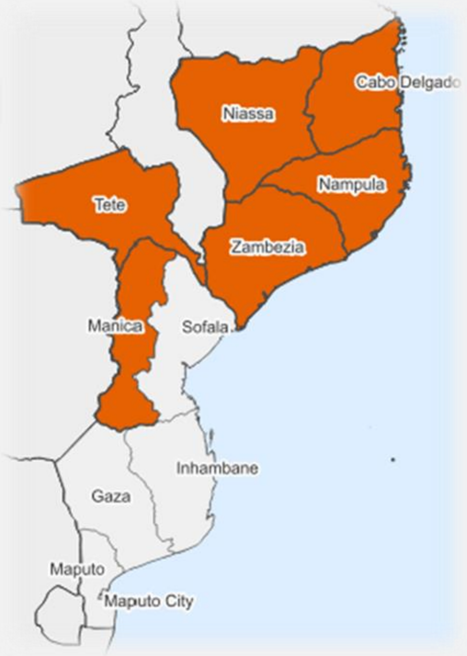
Safety and Sustainability in Artisanal and Small-Scale Mining Operations in Mozambique



Improving Safety and Sustainability in ASM is Essential to Protect Lives and Reduce Environmental Impacts.

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Overview

Mining is an activity that consists of the processes of prospection, exploration, extraction and processing of ores.

Mining can be classified into three main groups:

- Large-scale: so-called commercial or industrial mining operations
- Smaller-scale: so-called social use mining operations, e.g., quarries, sand pits, and clay mines
- Artisanal mining: extractive activities, informal, manual, or mechanized, and frequently clandestine.

Context

- According to the PanAfGeo (2020) in Mozambique, more than 100,000 people are directly involved in artisanal mining. In most cases, this is done informally and clandestinely, with a higher incidence in provinces with high mining potential, namely Manica, Tete, Zambézia, Niassa, Nampula, and Cabo Delgado.
- Among the main products extracted by small-scale miners highlights gold, precious and semi-precious stones (emeralds, tourmaline, morganite, and aquamarine). Less valuable products include clays, limestone, building stones, sand and others.
- Despite its glorious production figures, the PETA subsector is notorious for its deplorable environmental degradation, poor health/living conditions, and very low quality of life indicators, as well as an almost total disregard for best practices in workplace health and safety.

Hazard Identification and Risk Assessment

- What can go wrong in terms of safety and health?
- Which dangers or hazards are critical?
- What measures are need to prevent the occurrence of those hazards?
- What measures are need to mitigate the consequences of those hazards in case they take place?

AIM of Hazard Identification and Risk Assessment

- To describe the mining subsystems and components
- To identify hazards and possible consequences related to the mining
- To make a qualitative estimative of risks
- To propose preventive and mitigation measures of the identified risks

Hazard vs Risk

Hazard

A condition that has the potential to cause human injury or fatality, damage to property, damage to the environment or some combination of these.

Risk

A measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury. **In other words, risk** is a chance of injury or loss or bad consequences to happen.

Safety vs Health in Mining

Safety

- **Absence of:**
  - Injury and harm on human
  - Damage on property and the environment
- **Opposite = Accident**
- Safety deals with acute effects of hazards

Health

- State of physical and mental well-being – including the absence of disease or infirmity.
- Health issue deals with chronic effects of hazards

Hazard Effects

Acute: Immediate, short term

Chronic: Persistent, prolonged and repeated

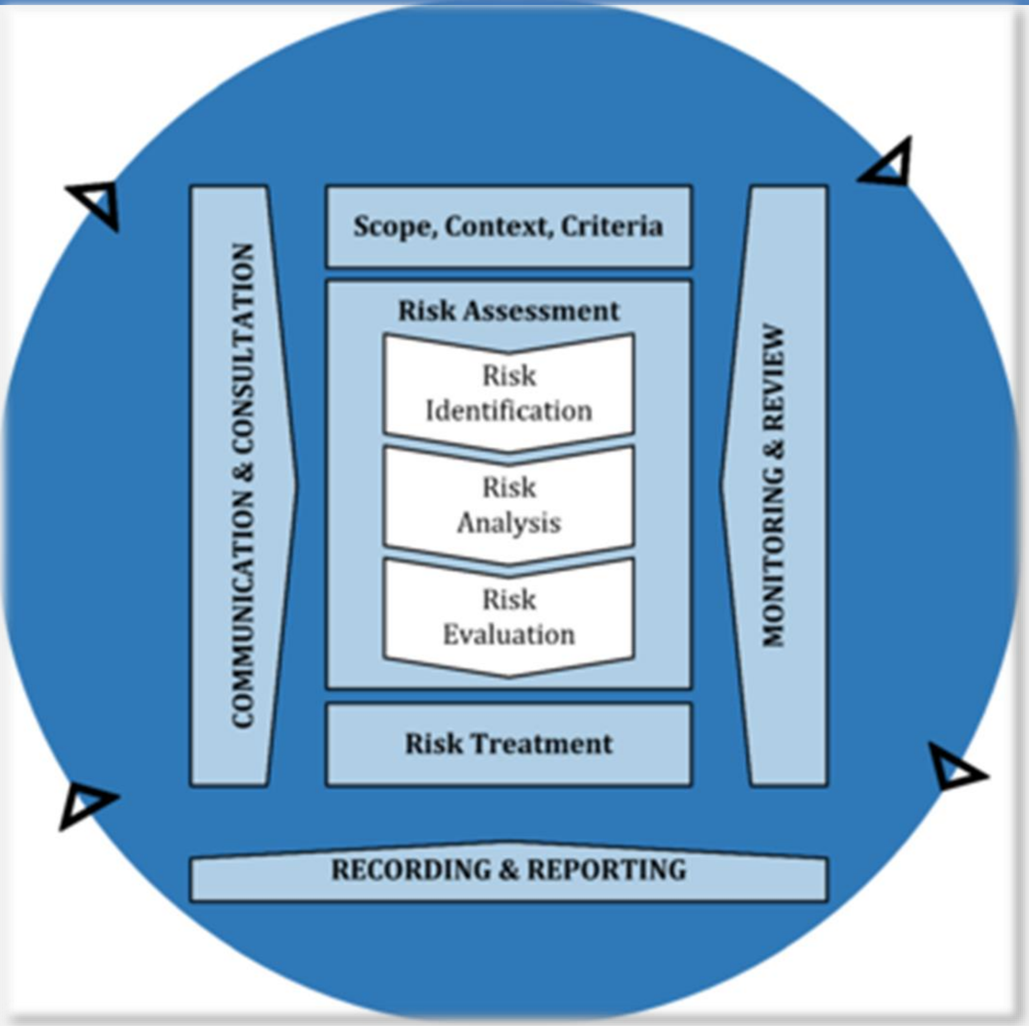
Sources of Hazards

- People
- Equipment/plant/process
- Work system
- Substances/materials
- The work environment

Broad Categories of Hazards

Category	Example
Safety Hazards	
Chemical Hazards	acidity, alkalinity, corrosivity, explosiveness, flammability, toxicity, asphyxation.
Mechanical Hazards	moving equipment, tripping hazards, impact and forces
Thermodynamics Hazards	high/low temperature, high pressure, vacuum, heat transfer
Electrical & Electromagnetic Hazards	high voltage, radiation, static electricity, electrical current
Health Hazards	noise, pollution, vibration, radioactivity,
External Threats	accidental damage by missiles and vehicles, act of god and natural causes

The Steps in Risk Management



ISO 45001 ISO 31000:2018

Do a Hazard Analysis → Identify the Hazards → Assess their Risks.

Common Analysis Techniques:

- Preliminary Hazard Analysis **(PHA)**
- Energy Flow/Barrier Analysis
- Failure Modes and Effects Analysis **(FMEA)**
- Fault Tree Analysis **(FTA)**
- System Hazard Analysis **(SHA)**
- Subsystem Hazard Analysis **(SSHA)**
- Operating & Support Hazard Analysis **(O&SHA)**
- Occupational Health Hazard Analysis **(OHHA)**
- Software Hazard Analysis
- … and many others

Preliminary Hazard Analysis (PHA)

Inductive Method

Identify the hazards and hazardous situations and events that can cause harm for a given activity, facility or system.

Inputs include:

- Information on the system to be assessed
- Details of the design of the system as are available and relevant.

Outputs include:

- A list of hazards and risks;
- Recommendations in the form of acceptance, recommended controls, design specification or requests for more detailed assessment.

Risk = consequence x likelihood

The fundamental rule is to define the consequence first, as different consequences have different likelihood.

Likelihood	Likelihood description	Frequency	Substance Exposure
ALMOST CERTAIN	Recurring event during the life-time of an operation/project.	Occurs more than twice per year.	Frequent (daily) exposure at > 10 x OEL.
LIKELY	Event that may occur frequently during the life-time of an operation/project.	Typically occurs once or twice per year.	Frequent (daily) exposure at > OEL.
POSSIBLE	Event that may occur during the life-time of an operation/project.	Typically occurs in 1-10 years.	Frequent (daily) exposure at > 50% of OEL. Infrequent exposure at > OEL.
UNLIKELY	Event that is unlikely to occur during the life-time of an operation/project.	Typically occurs in 10-100 years.	Frequent (daily) exposure at > 10% of OEL. Infrequent exposure at > 50% of OEL.
RARE	Event that is very unlikely to occur very during the life-time of an operation/project.	Greater than 100 year event.	Frequent (daily) exposure at < 10% of OEL. Infrequent exposure at > 10% of OEL.

	Consequence				
Likelihood	1 - Minor	2 - Medium	3 - Serious	4 - Major	5 - Catastrophic
A - Almost Certain	Moderate	High	Critical	Critical	Critical
B - Likely	Moderate	High	High	Critical	Critical
C - Possible	Low	Moderate	High	Critical	Critical
D - Unlikely	Low	Low	Moderate	High*	Critical
E - Rare	Low	Low	Moderate	High*	High*

Note: All risks that have a Critical risk classification from a qualitative analysis (using the risk determination matrix) must be re-evaluated using a Level 3 quantitative analysis.

*Consideration must be given to escalate all risks with a consequence of Major or Catastrophic and a classification of High to a Level 3 quantitative analysis.

The results of the PHA are usually reported by using a PHA worksheet (or, a computer program). A typical PHA worksheet is shown below. Some analyses may require other columns, but these are the most common.

System: Operating mode: Analyst: Date:

Ref.	Hazard	Accidental event (what, where, when)	Probable causes	Contingencies/ Preventive actions	Prob.	Sev.	Comments

Geological Setting

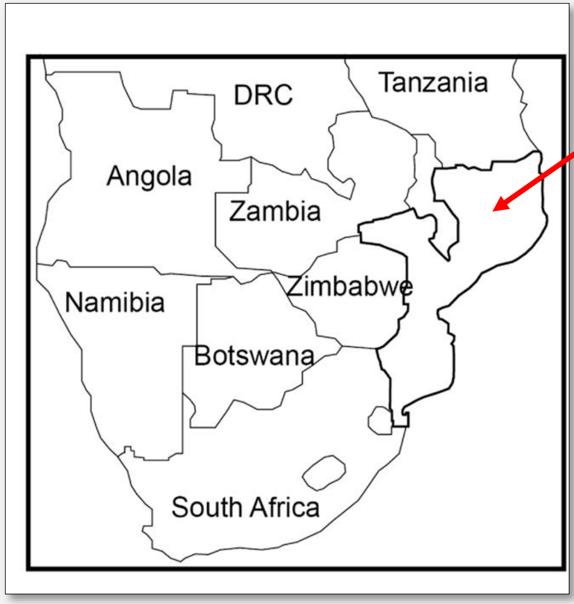


Figure 1: Location of Mozambique in Africa

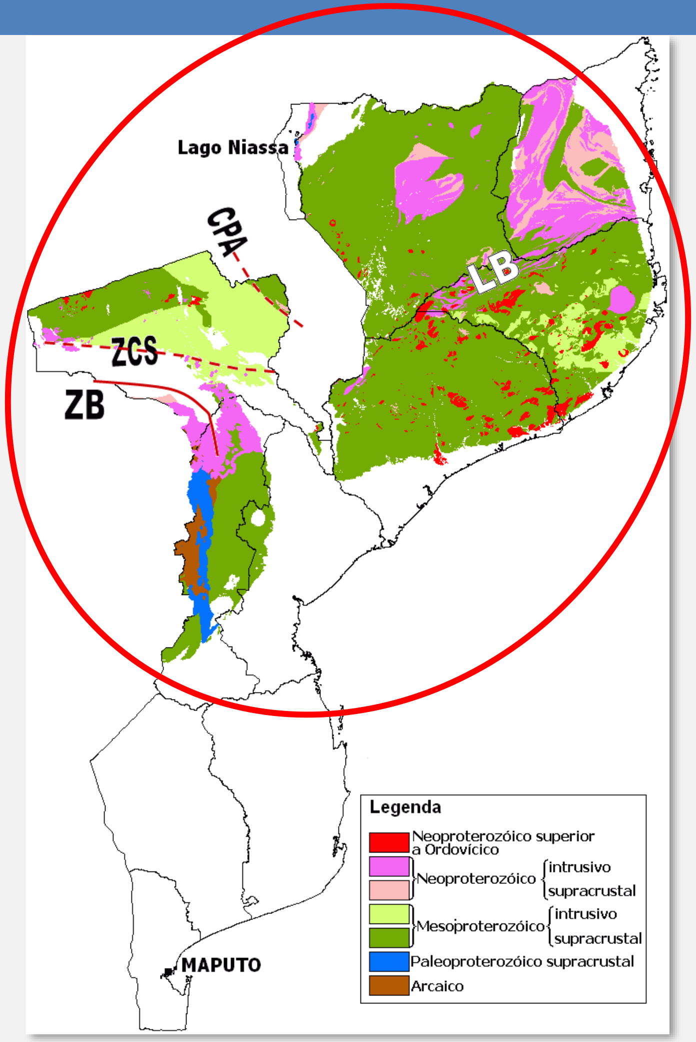


Figure 2: Precambrian geological units in the study areas

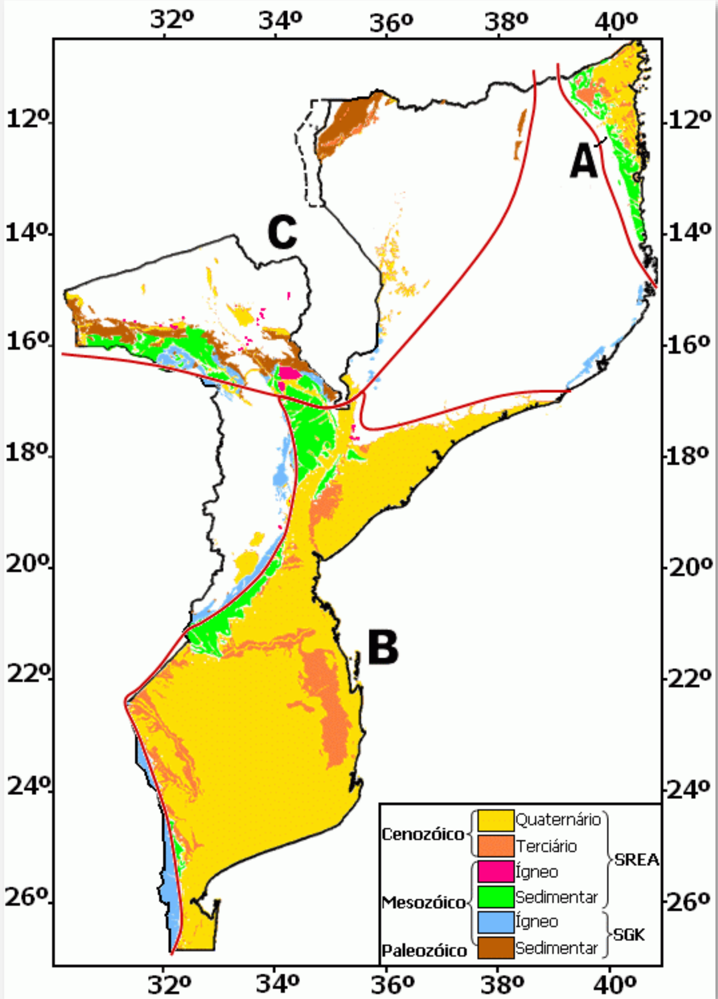


Figure 3: Phanerozoic geological units in the remaining provinces of Mozambique

Mineral Resources Distribution in Mozambique

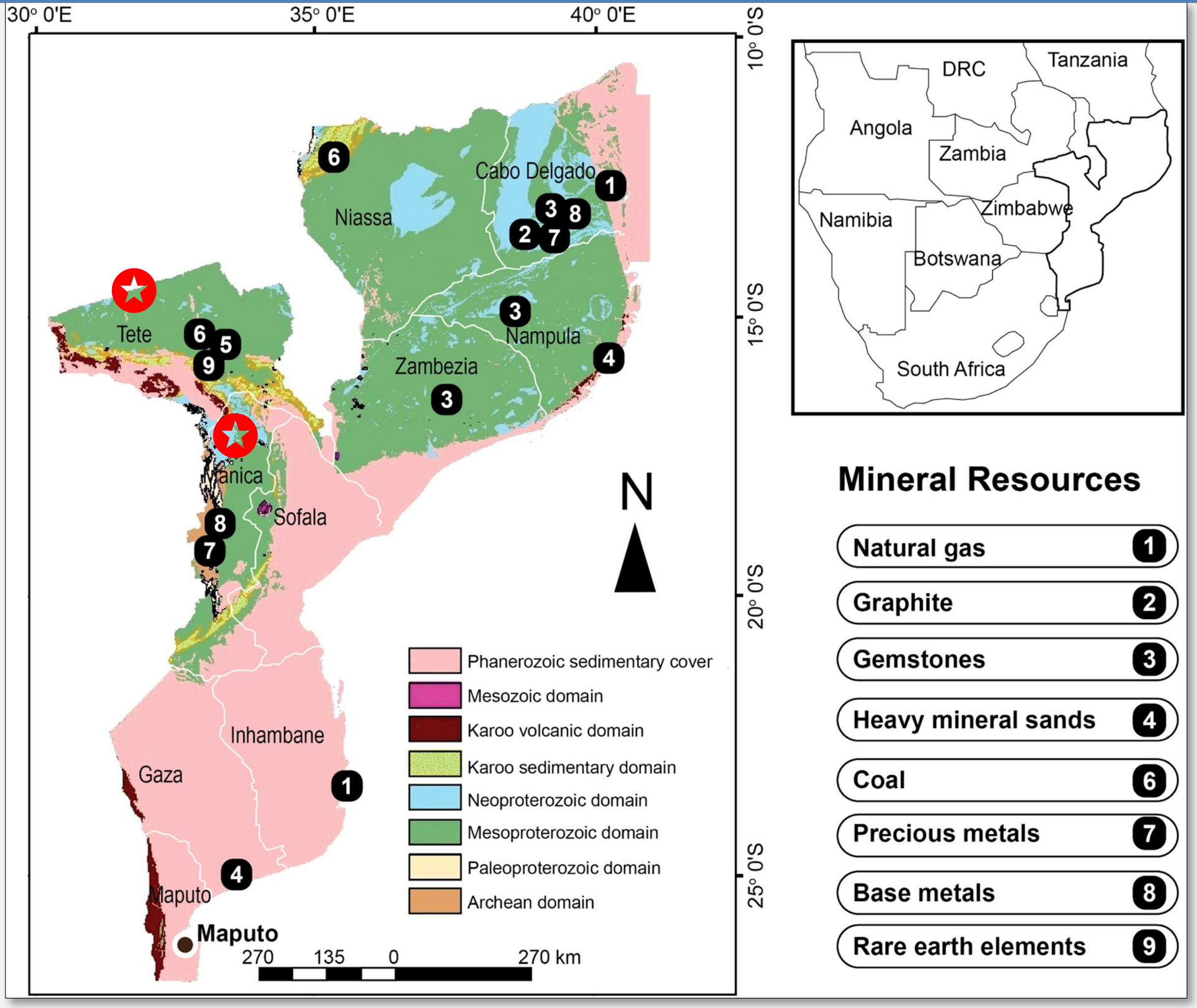


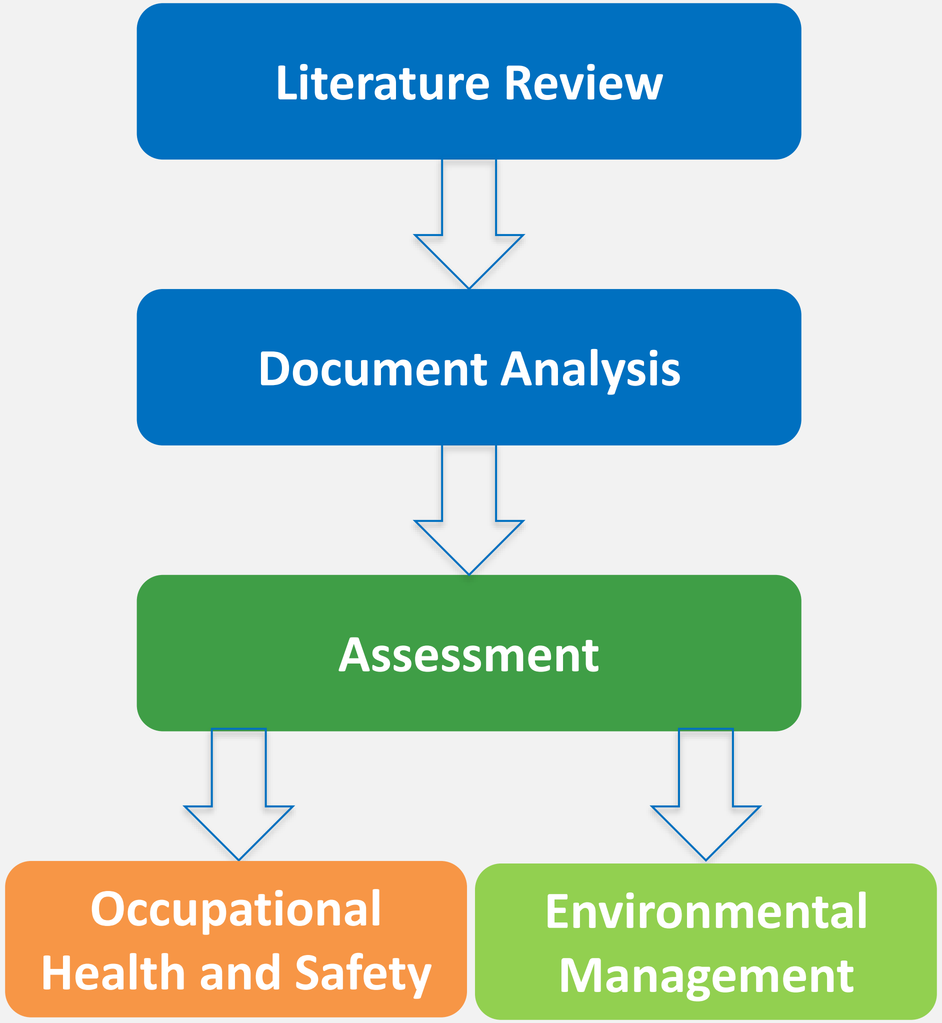
Figure 4: Geographical distribution of major mineral resources in Mozambique

Source: Nopeia et al., (2026)

Citing data from the National Institute of Mines (INAMI)…

- Manica: leading gold producer (65% – 2024)
- In total Mozambique produced 886 kg of gold last year:
  - Manica: 577 kg
  - Tete: 285 kg
- Significant unregistered production (illegal mining)

Methodology



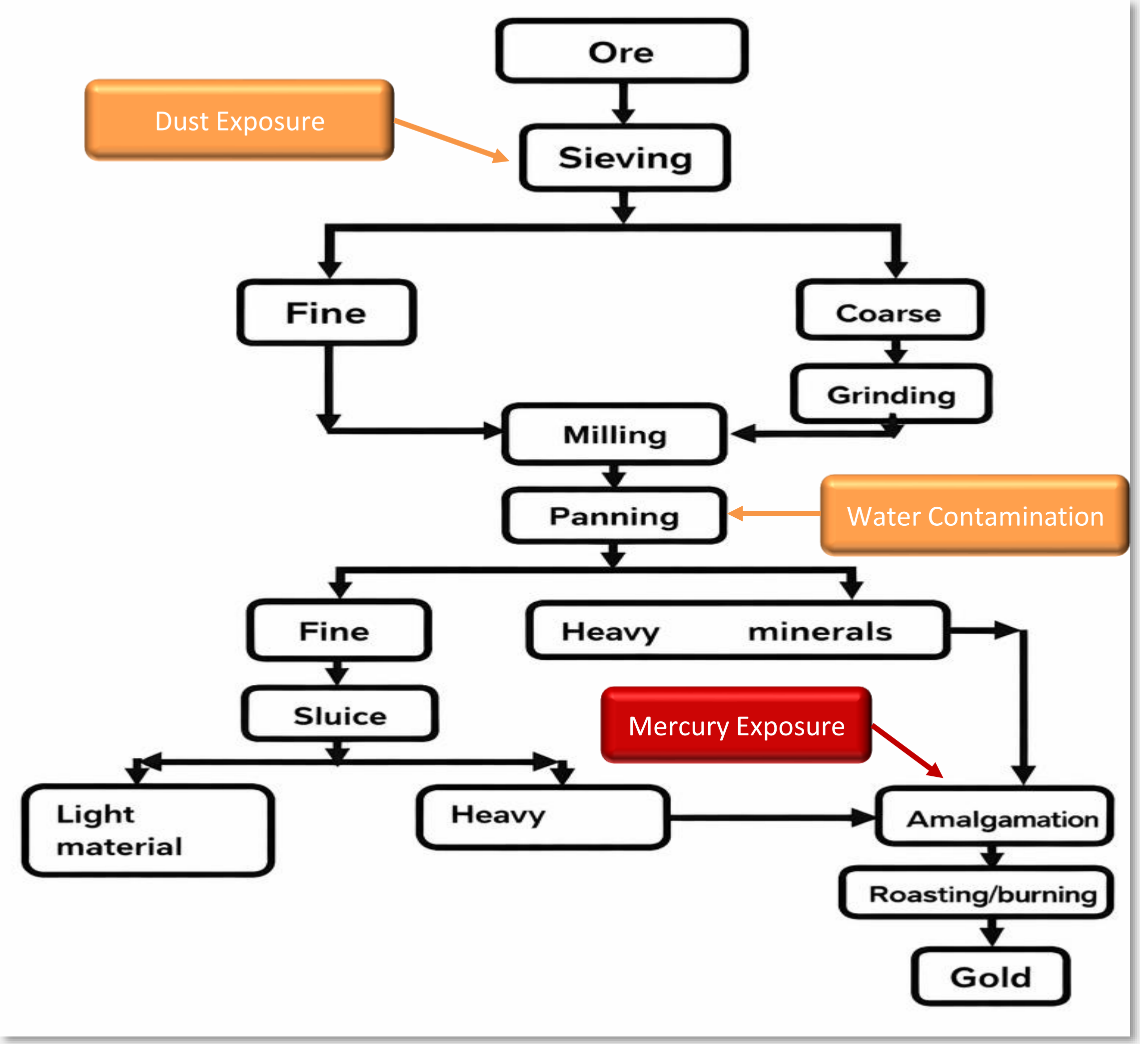
Key Health and Environmental Risks in Gold Processing

EXTRACTION STEPS

- Opening of the mine shaft
- Ore excavation
- Ore removal

EXTRACTION RISKS

- Slope instability
- Physical injuries
- Lack of PPE



Preliminary Risk Analysis in Gold Extraction

IDENTIFIED MECHANICAL / ACCIDENT RISKS		
Risk	**Causes**	**Consequences**
Mine Roof Collapse	• Structural limitations of the mine support system • Transversely interconnected shafts through underground tunnels • Stockpiling of soil near the mine workings • Occurrence of adverse natural phenomena (heavy rainfall, strong winds, etc)	• Impact and cut-related injuries, including fatalities in rare cases • Slope failures and landslides, particularly during the rainy season • Personnel entrapment/burial resulting in fatalities • Loss of equipment and damage to operational infrastructure
Slips, Trips and Falls	• Physical strain and fatigue among artisanal miners • Inadequate infrastructure for safe access to underground mine workings • Unsafe walkways and access routes characterized by uneven and unstable surfaces	• External and internal fractures, including fatalities in rare cases.

Figure 5: Unstable excavation area with unsafe working conditions.

Figure 6: Mine collapse incident resulting from structural instability.

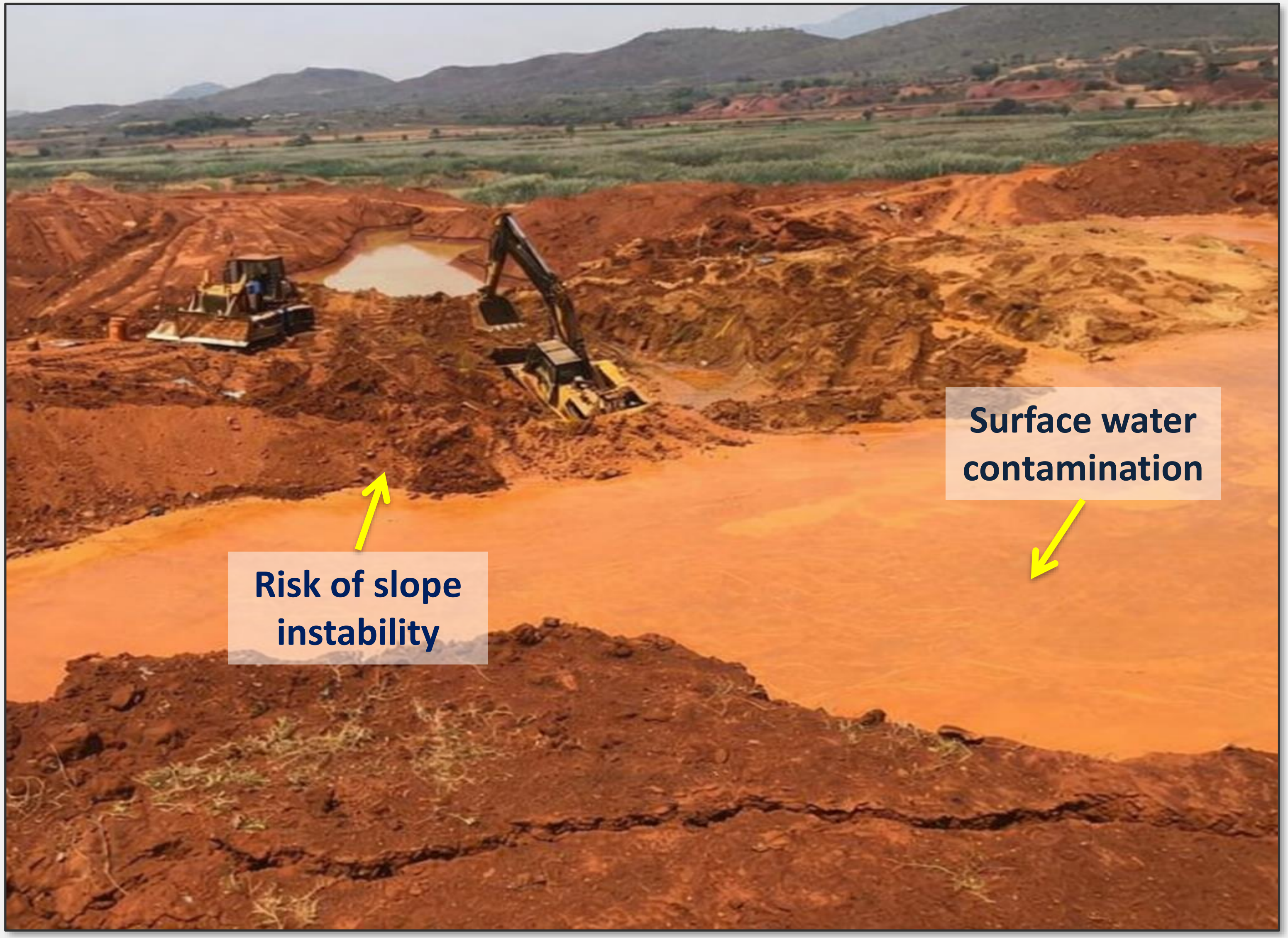


Figure 7: Unstable excavation areas and risk of slope failure in ASM operations.

Figure 8: Unstable shaft support.

Preliminary Risk Analysis in Gold Extraction

IDENTIFIED PHYSICAL RISKS		
Risk	**Causes**	**Consequences**
Heat, Humidity, Low Oxygen Level	• Reduced space and air circulation inside the underground mine • Water infiltration into the mine during the rainy season	• Asphyxia, fatigue, fainting, dizziness, nausea, headache, and death (rare cases)
Noise and Vibrations	• Noise from tools during task execution	• Numbness in hands and arms • Hearing loss, psychological disturbances

NOISE LEVEL MEASUREMENTS AT QUARRY SITE			
Day	**Processing Phase**	**Loading e Transport**	**Drilling**
1	100.03dB	80.04dB	105.04dB
2	101.04dB	82.01dB	106.08dB
3	100.07dB	82.07dB	104.02dB

- Measured noise levels confirm the identified risk of noise exposure, particularly during drilling operations.

Figure 9: Excavation instability and unsafe conditions in artisanal mining.

- Drilling activities consistently present the highest noise levels (>104 dB), exceeding recommended occupational exposure limits.

Preliminary Risk Analysis in Gold Extraction

IDENTIFIED CHEMICAL RISKS		
Risk	**Causes**	**Consequences**
Mercury Exposure	• Use of mercury during gold amalgamation • Poor handling and disposal practices • Dismantling, release, or removal of ore • Direct exposure during amalgamation and thermal processing	• Mercury poisoning • Severe respiratory issues • Environmental contamination • Respiratory problems, tiredness, and irritation of the respiratory tract • Release and inhalation of dust • External and internal fractures, including fatalities in rare cases.
Respirable Dust Exposure	• Manual ore crushing and griding	

- These chemical risks, particularly mercury exposure, represent significant health and environmental hazards in artisanal mining.

Figure 10: Dust generation during ore processing, illustrating exposure to respirable particles in artisanal mining.

Figure 11: Improper use of mercury by miners.

Preliminary Risk Analysis in Gold Extraction

IDENTIFIED ERGONOMIC RISKS		
Risk	**Causes**	**Consequences**
Excessive Effort	• Reduced space inside the mine • Repetitive tasks • Use of non-mechanized tools • Weightlifting • Inadequate and uncomfortable work positions	• Pain in the spine, upper and lower limb muscles, chronic injuries, fatigue, tiredness, eye irritation.

Figure 12: Manual access to underground pits without structural support.

Figure 13: Workers manually carrying heavy loads, highlighting ergonomic risks associated with repetitive strain and poor posture.

Preliminary Risk Analysis in Gold Extraction

IDENTIFIED ENVIRONMENTAL RISKS		
Risk	**Causes**	**Consequences**
Biological Hazards	• Stagnant water in the mine • Flooding inside the shaft, mainly during the rainy season • Heat and humidity inside the shaft	• Proliferation of diseases such as malaria, cholera
Environmental Degradation	• Removal of initial vegetation • Uncontrolled excavation and irregular distribution of shafts and trenches • Abandonment of extraction shafts	• Loss of initial vegetation • Susceptibility to phenomena such as erosion, landslides, sediment transport

Figure 14: Before and after view of an ASM site, illustrating environmental degradation and the need for sustainable mining practices.

- The comparison highlights significant land degradation and vegetation loss associated with artisanal mining activities.

Risk Category	Risk Description	Severity	Frequency	Risk Level	Recommendations
Mechanical / Accident	Mine collapse	IV	D	NT	1. Use timber for structural support (timbering) of all mine shafts to improve structural conditions.
Mechanical / Accident	Falls of miners and materials to different levels	IV	D	NT	1. Use of PPE; 2. Implementation of safe ladders; 3. Improvement of access ways in tunnels and mine shafts, and circulation; 4. Rotational work system.
Ergonomic	Excessive effort	III	E	NT	1. Increase tunnel height so miners can move without difficulty inside; 2. Invest in mechanized techniques that do not require excessive manual labor; 3. Always avoid, whenever possible, bent positions and monotonous movements; 4. Rotational work system.
Chemical	Dust (particulates)	II	E	M	1. Use of respirators and protective masks to reduce the possibility of inhaling dust or air containing heavy metals; 2. Use of wet dismantling techniques, water spraying during the process.
Physical	Heat, Humidity, Low Oxygen Levels	IV	C	NT	1. Use of fans/ventilators to allow air circulation inside the mine; 2. Drink plenty of water, as heat tolerance depends heavily on the amount of water consumed.
Physical	Noise and Vibrations	II	E	NT	1. Avoid long working periods; 2. Hearing protection is implied as a standard control for noise hazards exceeding permissible limits.
Biological	Microorganisms	IV	D	NT	1. Implementation of cleaning and fumigation techniques inside the shaft and surroundings.
Environmental	Environmental Degradation	III	E	NT	1. Adoption of environmental preservation strategies is ideal for sustainable mining, including conducting processing activities away from watercourses and promoting water reuse.

Sustainable Mining: Concept and Importance

Sustainable mining refers to the extraction of minerals and resources in a way that **minimizes environmental impact**, conserves natural resources and ensures the long-term viability of the mining operations.

Key Principles

- **Environmental stewardship:** Minimizing waste, reducing water and energy consumption, controlling pollution, and rehabilitating mined land.
- **Social responsibility:** Respecting local communities, ensuring fair labour practices, preserving cultural heritage, and promoting local economic development.
- **Economic viability:** Ensuring the long-term profitability and sustainability of mining operations.
- **Innovation and technology:** Adopting advanced technologies to improve efficiency and reduce environmental impact.
- **Transparency and accountability:** Reporting sustainability performance (ESG) and engaging with stakeholders.

Suspension of Mining Licenses in Manica Province

On October 2, 2025, the Mozambican government announced the immediate suspension of all **mining licenses in Manica province.**

Key Developments

- Immediate suspension of all mining licenses pending assessment.
- Environmental concerns due to river contamination from effluent and sediment discharge.
- Impact on both artisanal and commercial mining operations.
- Implementation of environmental audits and stricter licensing requirements.

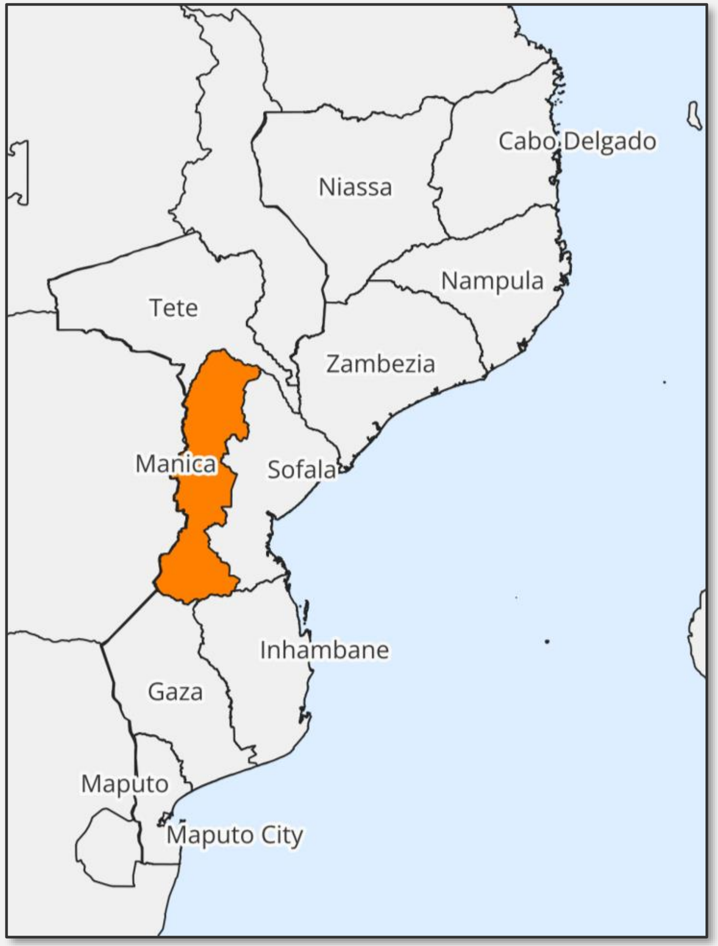


Figure 15: Location of Manica Province, a key mining region in Mozambique.

Implications of Mining Suspension in Manica Province

Environmental

- Reduction of ongoing environmental degradation
- Opportunity for ecosystem recovery
- Improved control of water contamination

Economic

- Temporary loss of income for miners
- Disruption of local economic activities
- Impact on gold production

Regulatory

- Strengthening of environmental governance
- Increased monitoring and compliance requirements
- Promotion of sustainable mining practices

Social

- Increased vulnerability of artisanal miners
- Need for alternative livelihoods
- Potential social instability in mining communities

- The suspension reflects the urgent need to balance economic benefits with environmental protection and sustainable resource management.

Recommendations for Sustainable ASM Practices

Context

The findings highlight the urgent need to shift from problem identification to practical, accessible solutions in artisanal and small-scale mining (ASM).

KEY ACTIONS

- Development and distribution of **illustrated health and safety manuals** tailored to artisanal miners
- Promotion of **mercury-free gold processing techniques**
- Training on **basic ventilation systems and structural support of mine shafts (e.g., wooden supports)**
- Provision of **accessible personal protective equipment (PPE)**
- Deployment of **mobile training teams** to promote good mining practices across ASM sites

EXPECTED OUTCOME

- Improved occupational health and safety
- Reduction of environmental impacts
- Support for the gradual **formalization of ASM activities**

These measures provide a practical pathway to safer, more sustainable, and responsible mining practices.

Final Remarks

- Artisanal and small-scale mining (ASM) presents significant physical, chemical, and environmental risks.
- The case of Manica Province highlights the real consequences of inadequate environmental management and regulatory enforcement.
- Transitioning to sustainable mining practices is essential to protect ecosystems, improve worker safety and ensure long-term resource viability.

Achieving sustainable mining requires coordinated efforts between government, industry, and local communities.