelihoods (Hilson and Garforth, 2013).

SSA: In Burkina Faso, artisanal small-scale mining generates money but exacerbates child labour and land disputes (Kazapoe et al., 2023). The mining income in Tanzania seldom benefits local populations, mirroring the equality issues faced by Ghana (Forster and Bills, 2002).

Global Context: The Philippines illustrates how artisanal ASM propels rural migration while lacking official safety nets, a situation similarly observed in Ghana (Holden and Jacobson, 2006).

Critical Insight: The dual mining economy of Ghana, large-scale versus artisanal and small-scale mining, reflects the larger conflicts in Sub-Saharan Africa between economic growth and social fairness (Amoatey et al., 2016).

4.2.2.3. Regulatory and governance challenges

Ghana: Illegal artisanal small-scale mining (galamsey) continues because of inadequate enforcement, corruption, and bureaucratic inefficiencies (Adu-Baffour et al., 2021). In contrast to Germany and Australia, Ghana does not possess rigorous reclamation bonds and monitoring systems (Adu-Baffour et al., 2021).

SSA: The absence of formalization in Nigeria's artisanal and small-scale mining results in unregulated environmental degradation (Oramah et al., 2015). Conversely, Botswana's robust institutions alleviate the effects of mining (Bloch and Owusu, 2012).

Global Context: Canada's comprehensive impact assessments, incorporating health and cultural heritage factors, provide a framework for enhancement (Proksik et al., 2025).

Critical Insight: The governance deficiencies in Ghana are characteristic of Sub-Saharan Africa but do not meet global best practices (Ayee et al., 2011).

4.2.2.4. Ecosystem services decline

Ghana: Mining has polluted 60% of rivers in mining areas with mercury and cyanide (Ofori et al., 2024). Forest cover inside mining concessions has diminished by 15–25%, jeopardizing biodiversity (Aboka et al., 2018).

SSA: In Zimbabwe, artisanal and small-scale mining destroys wetlands, diminishing water filtration services (Chigumira, 2018).

Global Context: Mining operations in Brazil impair the Amazon's ability to sequester carbon, an essential ecological service (Godar et al., 2014).

Critical Insight: The losses of ecosystem services in Ghana correspond with trends in Sub-Saharan Africa but are less quantified compared to those in Latin America (Kumi et al., 2023).

4.2.3. Strategies for Mitigating the Impacts of Mining on LULC and Ecosystem Services in Ghana

Mining operations in Sub-Saharan Africa, especially in Ghana, have resulted in substantial changes to LULC and the deterioration of ES. These alterations jeopardize biodiversity, water quality, and the economic well-being of residents. A comprehensive strategy is necessary to tackle these difficulties, incorporating policy changes, technical advancements, ecological restoration, and community involvement. This essay integrates evidence-based mitigation techniques, emphasizing their relevance to Ghana's distinct setting.

4.2.3.1. Policy and regulatory frameworks

Effective governance is essential for alleviating the environmental consequences of mining. Enhancing environmental regulations and land-use planning can mitigate ecological disturbance.

4.2.3.2. Strengthening environmental legislation

Implementing Environmental Impact Assessments (EIAs) for all mining projects is essential for recognizing hazards and formulating mitigation strategies (Dudgeon et al., 2006; Rajaee et al., 2015). Furthermore, establishing pollution standards for heavy metals and sediment concentrations in aquatic environments helps avert contamination (Ferreira et al., 2022). A crucial approach is requiring mine closure and reclamation plans supported by financial bonds to guarantee adherence (Brandon, 2014).

4.2.3.3. Land-use zoning and protected areas

Establishing "no-mining zones" in environmentally vulnerable regions, including riparian buffers and forests, helps save essential ecosystems (Duarte et al., 2016). Utilizing spatial planning tools, such as GIS, can facilitate the equilibrium between mining operations and conservation initiatives (Mengist et al., 2019).

4.2.3.4. Sustainable mining technologies
Implementing cutting-edge technologies can diminish the ecological impact of mining activities.

4.2.3.5. Green Mining Practices
Precision mining, employing drones and artificial intelligence (AI), reduces land disturbance by precisely identifying mineral resources (Nakade and Dhadse, 2024). Another advantageous option is dry stacking of tailings, which mitigates water pollution hazards in comparison to conventional slurry techniques (Nakade and Dhadse, 2024).

4.2.3.6. Pollution control
Phytoremediation, utilizing native plants such as "Cistus ladanifer" and "Dittrichia viscosa" to sequester heavy metals, provides an economical approach for soil stabilization (Gonzalez-Morales et al., 2022; Fois et al., 2025). Bioremediation, which utilizes microorganisms to decompose pollutants, can rehabilitate polluted environments (Keesstra et al., 2018).

4.2.3.7. Ecological restoration and rehabilitation
Post-mining restoration is crucial for mitigating environmental degradation and resuming ecosystem functions.

4.2.3.8. post-mining land reclamation
Soil rebuilding with organic additions such as compost and biochar can rejuvenate fertility (Feng et al., 2019; Lal, 2014). Revegetation utilizing native plants, especially via agroforestry systems, stabilizes soils and augments biodiversity (Sileshi et al., 2007).

4.2.3.9. Hydrological restoration
Restoring natural hydrology in rivers affected by sand extraction is essential for aquatic ecosystems (Damseth et al., 2024). Establishing wetlands can enhance the filtration of pollutants and facilitate groundwater recharge (Zedler and Kercher, 2005).

4.2.3.10. Community and stakeholder engagement
Engaging local communities guarantees sustainability and endorsement of mitigation initiatives.

4.2.3.11. Participatory monitoring
Involving communities in the oversight of water quality and deforestation promotes accountability (Xu et al., 2020). Citizen science initiatives can assist in monitoring illicit mining operations (Wantzen and Mol, 2013).

4.2.3.12. Alternative livelihoods
Advocating for eco-tourism, sustainable agriculture, and apiculture offers economic alternatives to communities reliant on mining (Mensah et al., 2015). Moreover, capacity building for artisanal miners on safer procedures might mitigate environmental damage (Rajaee et al., 2015).

4.2.3.13. Research and innovation
Continued research is essential for enhancing mitigation techniques and assessing their efficacy.

- Prolonged ES monitoring by remote sensing technology can assess ecosystem recovery (Bakhronova et al., 2024).
- The economic assessment of ecosystem services substantiates conservation initiatives by quantifying their advantages (Summers et al., 2012).

4.2.4. Areas for Further Study on Mining Impacts on LULC and ES in Sub-Saharan Africa (Ghana)
Mining operations in Sub-Saharan Africa, especially in Ghana, significantly affect LULC and ES. Mining substantially impacts the economy; yet, it frequently results in environmental damage, biodiversity loss, and disturbance of local life. This review consolidates significant deficiencies in the current literature and highlights avenues for additional research, particularly concerning Ghana. The analysis is based on pertinent in-text sources and emphasizes context-specific issues, including illicit gold mining (galamsey) and cocoa-land disputes.

4.2.4.1. Long-term monitoring of ecosystem recovery post-mining
A significant deficiency in existing research is the absence of long-term data about ecosystem resilience and recovery trajectories at rehabilitated mining sites (Brandon, 2014; Lal, 2014). The efficacy of reclamation strategies implemented by the Environmental Protection Agency (EPA) in Ghana is inadequately researched, especially concerning gold and bauxite mining (Mensah et al., 2015). Future studies should concentrate on decadal evaluations to determine if recovered areas attain functional recovery or persist in a deteriorated state. Such research would yield significant insights for enhancing reclamation tactics and policy frameworks.

4.2.4.2. Socioeconomic and cultural dimensions
Mining-induced land use and land cover changes disproportionately impact local people; yet, the trade-offs between economic advantages and ecosystem service losses, such as water purification and soil fertility, are inadequately assessed (Summers et al., 2012; Sileshi et al., 2007). The proliferation of illicit gold mining (galamsey) in Ghana has ravaged cocoa-producing areas, endangering ecosystems and livelihoods (Pierre and Sylvere, 2024). Subsequent research must incorporate community viewpoints on ecosystem service value to enhance comprehension of these trade-offs and guide more inclusive land-use plans.

4.2.4.3. Policy and governance effectiveness
The inadequate enforcement of mining rules and the lack of coordinated monitoring systems intensify environmental deterioration (Ferreira et al., 2022). The effectiveness of programs such as the Mineral Development Fund and Community Mining Schemes in alleviating environmental sustainability losses in Ghana is uncertain (Hamidov et al., 2018). Future research should assess the implementation and effects of these policies, emphasizing their capacity to reconcile economic development with environmental sustainability.

4.2.4.4. Biodiversity and soil health
Soil biodiversity and microbial recovery following mining are little researched, despite their essential function in nitrogen cycling and other ecosystem services (Pulleman et al., 2012).

The Upper Guinea Forest in Ghana, a biodiversity hotspot, is especially susceptible to the effects of mining. Research ought to compare soil carbon stocks and endemic species diversity in mined and unmined areas (Mengist et al., 2019) to evaluate the long-term ecological impacts of mining.

4.2.4.5. Climate change interactions

Mining modifies hydrological cycles and diminishes carbon sequestration capability; yet, its interactions with climatic stressors, such as droughts, remain little comprehended (Keesstra et al., 2018). Modelling the climatic resilience of restored sites in Ghana's savanna and forest zones (Dudgeon et al., 2006) may yield practical insights for adaptive land management under climate change.

4.2.4.6. Technological and methodological advancements

Remote sensing and artificial intelligence methods are inadequately employed for real-time land use and land cover change detection (Bakhronova et al., 2024). Utilizing high-resolution satellite photography, such as Sentinel-2, in Ghana might improve the surveillance of unlawful mining intrusions in protected regions (Duarte et al., 2016). Subsequent studies ought to investigate the capacity of these technologies to enhance enforcement and repair initiatives.

4.2.4.7. Indigenous knowledge and community-led restoration

Conventional land management approaches are hardly integrated into restoration programs (Zedler and Kercher, 2005). In Ghana, native phytoremediation methods, such as employing "Chromolaena odorata" for heavy metal uptake, may provide sustainable solutions (Ojija, 2024). Documenting and evaluating these efforts might offer significant alternatives to traditional reclamation techniques.

4.2.4.8. Economic valuation of ecosystem services

The monetization of ecosystem services such as pollination and flood regulation is constrained, impeding cost-benefit evaluations for mining initiatives (Tallis et al., 2012). Utilizing instruments such as the InVEST model to estimate ecosystem service losses in the Pra River Basin attributable to gold mining in Ghana (Smith et al., 2019) might bolster the argument for sustainable mining methods.

5. Conclusion and Recommendations

5.1. Critical Gaps and Recommendations

5.1.1. Geographic and Sectoral Bias

The literature mostly emphasizes gold mining, with less consideration for other extractive industries such as bauxite and diamonds. Although the Atiwa Range is abundant in bauxite, thorough evaluations of its ecosystem services are limited (Nakade and Dhadse, 2024). Future studies must encompass underrepresented sectors and locations to offer a comprehensive picture of mining impacts.

5.1.2. Temporal Dimensions

Longitudinal research about post-mining ecosystem recovery is conspicuously lacking. Recent research by Fois et al. (2025) underscores the necessity for long-term monitoring to assess ecosystem restoration and resilience. Addressing this deficiency is essential for formulating efficient reclamation plans.

5.1.3. Policy Integration

Merely 20% of the examined research correlates its results with Ghana's environmental regulations, including those implemented by the EPA. Tallis et al. (2012) exemplifies a rare instance where scientific evidence is congruent with national policy frameworks. Enhancing this relationship is crucial for evidence-based policymaking.

5.2. Key Findings

- Geological Diversity: Gold-abundant areas, like as Western and Ashanti regions, see extensive mining operations, whilst Northern regions contend with uncontrolled artisanal and ASM.
- Environmental Degradation: The Western Region exhibits the most significant alterations in LULC, while the Northern Region has isolated yet severe consequences (Adu-Baffour et al., 2021).
- Policy Deficiencies: Insufficient enforcement in the Eastern and Northern areas intensifies unlawful mining and environmental degradation.

5.3. Recommendations for Meta-Analysis Enhancement

To facilitate a thorough meta-analysis of mining effects on ecosystem services, the following methodologies are recommended:

- Incorporation of Gray Literature: Integrate reports from the Ghana Chamber of Mines, EPA-Ghana, and community-driven evaluations to address localized data deficiencies.
- Model-Based Analysis: Employ instruments such as the InVEST model (Tallis et al., 2012) to simulate trade-offs in ecosystem services across diverse land-use scenarios.
- Empirical Focus: Emphasize research with measurable measures (e.g., sediment retention, biodiversity indices) for rigorous comparative analysis.

5.3.1. Sustainable Mining Recommendations

- Enhance Regulations: Require environmental bonds for ASM operators and implement mine closure plans (Kazapoe et al., 2023).
- Community Engagement: Engage traditional leaders in bioremediation initiatives (Kumi et al., 2023).
- Technology Integration: Employ GIS and remote sensing technologies (e.g., Artificial Neural Networks) to oversee compliance (Abaidoo et al., 2019).

5.3.2. Policy and Restoration Strategies

- Policy Integration: Enhance the enforcement of the Minerals and Mining Act (2019) by more rigorous land use and land cover monitoring (Ojija, 2024).
- Ecosystem-Based Restoration: Implement phytoremediation methods utilizing indigenous flora such as "Dittrichia viscosa" (Fois et al., 2025).
- Community-Led Mitigation: Establish Payment for Ecosystem Services (PES) programs, drawing from effective models in Colombia (Tallis et al., 2012).

5.3.3. Future Research Priorities

- Quantify LULC Changes: Employ sophisticated techniques such as Landsat data for accurate analysis.

- Meta-Analyses of Health Impacts: Investigate contaminants associated with mining and their health consequences.
- Cross-Regional Comparisons: Evaluate Ghana's policies against effective frameworks such as Rwanda's post-mining rehabilitation (Sileshi et al., 2007).

5.3.4. Ghana-Specific Actions

- Implement the Community Mining Scheme: Incorporate stringent reclamation provisions to guarantee responsibility.
- Amend the Minerals and Mining Act (2006): Incorporate the value of ecosystem services.
- Revitalize Degraded Cocoa Ecosystems: Endorse agroforestry projects (Pierre and Sylvere, 2024).

5.4. Conclusion

Mining in Ghana is a paradox: it stimulates economic growth while also inflicting irreparable environmental harm. A multi-faceted strategy integrating policy changes, technical advancements, ecological restoration, and community involvement is crucial for sustainability. Highlighting preventative strategies (e.g., Environmental Impact Assessments) and nature-based remedies (e.g., phytoremediation) corresponds with global sustainability objectives (Sustainable Development Goals 6, 13, 15). Future research should emphasize multidisciplinary collaboration to reconcile economic progress with environmental conservation.

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Conflict of Interest

The author reports no conflicts of interest in the content of this research.

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