



Final Report

Research and Analysis of the
Composition and Environmental
Impact of Ore Dressing Agent
Comprising Sodium Isocyanate
for ASGM in Suriname and
Developing Sustainable
Environmental Regulations

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Presented to: National Environmental Authority (NMA)

List of Acronyms and Abbreviations

ACT	Amazon Conservation Team
ADD	Average Daily Dose
ASGM	Artisanal and Small-Scale Gold Mining
ASTM	American Society for Testing and Materials
BOG	Bureau of Public Health
BS	British Standards Institution
CI	Conservation International Suriname
CIP	Carbon -in-Pulp Leaching
CIL	Carbon -in-Pulp Leaching
CMSI	Consolidated Mining Standard Initiative
CN ⁻	Cyanides
CR	Carcinogenic Risk
EBS	Suriname Energy Company
EFA	Environmental Framework Act
EIA	Environmental Impact Assessment
EPA	U.S. Environmental Protection Agency
FMO	Dutch Development Bank
GEF	Global Environment Facility
GGs	Green Growth Suriname
GHS	Globally Harmonized System
GMD	Geological Mining Department
GPS	Global Positioning System
HDPE	High-Density Polyethylene
HI	Hazard Index
HQ	Hazard Quotient
IDB	Inter-American Development Bank
IFC	World Bank Group
ILO	International Labour Organization
IRMA	Initiative for Responsible Mining Assurance
ISO	International Organization for Standardization
JP	Ministry of Justice and Police
KKF	Suriname Chamber of Commerce and Industry
MEA	Multilateral Environmental Agreement
MOPS	Multi-Annual Development Plan of Suriname
MSDS	Material Safety Data Sheets
NCCR	National Coordination Centre for Disaster Management

NESGL	Novel Eco-Friendly Synthetic Gold Lixiviant
NGO	Nongovernmental Organization
NH	Ministry of Natural Resources
NMA	National Mining Authority
NVB	National Women's Movement
PLS	Pregnant Leach Solution
PPE	Personal protective equipment
QA/QC	Quality Assurance/Quality Control
OECD	Organization for Economic Co-operation and Development
RACI	Responsibility Assignment Matrix
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
RfD	Reference Dose
ROI	Region of Interest
SDS	Safety Data Sheet
SF	Slope Factor
SIHF	Suriname Indigenous Health Fund
SSB	Suriname Standards Bureau
TCLP	Toxicity Characteristic Leaching Procedure
TOR	Term Of Reference
UNEP	United Nations Environment Programme
UNDP	United Nations Development Programme
VGS	Suriname Gold Miners Association
WHO	World Health Organization
WWF	World Wildlife Foundations

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EXECUTIVE SUMMARY

The findings presented in this report are intended to support evidence-based policymaking, strengthen national regulatory capacity, and guide sustainable technological transition in Suriname's ASGM sector. Through this integrated assessment – combining environmental data, stakeholder analysis, and technological evaluation – the study aims to provide practical recommendations that align with Suriname's commitments to sustainable resource management and the protection of its people and environment. Field conditions and accessibility were not always optimal and where SAFE can keep contributing to the expansion/bettering of research data, our commitment is high and our willingness to assist the NMA remains unshakable.

The research followed a comprehensive design aligned with international standards, including BS 10175:2011+A2:2017 for environmental site investigations. Fieldwork was conducted at selected ASGM sites within Sarakreek resort of Brokopondo district based on clearly defined criteria related to mining activity intensity and environmental vulnerability. Detailed sampling protocols were implemented for soil, surface water, barren solution, and tailings-based gold ore.

Environmental samples were analyzed for pollutants linked to gold ore processing agents. The study assessed soil and water contamination levels, particularly focusing on mercury, cyanides and heavy metals.

A dual-path risk assessment framework was applied, encompassing both ecological and human health risks. Exposure scenarios for dermal contact, ingestion, and inhalation were modelled to evaluate carcinogenic and non-carcinogenic risk levels. Quality assurance and control (QA/QC) procedures were rigorously maintained throughout sampling, laboratory analysis, and data handling.

Stakeholder engagement formed a core part of the methodology. Structured interviews and focus group discussions (FGDs) were conducted with local communities, miners, and government stakeholders. These engagements provided key insights into local practices, risk perceptions, and the current state of environmental governance.

An assessment of the suitability of mercury- and cyanide-free gold processing technologies for Suriname's artisanal and small-scale gold mining (ASGM) sector was conducted, leading to the identification of the most appropriate technologies to advance mercury-free gold recovery. The evaluation considered technical efficiency, economic feasibility, local adaptability, and environmental performance to ensure the practical applicability of the recommended solutions.

In parallel, the Suriname National Code for the Management of Alternative Lixiviants in Artisanal and Small-Scale Gold Mining was developed. This code establishes a framework to ensure the safety of miners, protect communities and ecosystems, and promote responsible research and technological adoption. It provides clear guidance on the testing, regulation, and controlled use of alternative lixiviants, such as Jinchan, while reinforcing Suriname's commitment to a safe and sustainable transition toward cleaner gold extraction practices.

Preliminary findings:

1. Jinchan is a thiourea–chloride – nitrate lixiviant containing chemically complexed cyanide species. While it is promoted as a safer, environmentally friendlier alternative to conventional cyanide leach solutions, its formulation only reduces acute toxicity rather than eliminating risk. The reagent can still pose significant hazards to human health, causing irritation to the eyes, skin, and respiratory system,

and may generate toxic sulphides or cyanamide under acidic conditions.

2. Field investigation results indicate that Jinchan lixiviant is not fully eco-friendly, though it is more environmentally favourable than cyanide. Despite being thiourea-based and free of cyanides initially, Jinchan can generate certain amounts of free cyanide (CN^-) through decomposition of thiourea ($\text{SC}(\text{NH}_2)_2$) under acidic or oxidizing gold-leaching conditions. Barren solution samples, particularly from Bohmila, show notable cyanide contamination, posing potential risks to the environment and human health if untreated effluents reach surface or groundwater.

3. It was established that mercury concentrations in water samples did not exceed the reference limits set by the World Health Organization (WHO; 0.006 mg/L) or the U.S. Environmental Protection Agency (EPA; 0.002 mg/L). This is because volatile mercury evaporates, while the remaining mercury adsorbs onto clay particles and settles in sediments. Therefore, to assess mercury pollution, only sediment samples should be analyzed.

4. Cyanide concentrations in water samples were mostly below reference limits. The drinking water threshold of 0.2 $\mu\text{g/L}$ was exceeded in one sample (Figure 9, W1) from the Ero Bergi site. While this indicates no acute ecological or dietary threat, it may pose a risk if untreated surface water is consumed. Overall, cyanide contamination appears localized and linked to site-specific discharges rather than widespread in natural waters.

5. Heavy metals detected in natural water samples (As, Cd, Co, Cu, Ni, Pb, Sb, and Zn) were well below EPA limits for aquatic life, drinking water, and human exposure. However, barren solutions, particularly at Bohmila, showed elevated Cu and Pb levels exceeding safety thresholds, posing potential risks if unmanaged. These findings highlight the need for strict handling and disposal of barren solutions and regular monitoring of process water discharges, especially in artisanal gold mining areas.

6. Mining process accepted within the limits of gold mining site directly impact on the level of soil contamination with mercury. Sites employing amalgamation (especially alongside other chemical methods) tend to show higher mercury contamination, whereas sites relying solely on heap leaching generally have lower impacts on soil mercury.

7. The findings indicate that most metals show low geo-accumulation across the study areas. However, elements such as Co, Ni, Cu, As, and particularly Hg in Kwangoe, indicate localized low to moderate contamination. The elevated Hg in Kwangoe signals potential heavy contamination that requires further investigation. Bohmila and Ero Bergi appear generally less contaminated but still show some accumulation of Co and Ni.

8. In ASGM areas of Suriname's tropical forests, elevated soil concentrations of Cu, Zn, Ni, and Co result from naturally metal-rich geology, poorly controlled mining practices, waste dumping, and enhanced metal mobilization under acidic or complexing conditions. Together, these factors raise metal levels well above both global reference standards and local pre-mining background levels.

9. The Nemerov Comprehensive Index (Pi) provides a balanced and realistic assessment of spatial variations in soil quality and helps identify sites where localized contamination may be masked by lower average levels, as observed at Ero Bergi and Kwangoe. At Bohmila, contamination with heavy metals and mercury generally indicates moderate pollution pressure. In contrast, Ero Bergi shows localized zones of significant contamination. Kwangoe exhibits severe localized contamination, particularly from mercury, which should be prioritized in future monitoring and management strategies to protect both environmental and public health.

10. The results indicate low non-carcinogenic risk values from contaminated soil exposure, with no immediate need for remediation. However, soil pollution is only one source of health risk for local residents in ASGM areas. Communities are also exposed to contaminated surface and groundwater,

mercury vapor from amalgamation, chemical residues from lixiviants such as cyanide or sodium isocyanate, and heavy metal bioaccumulation in fish and crops. While soil contamination alone does not exceed health thresholds, it contributes to the overall cumulative risk and should be considered in evaluating long-term health impacts and developing integrated risk management strategies.

11. Carcinogenic risk from soil exposure at ASGM sites is relatively low, with arsenic ingestion identified as the primary pathway of concern. These findings highlight the importance of continuous monitoring and considering soil exposure within the broader cumulative risk faced by local communities, who are also exposed to mercury emissions, contaminated water, and bioaccumulation of contaminants in the food chain.

12. The assessment indicates that water pollution in ASGM areas poses clear non-carcinogenic health risks, mainly through direct ingestion of river water, with dermal exposure contributing to a lesser extent. Bohmila and Ero Bergi show the highest hazard index values, with Ero Bergi presenting wide variability and peak risks, while Kwangoe demonstrates lower but still concerning levels. Most of the overall risk (97.4%) comes from cyanides (91%), followed by lead (4.5%) and mercury (2%), underscoring cyanide as the dominant driver of health concerns. The most sensitive systems affected by cyanide exposure include the nervous, cardiovascular, and respiratory systems, along with the thyroid, liver, and kidneys.

13. Survey results revealed that most artisanal miners are unaware of safe handling practices, environmental consequences, or their legal obligations regarding chemical use. This lack of oversight and education increases the likelihood of misuse, accidental releases, and long-term contamination of soil and water resources. Strengthening enforcement mechanisms alongside targeted awareness campaigns is essential to ensure responsible chemical management in the ASGM sector.

14. Preliminary findings reveal significant gaps in regulatory enforcement regarding the use of chemical lixiviants in ASGM operations in Suriname, particularly in remote interior regions. While national legislation may restrict or control hazardous substances such as cyanide, enforcement on the ground is often weak or absent due to limited institutional capacity, lack of monitoring infrastructure, and logistical challenges. This regulatory vacuum permits the unsupervised use of alternative lixiviants like Jinchan, whose environmental impacts are not systematically assessed. Additionally, public awareness of the potential risks associated with chemical leaching agents remains low, especially among miners and nearby communities.

15. Initial findings from the survey of the Suriname Geological Mining Service reveal significant structural and institutional weaknesses in the governance of chemical use within the artisanal and small-scale gold mining sector, including fragmented regulation, inadequate enforcement, and limited monitoring capacity. The strong consensus among respondents on the need for stricter cyanide regulation, centralized monitoring, and targeted reforms underscores both the urgency and institutional readiness to establish a comprehensive, transparent, and accountable national framework for sustainable chemical management in ASGM.

16. Preliminary findings reveal significant gaps in regulatory enforcement regarding the use of chemical lixiviants in ASGM operations in Suriname, particularly in remote interior regions. While national legislation may restrict or control hazardous substances such as cyanide, enforcement on the ground is often weak or absent due to limited institutional capacity, lack of monitoring infrastructure, and logistical challenges. This regulatory vacuum permits the unsupervised use of alternative lixiviants like Jinchan, whose environmental impacts are not systematically assessed. Additionally, public awareness of the potential risks associated with chemical leaching agents remains low, especially among miners and nearby communities.

17. If the gold present in Suriname's ASGM tailings is primarily free-milling, technologies such as the Cleangold Sluice, Blue Bowl, and Borax Method can serve as effective replacements for Jinchuan leaching. These systems combine high gold recovery with low operational costs and minimal environmental impact, offering practical and sustainable alternatives that support Suriname's transition toward responsible, mercury- and cyanide-free gold production.

18. Given the current conditions in the ASGM sector – characterized by remote mining sites, limited tailings management, and the potential exposure of downstream communities – the most protective course of action for public health and the environment is to impose a moratorium or ban on the use of Jinchuan and other alternative lixiviants in ASGM operations. Such measures should remain in place until comprehensive investigations, rigorous environmental and safety controls, and transparent monitoring mechanisms are established to ensure responsible use.

Based on the results, the study offers *practical recommendations* for Suriname's regulatory authorities:

1) *Enhance National Regulations*

- Strengthen legal frameworks for the use of hazardous chemicals such as cyanide and sodium isocyanate.
- Introduce clear permit systems, labelling requirements, and safe handling protocols.
- Integrate chemical-specific rules into existing mining and environmental legislation.

2) *Implement Monitoring and Reporting Mechanisms*

- Establish mandatory reporting for chemical imports, storage, transport, and usage.
- Introduce regular inspections and data collection for compliance verification.
- Develop a centralized database to track chemical life-cycle management in ASGM.

3) *Provide Safer Alternatives and Capacity Building*

- Promote adoption of non-toxic or less hazardous reagents.
- Offer training programs for miners and chemical handlers on safe operational practices.
- Provide access to personal protective equipment (PPE) and technical support.

4) *Increase Community Awareness and Participation*

- Conduct public awareness campaigns on chemical hazards and environmental impacts.
- Involve local communities in monitoring and reporting unsafe practices.
- Encourage stakeholder engagement in decision-making on chemical management.

5) *Align with International Best Practices*

- Incorporate guidance from the International Cyanide Management Code (ICMC).
- Follow principles of the Minamata Convention on Mercury for mercury-free practices.
- Adopt voluntary international standards such as IRMA or other chemical safety guidelines.

6) *Support Sustainable and Responsible Mining Practices*

- Integrate chemical safety into site rehabilitation and environmental protection plans.
- Promote continuous improvement through feedback loops, audits, and lessons learned.
- Foster collaboration between government, miners, NGOs, and international partners.

This research serves as a foundation for developing sustainable environmental regulations tailored to the Surinamese ASGM context, aligning public health protection with the realities of the mining sector.

1. INTRODUCTION

1.1 Project Background

Artisanal and small-scale gold mining is a significant contributor to Suriname's economy, providing livelihoods for an estimated 20,000 individuals, particularly in the country's interior regions (First National Action Plan on Artisanal and Small-Scale Gold Mining in Suriname, 2023) (Figure 1). Notwithstanding its economic importance, the ASGM sector is characterized by informal practices, limited regulatory oversight, and widespread use of hazardous substances such as mercury. These practices pose severe risks to human health, freshwater ecosystems, and biodiversity, particularly in the interior regions inhabited by Indigenous and tribal communities.

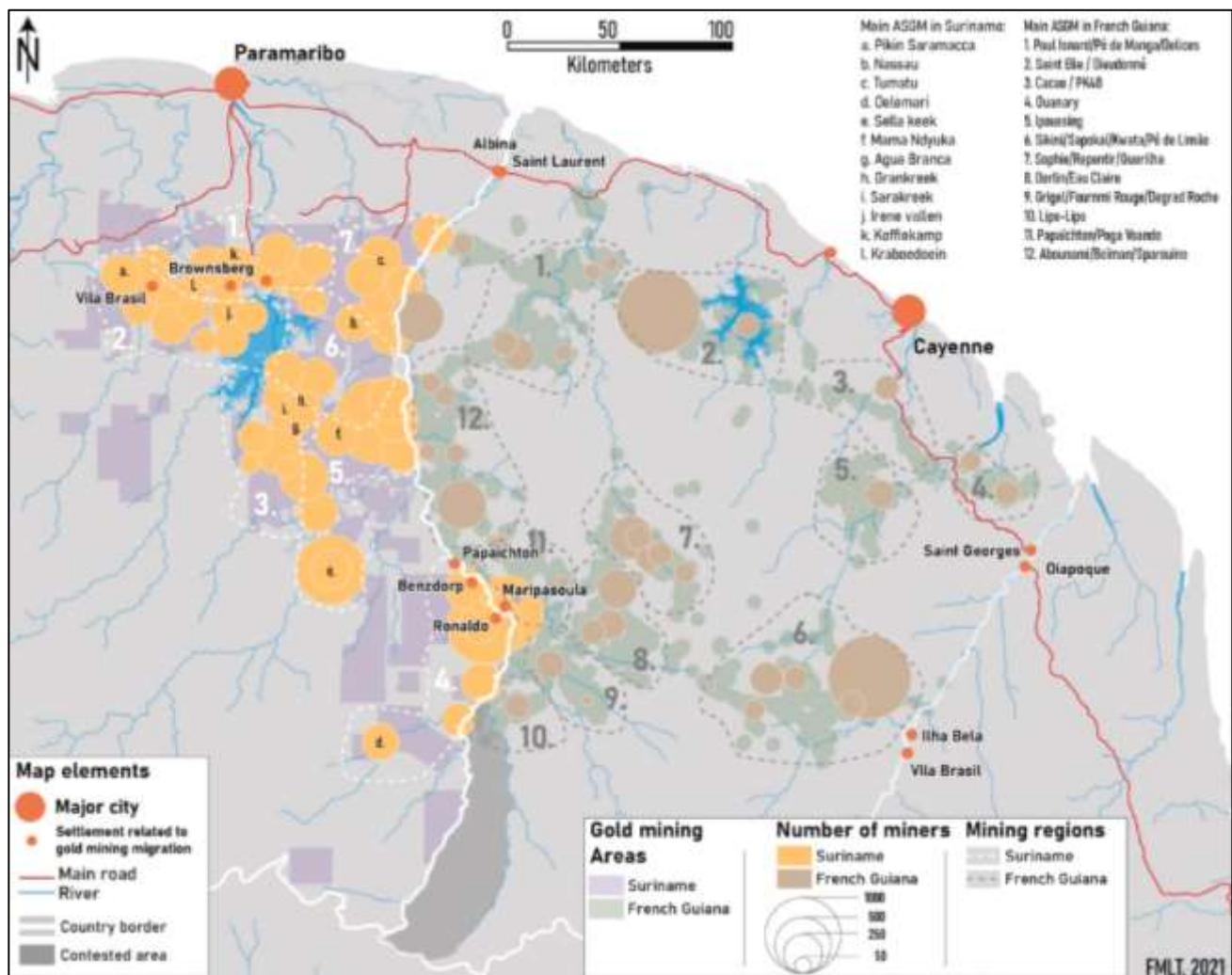


Figure. 1. Main artisanal and small-scale gold mining areas in Suriname and French Guiana with approximate population figures (Source: Heemskerk et al., 2022)

In recent years, growing global awareness of the environmental and social impacts of ASGM has led to increased efforts to formalize the sector and transition toward safer, more sustainable technologies. Suriname, as a signatory to international conventions such as the Minamata Convention on Mercury, has committed to reducing and, where feasible, eliminating the use of mercury in gold processing. At the same time, new alternative lixiviants – marketed as “environmentally friendly” substitutes for cyanide or mercury – have emerged on the international market. However, these substances, including products such as Jinchan, remain largely untested in Suriname’s geological and socio-environmental context.

Against this background, this study was commissioned to assess the current state of ASGM practices in Suriname, evaluate pollution levels and associated risks, and explore viable mercury- and cyanide-free technologies for gold extraction. The research also provides a scientific basis for the development of a National Code for the Management of Alternative Lixiviants in Gold Mining, establishing clear standards and prohibitions to prevent environmental degradation and protect public health.

1.2 Project Objectives

The main objective of this research is to investigate the chemical composition and properties of commercially available ore dressing agent marketed in Suriname under the trade name Jinchan – in order to inform the development of strict environmental regulations. A detailed description of the project’s specific objectives is presented in Figure 2.



Figure. 2. Project objectives – detailed overview

1.3 Novel Eco-Friendly Synthetic Gold Lixiviants Characteristics

For more than a hundred years, cyanide has been widely used in gold mining operations across the globe as a primary leaching agent due to its cost-effectiveness and ability to achieve high gold recovery rates from diverse ore types (Aylmore, 2016a, 2016b; Zhang et al., 2022). Its strong affinity for gold and efficiency in extraction have made it the preferred choice in the industry (more than 83 per cent of the world's gold is extracted via cyanidation) (Li et al., 2023). However, despite its advantages, cyanide is an extremely toxic substance¹ that poses significant environmental and health risks if not handled properly (Hilson & Monhemius, 2006; Sun et al., 2020). Accidental spills or inadequate waste management can lead to severe ecological damage, contaminating water sources and harming aquatic life. As a result, there is growing concern over its use, prompting research into safer and more sustainable alternatives for gold extraction.

The increasing environmental concerns associated with the widespread use of cyanide in gold mining – particularly in both large-scale operations and artisanal and small-scale gold mining (ASGM) – have highlighted the urgent need to develop alternative leaching reagents that are more environmentally sustainable while maintaining high gold recovery efficiency.

The search for alternatives to cyanide in gold ore processing has led to the development and evaluation of various cyanate-based and non-cyanide-based alternative ore dressing agents. An optimal alternative lixiviant² must satisfy the "3E" criteria: Effectiveness, Eco-friendliness, and Economic viability (Zuo-wei et al., 2022). Among these, efficiency remains the fundamental prerequisite for adoption, as it directly impacts gold recovery rates. Economic feasibility governs the scalability and commercial viability of the lixiviant, while environmental sustainability is becoming a critical consideration in modern mining practices. Each of these criteria encompasses specific evaluation metrics:

- Eco-friendliness is assessed based on the lixiviant's toxicity, biodegradability, and the complexity of detoxification processes.
- Economic viability depends on factors such as reagent cost, consumption rates, equipment requirements, and pollution mitigation expenses, which collectively influence commercialization

¹ Cyanide Toxicity ABCs

► A cyanide is a chemical compound containing a 'cyano-group' which consists of a carbon atom triple-bonded to a nitrogen atom. While carbon and nitrogen are ubiquitous and non-toxic on their own, the 'cyano-group' structure produces toxic effects because these molecules can inhibit cytochrome c oxidase – a critical enzyme for oxygen-based life, required for oxygen based APT synthesis (i. e. proper functioning of life-sustaining electron transport chain of eukaryotic cells).

► In the ASGM sector water-soluble salts of sodium cyanide (NaCN) and/or potassium cyanide (KCN) are dissolved in water to leach gold and silver from gold ores. These CN salts are toxic and must be managed safely and responsibly. CN chemicals or effluent, if spilled into the environment (especially aquatic systems) can result in lethal consequences to fish and other organisms.

► Hydrogen cyanide gas (HCN) is extremely hazardous; if inhaled by humans, the gas can rapidly inhibit function of cellular respiration leading to asphyxiation. Severe exposure results in headache, coma, seizures, and can result in rapid death.

► If/when aqueous CN solutions have a pH below 9, HCN gas (highly toxic) will be released from the solution. If neutral or acidic conditions are present (<pH of 7) HCN release can be rapid.

► HCN is detectable by bitter smell (similar to almond). Inhalation of HCN fumes can be dangerous even at low levels. At very high concentration the bitter odor of HCN can be undetectable, and this factor compounds the workplace risk factor: odor should not be relied upon as a method to detect, monitor or gauge dangerous HCN levels.

► Because HCN poisoning can occur very rapidly, recovery from poisoning depends upon severity of exposure but also promptness with which antidotes are administered. Common antidotes include amyl nitrite, sodium nitrite, and sodium thiosulfate. Antidotes are typically administered by needle injection, although drug manufactures have elaborated modern CN antidote medications (Source: D. Stapper, K. Dales, P. Velasquez, and S. Keane. 2021. *Best Management Practices for Cyanide Use in the Small-Scale Gold Mining Sector*. Published by the PlanetGOLD Programme (Global Environment Facility and United Nations Environment Programme). October, 2021).

² A lixiviant is a chemical used in hydrometallurgy to extract elements from its ore (Source: <https://en.wikipedia.org/wiki/Lixiviant>).

potential.

- Effectiveness is determined by leaching kinetics, gold recovery efficiency, selectivity (minimizing co-dissolution of impurities), and versatility across diverse ore types.

This multi-faceted evaluation framework ensures that alternative lixivants not only match cyanide's performance but also align with sustainable and cost-effective mining practices. Table 1 represents the comparative evaluation of cyanide- and non-cyanide-based gold recovery methods.

Table 1. **Comparative evaluation of cyanide- and non-cyanide-based methods of gold recovery**
(developed by the authors)

Criteria	Cyanide-Based Methods	Non-Cyanide-Based Methods
Common Lixivants	Sodium cyanide (NaCN), Potassium cyanide (KCN)	Thiosulfate, Thiourea, Glycine, Halides, Ionic Liquids, Bioleaching
Gold Recovery Efficiency	High (80–95%)	Moderate to high (50–90%), depending on the method
Environmental Impact	High toxicity; hazardous to ecosystems and water sources	Generally lower toxicity, but some alternatives (thiourea, halides) can be hazardous
Health Risks	Severe; cyanide exposure can cause poisoning and fatality	Reduced risks, though some (e.g., thiourea) pose carcinogenic concerns
Operational Feasibility	Well-established; widely used in industrial and ASGM settings	Varies; some methods require specialized equipment or conditions
Cost Efficiency	Relatively low cost, but high regulatory and detoxification expenses	Costs vary; some (e.g., glycine) are cost-effective, while others require more investment
Residue Management	Requires strict detoxification (e.g., INCO/SO ₂ process)	Some residues are biodegradable or less persistent
Adoption in ASGM	Widely adopted, but increasingly restricted due to regulations	Emerging interest; adoption depends on accessibility and cost-effectiveness
Regulatory Restrictions	Strict regulations in many countries due to toxicity	Generally, more favorable regulatory acceptance

The Figure 3 presents a structured timeline of gold leaching reagents, categorizing their development and commercialization periods. It highlights both traditional and alternative lixivants used in gold extraction, along with their historical progression.

Notably, while research into eco-friendly gold lixivants has significantly advanced since the 2010s, widespread commercialization of these alternatives has yet to be achieved. This gap between development and implementation stems from several key factors:

1. **Technological barriers:** Many green lixivants (e.g., glycine, thiosulfate, and deep eutectic solvents) still face challenges in leaching kinetics and recovery efficiency compared to conventional cyanidation (Zhang et al., 2022).
2. **Economic considerations:** The higher reagent costs and need for process modifications present financial hurdles for mining operations. For instance, while cyanide costs approximately 1.8–2

USD/kg³, alternatives like glycine range from 11.8-14.5 USD/kg⁴.

3. Infrastructure limitations: Most mining technologies applied in ASGM are optimized for mercury-based processes, requiring significant capital investment to adapt to alternative systems (Stapper et al., 2021).
4. Regulatory inertia: Despite their environmental benefits, many alternative lixivants lack standardized regulatory frameworks, slowing adoption (Veiga et al., 2020).

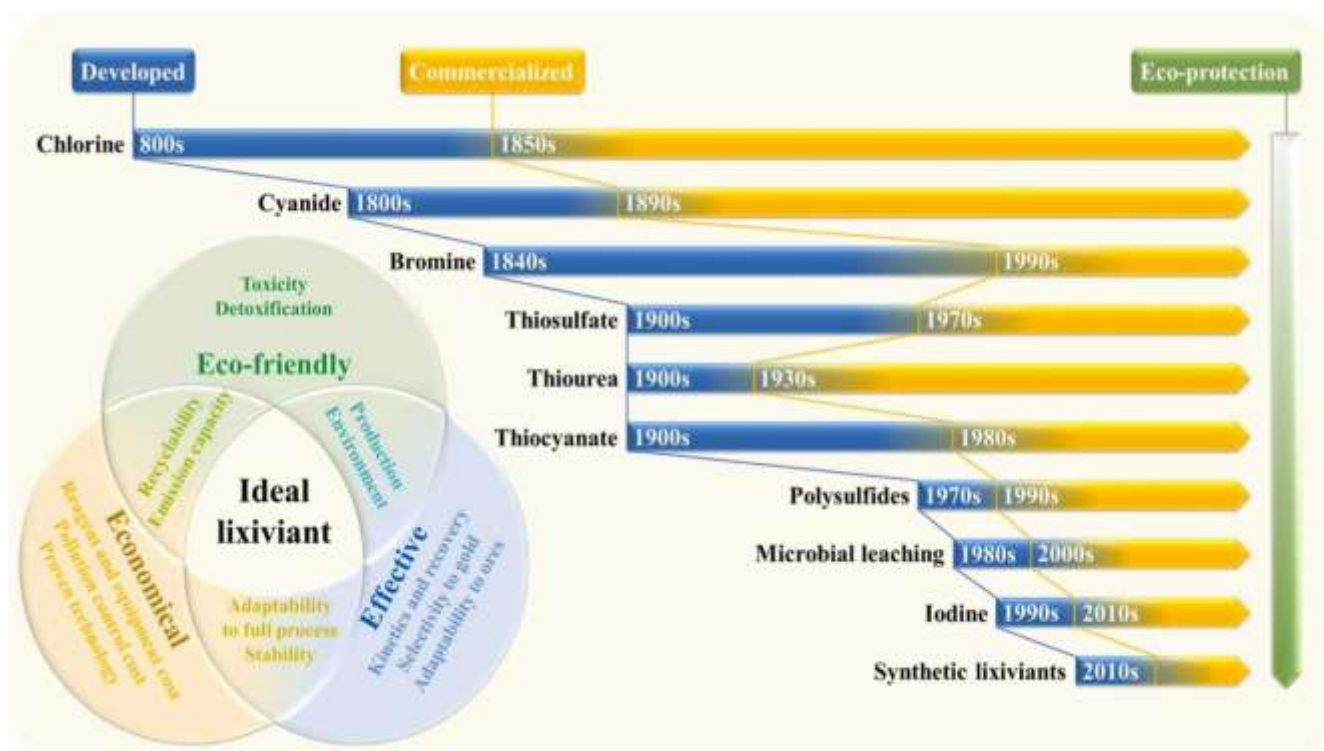


Figure 3. **Evolution of gold lixivants: from cyanide to sustainable alternatives**

(Source: Zuo-wei L., Xue-yi G., Qing-hua T., Lei Zh. (2022). A systematic review of gold extraction: Fundamentals, advancements, and challenges toward alternative lixivants. *Journal of Hazardous Materials*, 440, 129778. <https://doi.org/10.1016/j.jhazmat.2022.129778>)

The existing wide range of gold lixivants can be subdivided into three groups (Figure 4):

1. Traditional gold lixivants, which have been known for decades and were historically used either before cyanide's dominance or as niche alternatives.
2. Novel or alternative gold lixivants, including halide-, thiosulfate-, and glycine-based agents, as well as bioleaching agents, ionic liquids, and deep eutectic solvents.
3. Novel eco-friendly synthetic gold lixivants (NESGLs), whose application in the gold mining industry has been increasing, although no detailed statistics are available at this stage.

Each group has distinct chemical properties, advantages, and limitations in gold extraction.

³ Source: <https://www.intratec.us/chemical-markets/sodium-cyanide-price>

⁴ Source: <https://www.chemicalsuppliers.com/buy-glycine>

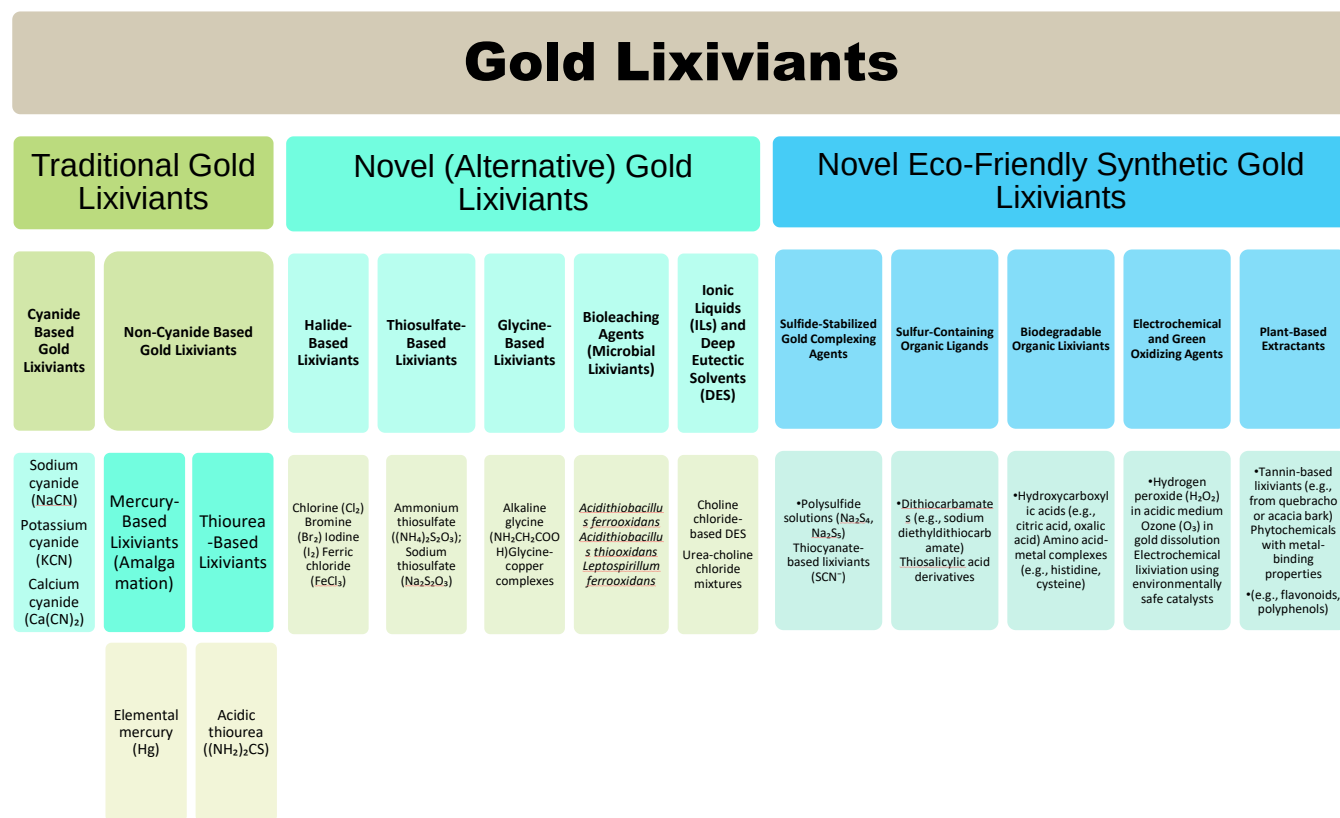


Figure. 4. Classification of traditional and alternative gold lixiviants (developed by the authors)

Artisanal and small-scale gold mining in Suriname remains heavily dependent on mercury due to its effectiveness and availability. While numerous non-cyanide lixiviants have been developed, their adoption faces significant barriers, including safety concerns, high costs, and technical challenges. Table 2 describes the major constraints on the adoption of non-cyanide lixiviants.

Table 2. Major constraints on the adoption of non-cyanide lixiviants by Surinamese ASGM (developed by the authors)

Constrain	Description															
Safety Risks	Some lixivants can form toxic byproducts: - Thiourea: Forms toxic sulfides and cyanamide in acidic conditions. - Halides (I₂/Br₂/Cl₂): Release dangerous fumes (iodine vapor, chlorine gas). - Thiosulfate: Can decompose into sulfites/sulfides if mishandled.															
High Costs and Limited Availability	<table><tr><th>Lixiviant</th><th>Cost (USD/kg)</th><th>Availability in Suriname</th></tr><tr><td>Sodium Cyanide</td><td>~1.8–2.0</td><td>Widely available (imported)</td></tr><tr><td>Sodium Thiosulfate</td><td>~28.0–34.0⁵</td><td>Limited (must be imported), expensive</td></tr><tr><td>Thiourea</td><td>~3.00–5.00⁶</td><td>Limited (must be imported), expensive</td></tr><tr><td>Iodine</td><td>~45.0–60.0⁷</td><td>Very expensive and hazardous for untrained miners</td></tr></table> Miners often default to mercury/cyanide due to black-market access.	Lixiviant	Cost (USD/kg)	Availability in Suriname	Sodium Cyanide	~1.8–2.0	Widely available (imported)	Sodium Thiosulfate	~28.0–34.0 ⁵	Limited (must be imported), expensive	Thiourea	~3.00–5.00 ⁶	Limited (must be imported), expensive	Iodine	~45.0–60.0 ⁷	Very expensive and hazardous for untrained miners
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Thiourea	~3.00–5.00 ⁶	Limited (must be imported), expensive														
Iodine	~45.0–60.0 ⁷	Very expensive and hazardous for untrained miners														
Technical Challenges	Most alternatives require pH control or catalysts: - Thiosulfate: Needs copper + ammonia catalyst (pH 7–10) (Xie et al., 2021). - Thiourea: Requires strong acid (pH 1–2) and oxidant (Fe³⁺/H₂O₂) (Juarez & Dutra, 2000). - Slow leaching: Most alternatives are slower than cyanide, reducing profits.															

⁵ https://www.sigmaaldrich.com/SR/en/search/sodium-thiosulfate?focus=products&page=1&perpage=30&sort=relevance&term=sodium%20thiosulfate&type=product_name

⁶ <https://www.alibaba.com/showroom/thiourea-price.html>

⁷ <https://www.statista.com/statistics/1001991/average-price-iodine-us/>

International studies indicate that cyanate-based agents like thiocyanate (Brbosa-Filho & Monhemius, 1994) and novel (alternative) gold lixiviants present viable alternatives to traditional mercury and cyanide leaching, offering reduced toxicity and environmental and health impact (Table 3).

Table 3. **Overview of environmental and health impact of some lixiviants utilized in ASGM** (*developed by the authors*)

Agent name	Agent type	Intended function	Associated mining process and recovery rate (%)	Environmental impact	Health impact
Sodium Cyanide (NaCN)	Cyanide-based lixiviant	Used for leaching gold from ore in cyanidation	Cyanidation, 90-95	Highly toxic to aquatic life, persistent in water, risk of accidental spills leading to water source contamination Acute aquatic toxicity (LC ₅₀): 0.05–0.15 mg/L (extremely to very toxic to fish) (Eisler et al., 1999)	Acute poisoning can cause respiratory failure, cardiac arrest, and death LD ₅₀ : 6 mg/kg (extremely toxic) (ILO Report, 2024)
Thiosulfate (Na₂S₂O₃)	Novel (alternative) gold lixiviant	Less toxic alternative to cyanide for gold leaching (Abbruzzese et al., 1995)	Non-cyanide leaching, 85-90 (Hou et al., 2023; Lin et al., 2024)	Lower toxicity compared to cyanide, but potential sulfur-related contamination in water Aquatic toxicity (LC ₅₀): >100 mg/L (low toxicity to fish) (Chaka & Rupprecht, 2024)	Mild irritant; safer than cyanide but can cause nausea in high exposure LD ₅₀ : >5000 mg/kg (practically non-toxic) (Brenner et al., 2017)
Thiourea (SC(NH₂)₂)	Non-cyanide-based lixiviant	Strong gold solvent, used as an alternative to cyanide (Ubaladini et al., 1998)	Thiourea leaching, 80-88	Less persistent than cyanide but can form toxic byproducts in acidic conditions Aquatic toxicity (LC ₅₀): 50–100 mg/L (toxic to fish) (Ray et al., 2022)	Possible carcinogen; skin and eye irritation LD ₅₀ : 125–640 mg/kg (moderately toxic) (Ray et al., 2022)
Glycine (C₂H₅NO₂)	Novel (alternative) gold lixiviant	Uses glycine in alkaline solutions to dissolve gold	Glycine leaching, 70-80	Biodegradable and low toxicity, minimal environmental persistence Rapid biodegradability (complete in <5 days) Aquatic toxicity (LC ₅₀): >100 mg/L (practically non-toxic) (Redrovan et al., 2024)	Generally safe; low health risks at working concentrations LD ₅₀ : >5000 mg/kg (practically non-toxic)

While no gold leaching agent currently matches cyanide's efficiency in all scenarios, thiosulfate (Na₂S₂O₃) emerges as the most viable alternative for ASGM, offering near-cyanide recovery rates (85–90%) with significantly lower toxicity, minimal infrastructure needs – critical for remote or small-scale operations – and no requirement for complex detoxification, thereby reducing operational risks and costs.

For environmentally sensitive areas or community-focused mining, glycine (C₂H₅NO₂) presents a promising future solution, with negligible toxicity (biodegradable, non-carcinogenic) and ongoing technological advancements aimed at improving its currently lower recovery rates (70–80%).

Thiosulfate's balance of efficiency and safety makes it the practical choice for ASGM today, while glycine represents the gold standard for tomorrow's responsible mining.

Continued research and case studies are essential to validate these alternatives and promote their widespread adoption in gold ore processing in Suriname.

In recent years, novel eco-friendly synthetic gold lixiviants (NESGLs) have gained significant attention and are now being utilized in industrial gold extraction (Qihao et al., 2023). These lixiviants are composed of leaching, complexing, and protective agents that work together to extract gold efficiently. The key components play a crucial role in dissolving gold, stabilizing the lixiviant structure, and maintaining its effectiveness. They are linked by covalent bonds and function similarly to free cyanide ions, facilitating gold complexation, dissolution, and extraction (Oraby et al., 2017).

One of the key advantages of NESGLs is their compatibility with existing cyanidation infrastructure, allowing for gold leaching without requiring significant changes to equipment or processes. Additionally,

they generate minimal hazardous waste, reducing environmental impact. Malyshev et al. (2025) compared traditional cyanidation with Jinchan leaching and found that Jinchan not only achieved superior gold recovery but also lowered costs. Similarly, Zhang et al. (2022) reported that replacing cyanide with "Minjie" lixiviant improved the gold recovery rate from silicate gold ore by 0.5%. These findings highlight the potential of NESGLs as a sustainable and cost-effective alternative to traditional cyanidation. Table 4 contains some information about this lixiviant.

Table 4. **Novel eco-friendly synthetic gold lixiviant (NESGLs)** (developed by the authors)

Lixiviant	Formula	Manufacturer	Leaching Mechanism	Advantages
1	2	3	4	5
Jinchan 	$\text{SC}(\text{NH}_2)_2$, NaSiO_3 , NaOH , $(\text{NaPO}_3)_6$ (Beyuo et al., 2016)	Guangxi Senhe High Technology Co., Ltd., China	Uses thiourea ($\text{SC}(\text{NH}_2)_2$) as the primary lixiviant, combined with sodium silicate (Na_2SiO_3), sodium hydroxide (NaOH), and sodium hexametaphosphate ($(\text{NaPO}_3)_6$) to enhance gold dissolution. Leaching rate – 87–91%	At present, is the only patented product for “environmentally friendly gold extraction” around the world. The product, used in gold production directly as the substitute for sodium cyanide without changing original process and equipment enjoys advantages such as low toxicity, environmental protection, high recovery, good stability, convenient operation, quick recycle, low dosage, low cost and convenient storage and transportation ⁸ .
Sandioss 	Na_2O – 30%, N – 20%, NH – 20%, CaO – 20%, Fe_2O_3 – 10% ⁹	Shanghai Sandioss New Material Co., Ltd., China	The leaching process is a non-cyanide gold extraction method that operates under alkaline conditions ($\text{pH} \sim 11$) and relies on a specialized lixiviant formulation to dissolve gold. It appears to function as a direct replacement for cyanide in conventional leaching methods, using a single non-toxic reagent to extract gold efficiently. Leaching rate – 79–91% (Heras et al., 2018; Zhang et al., 2022).	This product doesn't change original gold-leaching equipment and cyanide process. It can be applied to disseminated gold deposit, primary ore, oxide ore, semi-oxide ore, sulphide ore, gold concentrate, cyanidation slag, E-waste, heap spraying, carbon leaching and pond leaching. The product has higher recycling rate of leaching, faster rate of dissolution, lower cost and excellent performance of extraction, easy operation, safe warehouse, convenient transportation. Sodium cyanide can be substituted with “Sandioss” completely (Zhang et al., 2022).

⁸ <https://en.gxshgk.com/product/jin-chan-metallic-ore-dressing-agent/>

⁹ <http://www.sandioss.com/en/h-col-126.html>

1	2	3	4	5
Eco Friendly Gold Leaching Reagent YX500 	Unknown, manufacturer announced that this lixiviant is non-cyanide	Y&X Beijing Technology Co., Ltd., China	Synergetic leaching: during the gold leaching process, the synergistic effect of various elements enables the cyanide group to chelate and dissolve gold, thereby realizing the goal of gold extraction. Leaching rate – 86.5 % (Malyshev et al., 2025).	Low toxicity and environmental protection, high recovery rate, good stability, convenient operation, fast recovery, less dosage, low cost, and convenient storage and transportation. It is suitable for large and small scale of gold and silver oxide ore heap leaching, pool leaching, CIP, CIL and other leaching process, especially suitable for large-scale heap leaching ¹⁰ .
CNLITE Eco-Gold Reagent 	Na ₂ O – 30%, N – 5%, NH ₄ – 20%, CaO – 20%, Fe ₂ O ₃ – 10%	Guangzhou Mining Co., Ltd., China	Facilitates gold extraction through a leaching process similar to traditional cyanidation but with reduced environmental impact. When introduced into an alkaline slurry (maintained at a pH of 10-12), it dissolves and interacts with gold-bearing ores. The reagent forms stable complexes with gold ions, effectively dissolving the gold into the solution. Leaching rate – 91–98% ¹¹	Its active component is a carbon polymer. Its cyanide-like group (CN ⁻) is covalently bonded, unlike the ionic bonds in sodium cyanide. This structure minimizes toxic cyanide ion release, making CNLITE low-toxicity or non-toxic. It is non-oxidizing, non-combustible, non-explosive, and non-radioactive. It offers a high leaching rate (88 – 92%), effectively dissolving gold and achieving extraction efficiencies comparable to or better than those obtained with sodium cyanide. It is suitable for various gold extraction methods, including heap leaching, pool leaching, CIP, and CIL processes. It can be applied to different types of ores, such as oxidized gold and silver ores, sulfide ores, and cyanide tailings ¹² .
ASTODEP 500ST 	C ₃ N ₃ O ₃ Na ₃ sodium cyanurate (or trisodium cyanurate)	UTS (Shanghai) Industrial Co., Ltd., China	Sodium cyanurate gold leaching operates through a controlled cyanide release mechanism, where sodium cyanurate acts as a cyanide reservoir. Unlike free cyanide (NaCN), which dissolves instantly in solution,	The reagent is an eco-friendly alternative that can replace highly toxic sodium cyanide. It can be used either as a complete replacement for sodium cyanide or in combination with it, and is applicable in the enrichment processes of various gold-bearing ores and materials, including gold, oxide silver ores, primary ores,

¹⁰ https://www.yxbjtech.com/sale-44017623-stimulate-eco-friendly-gold-leaching-reagent-yx500-for-better-recovery-index.html#desc_p_box_1

¹¹ <https://www.cnlitereagent.com/product/cnlite-eco-friendly-gold-leaching-reagent/>

¹² https://www.cnlitereagent.com/special-guide/cnlite-eco-friendly-gold-leaching-chemicals/?utm_source=chatgpt.com/

			sodium cyanurate gradually releases cyanide ions (CN^-) as it dissolves, maintaining a stable and controlled cyanide concentration in the leaching environment. The free cyanide ions react with gold in the ore, forming the soluble gold-cyanide complex $[\text{Au}(\text{CN})_2]^-$, similar to conventional cyanidation.	cyanide tailings, gold concentrates, roasting slag, and anode slimes. The processes it can be used in include heap leaching, vat leaching, carbon pulp processes, and agitation leaching ¹³ .
EG200 (Earth Gold) 	A solid clathrate containing some cyanide, where the cyanide is securely bound within the clathrate's chemical structure. Its toxicity is significantly lower than that of free cyanide because most of the cyanide ions (CN^-) remain trapped and are not readily released ¹⁴	ASIA's Resource Connections and Venture International, China (Beijing), Australia (Melbourne), South Africa (Johannesburg)	The leaching and extraction cycle is similar to the process with sodium cyanide. Lixiviant forms a stable complex with gold, allowing it to be separated from the ore. Leaching rate – 80–91% (Verhoin, 2016)	The reagent is non-combustible, non-explosive, has no oxidation risk, is not radioactive hazard, has low toxicity, contains a common chemical product and is safe and environmentally-friendly. Unlike cyanide it reduces the presence of arsenic (As) and Sulphur (S). It is suitable for spraying, tank leaching and carbon leaching (agitation) processes. <i>Note:</i> A product marketed as an "environmentally friendly" gold-processing alternative ("Gold Dressing Agent" and "Earth Gold") was found to contain 17–27% sodium cyanide – a highly toxic chemical (Creagh, 2016).
MSDS–Goldix 570 	Main components: Na_2O – 35–50%, N – 12–16%, NH_4 – 7–12% Proprietary components: H_2O – 1–4%, Ca – 1–5%,	Shenyang Florrea Chemicals Co., Ltd., China	The leaching and extraction cycle is similar to the process with sodium cyanide but is easier to implement. The enriched or depleted solution can be reused (Verhoin, 2016). Leaching rate – 85–93% ¹⁵	The reagent effectively leaches gold ions and, compared to sodium cyanide, offers higher efficiency and shorter leaching time. The Goldix 570 heap filtration process is 25% shorter than that of sodium cyanide. Its use reduces environmental impact compared to sodium

¹³ <https://utsrus.com/reagent-dlya-vyshchelachivaniya-zolota-astodep-500st-1775?ysclid=m8ri5lft7570799120>

¹⁴ <https://www.asias-connections.com/products/earthgold/>

¹⁵ <https://pdfcoffee.com/qdownload/case-study-florrea-goldix-570-gold-leaching-reagent-pdf-free.html>

	Fe ₂ O ₃ – 1–5%			cyanide.
1	2	3	4	5
Flotent GoldSC 570 	The reagent formula is not disclosed, but it is stated that it contains Na ₂ O, N, H ₂ O, Ca, Fe, NH ₄ , and other components.	SNF Flocculant Co., Ltd., China	The reagent selectively dissolves gold by forming a stable gold complex. The reaction avoids toxic cyanide complexes (Au(CN) ₂ ⁻), instead using a non-toxic ligand for solubilization. The dissolved gold complex is efficiently adsorbed onto activated carbon (similar to cyanide-based CIL/CIP processes). Leaching rate – 80–92% (Barchenkov & Kudyarov, 2016)	The reagent is a high-performance, non-toxic alternative to sodium cyanide in heap leaching and adsorption gold extraction processes. With low toxicity, comparable to caustic soda used in cyanidation, it presents a safer alternative. Additionally, its eco-friendly nature reduces environmental risks. Unlike cyanide, it allows for safe transport and storage without the need for strict safety measures (Kurkov et al., 2020).

The acute toxicity of NESGLs is much lower than that of sodium cyanide (NaCN) thus replacing NaCN with alternative lixivants could significantly reduce toxicity risks (Table 5). However, proper handling protocols remain essential as some NESGL components may still present moderate hazards at high exposure levels.

Table 5. LD₅₀ of the novel eco-friendly synthetic gold lixivants (NESGLs) in lab rat/mouse

Lixiviant	NaCN	Jinchan	Sandioss	YX500	CNLITE Eco-Gold Reagent	ASTODEP 500ST	EG200 (Earth Gold)	MSDS–Goldix 570	Flotent GoldSC 570
Oral LD ₅₀ , mg/kg	6.44	> 2000	584	> 2000	> 2000	> 4600	584	50.1	50.1
Toxicity level	Very high	Low	Moderate	Low	Low	Low	Moderate	High	High

Replacing cyanide with non-cyanide, environmentally friendly gold lixivants (NESGLs) in gold extraction could be a practical solution. These alternatives can be used without modifying existing cyanidation equipment or processes like heap leaching, pond leaching, carbon-in-pulp (CIP), or carbon-in-leach (CIL). Additionally, key leaching conditions – such as ore particle size, pulp density, pH levels, and agitation speed – remain unchanged, making the transition straightforward.

However, research on NESGLs is still very limited, especially in artisanal and small-scale gold mining (ASGM). Most studies so far have only compared NESGLs to cyanide in terms of efficiency, with little focus on their environmental impact. Moreover, nearly all research has examined their use in oxide gold ores, leaving questions about their effectiveness in other ore types unanswered. These gaps highlight the need for more in-depth studies to fully understand NESGLs' potential and limitations.

To support the comparative assessment of Jinchan and mercury within the scope of this study, their Safety Data Sheets (SDS) were reviewed side by side. The Table 6 summarizes key information on product identification, chemical composition, hazard classification, health and environmental risks, handling, personal protective equipment (PPE), accidental release measures, disposal considerations, and regulatory compliance.

Table 6. Comparative overview of Safety Data Sheets (SDS) for Jinchan and Mercury

SDS Component	Jinchan SDS Reviewed	Mercury SDS Reviewed	Key Differences / Notes
Product Identification	Trade name (Jinchan), intended use as gold ore lixiviant	Trade name (Mercury), intended use in gold amalgamation	Jinchan is a chemical lixiviant; mercury is a heavy metal used for amalgamation
Chemical Composition	Active constituent (sodium isocyanate) and declared additives	Elemental mercury (Hg), no additional additives	Jinchan is synthetic; mercury is elemental and naturally toxic
Hazard Classification	Acute and chronic health hazards, environmental hazard statements	Toxic, highly hazardous via inhalation, ingestion, skin contact; environmental hazard statements	Mercury is more acutely and chronically toxic, especially neurologically
Health Effects	Potential impacts via inhalation, skin contact, ingestion	Neurological, renal, and developmental effects via exposure	Mercury has severe systemic effects; Jinchan mainly causes chemical irritation/respiratory risk
Environmental Risks	Aquatic toxicity, soil and water contamination risks	High toxicity to aquatic organisms; persistent environmental contaminant	Mercury is persistent and bioaccumulative; Jinchan is less persistent
Handling and Storage	Recommended storage conditions and handling precautions	Store in tightly sealed containers, avoid vapor release	Mercury requires strict containment to prevent vapor exposure; Jinchan follows standard chemical storage
Personal Protective Equipment	Required protective measures during use	Gloves, respirator, protective clothing to prevent exposure	Mercury exposure requires stricter PPE due to vapor inhalation risk
Accidental Release Measures	Spill containment and clean-up procedures	Mercury spill kits, avoid vacuum cleaners; use specialized clean-up	Mercury spills are more hazardous and harder to clean up than Jinchan
Disposal Considerations	Waste handling and disposal guidance	Disposal as hazardous waste according to regulations	Mercury requires strict hazardous waste disposal; Jinchan can follow chemical disposal guidelines
Regulatory Information	Compliance references and restrictions (where provided)	Listed as hazardous substance; compliance with local and international regulations	Mercury is highly regulated due to toxicity; Jinchan regulations are less stringent

Additionally, a column highlighting the key differences between the two substances is included to clearly demonstrate the relative hazards, environmental persistence, and regulatory requirements of each product. This comparative overview provides a concise reference for evaluating safety, risk management, and regulatory implications.

1.4 Novel Eco-Friendly Synthetic Gold Lixiviants Usage in Surinamese ASGM

In Suriname, most ASGM operations depend on gravity concentration, whether on land or floating rafts, and heavily involve mercury to extract gold from sediments. Sluicing – both with and without excavators – is the most widespread method, often paired with hammer mills to break down ore and improve gold recovery (Figure 5). Unfortunately, mercury use remains excessive in these processes, with whole ore amalgamation being a frequent practice despite its environmental and health risks.

Surinamese gold deposits consist of three main ore types (Kioe-A-Sen et al., 2016):

- **Greenstone Belt Deposits (Primary Source).** These sulfide-rich deposits, containing pyrite and arsenopyrite with free gold, are found in mines like Merian, Rosebel, and Gross Rosebel. However, gold is often locked in sulfides, requiring oxidation for extraction. Additionally, arsenic content can be high, reaching up to 1,500 ppm.
- **Alluvial and Eluvial Deposits (ASGM Dominant).** These deposits contain free-milling oxide ores which are primarily located along the Lawa and Tapanahony Rivers. They are favorable for small-scale gold mining because they allow for easy gravity-based gold recovery and have a low sulfide content of less than 5%.
- **Saprolitic Lateritic Deposits (Weathered Layers).** These partially oxidized transition ores overlie greenstone deposits and contain a mix of oxides and sulfides (10–30%). They also have moderate copper levels, ranging from 200 to 800 ppm.

Given that ASGM operations predominantly process free-milling quartz vein ores and alluvial placer ores and heap leaching is a widely used technique among local miners, the adoption of novel eco-friendly synthetic gold lixiviants presents a viable and sustainable alternative to both mercury amalgamation and cyanidation.

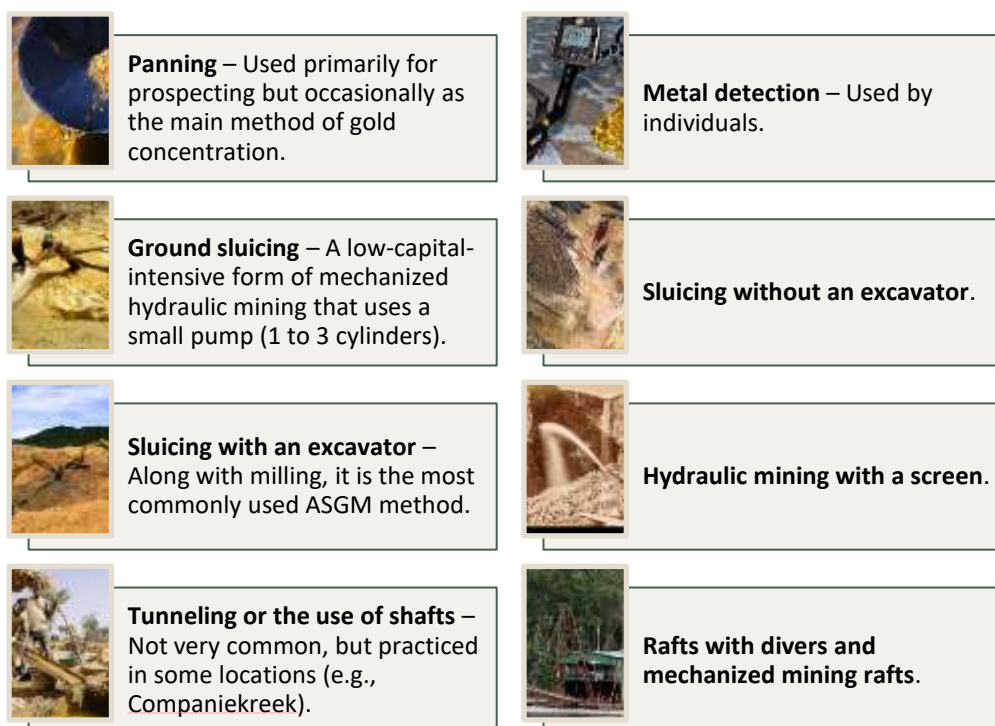


Figure 5. ASGM techniques used in Suriname

(Source: First National Action Plan on Artisanal and Small-Scale Gold Mining in Suriname (2023))

In recent years, Chinese mining teams operating in Suriname's artisanal and small-scale gold mining sector have increasingly adopted heap leaching methods, employing so-called "cyanide-free" and "environmentally friendly" lixiviants to extract residual gold from tailings generated by previous mining activities. However, these practices have raised significant environmental and health concerns, particularly due to the unregulated use of these chemicals and their unknown long-term effects. Key Issues Identified:

1. Questionable "Cyanide-Free" Claims

- Many of these lixiviants are marketed as non-toxic alternatives, but their chemical compositions are often undisclosed or misleading.
- Some agents may still contain cyanide derivatives or other hazardous compounds that react with residual mercury in tailings, forming highly toxic and carcinogenic mercury-cyanide complexes.

2. Regulatory Gaps in Suriname

- There is no formal oversight on the import, sale, or use of these leaching agents.
- No reliable statistics exist on the annual consumption of such chemicals.
- Lack of independent verification regarding their environmental safety – most claims come solely from manufacturers.

3. Environmental and Health Risks

- Heap leaching of mercury-contaminated tailings without prior mercury removal violates Minamata Convention (Annex C, Section 1b), which explicitly prohibits (Minamata Convention. 2013):

(i) Whole ore amalgamation

(ii) Open burning of amalgam

(iii) Amalgam burning in residential areas

(iv) Cyanide leaching of mercury-laden tailings without mercury removal.

- The combination of cyanide (or cyanide-like compounds) with residual mercury can produce mutagenic and neurotoxic compounds, posing severe risks to water sources, soil, and local communities.

4. Lack of Scientific Evidence on Safety

- No peer-reviewed studies confirm the environmental safety of these lixiviants.
- Most "evidence" comes from manufacturer-sponsored reports, raising concerns about bias and reliability.

The use of unverified "cyanide-free" lixiviants in Suriname's ASGM sector poses serious environmental and health risks, particularly when applied to mercury-contaminated tailings. Without strict regulation, independent testing, and proper mercury removal, these practices may lead to long-term ecological damage and public health crises. Immediate action is needed to enforce compliance with the Minamata Convention and promote truly sustainable gold extraction methods.

To minimize environmental and health risks associated with gold leaching in Suriname, the following measures should be implemented:

- **Strict regulation:** Authorities should enforce mandatory disclosure of chemical compositions and require independent toxicity testing before approving any leaching reagents.
- **Mercury removal mandate:** All tailings must be treated to eliminate mercury before leaching to prevent dangerous chemical interactions.
- **Independent monitoring:** Government agencies and NGOs should conduct thorough environmental impact assessments to verify manufacturer claims and ensure compliance with safety standards.
- **Promotion of safer alternatives:** The adoption of proven non-cyanide lixiviants, such as thiosulfate and glycine, should be encouraged, provided their safety and efficacy are transparently documented.

2. RESEARCH METHODOLOGY AND FIELD PREPARATION

The research methodology employed in this study integrates critical data review, stakeholder engagement, and field-based investigation to address significant knowledge gaps concerning the use of cyanide and non-cyanide lixiviants in Suriname’s artisanal and small-scale gold mining sector. Field preparation was guided by insights gained from the analysis of international case studies and a comprehensive evaluation of Suriname’s current mining practices, highlighting the deficient of relevant empirical data on environmental and human health impacts of “eco-friendly” lixiviants in tropical ecosystems. To fill this gap, a structured field research plan was developed, incorporating soil, water, and sediment sampling near ASGM sites. Additionally, tailored questionnaires were created for key stakeholder groups, including Indigenous communities, miners, and regulatory bodies, to gather first-hand perspectives on lixiviant usage, operational challenges, and policy needs. This multi-layered approach ensures a scientifically rigorous and context-specific foundation for evaluating the environmental sustainability and social acceptability of lixiviant alternatives in Suriname.

2.1 Overall Research Design and Approach

The overall research design follows a structured, standards-based approach to ensure reliability, transparency, and scientific rigor in the investigation of potentially contaminated sites. All field activities, sampling strategies, and investigation methods were conducted in accordance with BS 10175:2011+A2:2017 – Investigation of Potentially Contaminated Sites – Code of Practice (British Standards Institution, 2017). This standard provided the guiding framework for developing the sampling design, selecting investigation techniques, and implementing quality assurance protocols. The approach emphasizes systematic site characterization, the identification of contamination pathways, and the collection of representative environmental data across relevant media, including soil and water. Field investigations were carefully planned to align with both international best practices and the unique environmental conditions of Suriname’s ASGM regions, ensuring that the results are both scientifically valid and locally applicable. The sites investigation process is depicted in detail in Figure 6.

The research employed a mixed-methods approach, combining quantitative environmental sampling with qualitative site characterization to ensure a holistic understanding of contamination at ASGM (artisanal and small-scale gold mining) sites. The *quantitative* approach focused on the collection and laboratory analysis of soil and water samples to assess contaminant concentrations, while the *qualitative* aspect included the development of a conceptual site model to map contaminant sources, migration pathways, and potential receptors. Together, these approaches ensured a comprehensive, transparent, and scientifically valid assessment of environmental risks.

The *initial conceptual model* which provides an integrated framework for understanding possible contamination at ASGM sites was developed (Table 7). It outlines contaminant sources, migration pathways, and potential receptors to guide field investigation and risk assessment. The model helps prioritize areas for sampling, determine appropriate analytical techniques, and anticipate potential exposure scenarios. It also facilitates the integration of site-specific data with broader environmental and health risk considerations. The conceptual model will evolve throughout the investigation as new data become available, thereby refining the understanding of contamination dynamics and supporting more targeted risk assessments and mitigation planning.

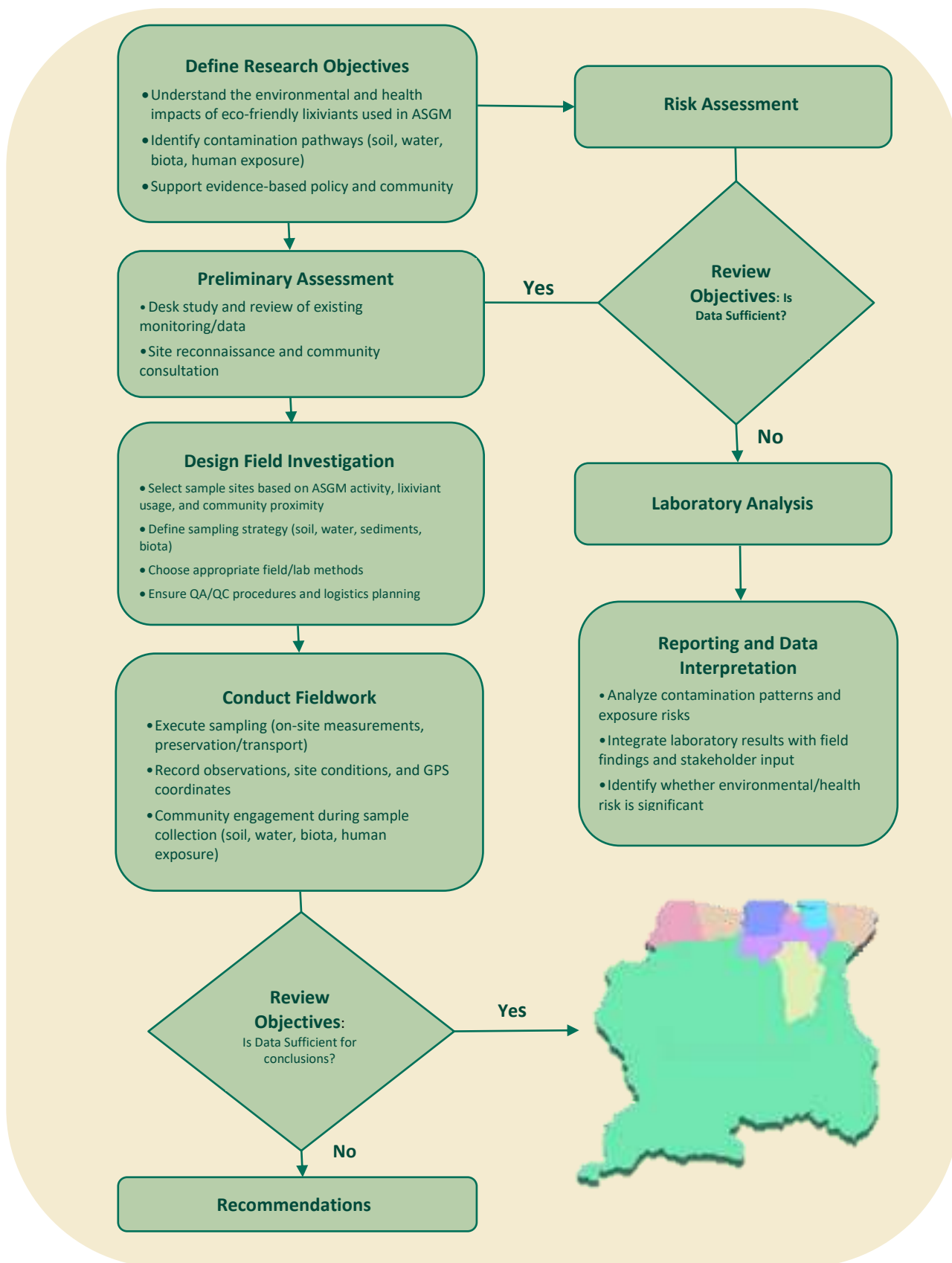


Figure. 6. Site investigation process flowchart (Developed by authors)

Table 7. **Conceptual site model** *(developed by the authors)*

Category	Details
Contamination sources and extent	Potential contaminants: mercury, cyanide, arsenic, antimony, copper, and lead Likely zones: tailings dumps, processing zones, barren solution collectors, and adjacent water bodies Expected depths: 0–2 m, potentially deeper near leaching areas Extent: localized hot spots, with lateral spread via runoff/infiltration
Site stratigraphy	Upper layers: disturbed or made ground, tailings Lower layers: natural alluvial or lateritic soils Stratification: clay – silt – sand variations affecting permeability
Strata variability and permeability	High spatial variability due to unregulated mining Sandy soils and tailings more permeable, increasing migration potential
Migration routes	Vertical: infiltration through permeable layers and tailings Horizontal: runoff, drainage channels, shallow groundwater Airborne: mercury vapor, tailings dust
Influential physical features	Abandoned pits and trenches Presence of tanks, drums, or illegal waste burial Eroded or cleared areas promoting surface transport
Natural attenuation or enhancement	Mercury methylation under anaerobic conditions Oxidation/reduction in variable redox zones
Groundwater characteristics	Likely shallow, unconfined aquifers Flow direction affected by topography and mining activities Seasonal groundwater fluctuations
Surface water features	Nearby creeks, rivers, or retention ponds High risk of contamination via runoff or direct discharge
Human receptors	On-site miners and local communities Vulnerable groups: children, women
Environmental receptors	Aquatic species in polluted waters Terrestrial fauna via soil exposure or food chain
Controlled waters	Impact on aquatic ecosystems Monitoring required to meet legal standards
Foreseeable events affecting the site	Seasonal floods spreading contamination Mining expansion altering hydrology

An intrusive investigation was chosen for this research, with hand augering selected as the primary method. Table 8 presents an overview of the advantages and disadvantages associated with this technique.

Table 8 **Intrusive investigation method description** (*developed by the authors*)

Aspect	Details
Description	Hand augering is a manual intrusive sampling method used to collect soil samples and observe soil profiles. It is widely used in environmental investigations, especially in remote or difficult-to-access areas. Various auger head designs are available to accommodate different soil types and sampling objectives
Advantages	Multiple auger designs are available for different soil types and sampling needs Preferred auger types allow recovery of core samples Enables visual inspection of the soil profile at pre-determined depth Ideal for sandy soils or areas with minimal obstructions Lightweight, portable equipment allows access to remote sites Cost-effective and requires no external power source
Disadvantages	Limited depth achievable, especially when obstructions like stones or compacted layers are present Performance highly dependent on soil type (e.g., difficult in clayey, rocky, or root-filled soils) Potential for cross-contamination from loose material falling down the borehole (can be mitigated by using plastic liners) Smaller sample volumes compared to mechanical drilling Physically demanding for operators, especially in dense soils Samples may be significantly disturbed, limiting their use for certain analyses

2.2 Site Selection Criteria and Rational

The selection of study sites was guided by a combination of environmental, geographical, and socio-economic factors to ensure that the data collected would be representative of typical conditions within active and abandoned ASGM regions in Suriname. The selection process was designed to capture variability in mining practices, environmental conditions, and potential exposure pathways relevant to public and ecological health.

Criteria Considered:

- *Proximity to water bodies:* Sites were prioritized based on their location near creeks and rivers commonly used for gold extraction, domestic water use, and recreational purposes. This allowed for direct assessment of water pollution and exposure risks.
- *Mining activity status:* Both *active* and *abandoned ASGM sites* were included to evaluate the environmental legacy effects of past operations and the ongoing impact of current practices.
- *Geographical distribution:* A range of locations across different gold-producing sites were selected to ensure spatial coverage and account for variations in geology, hydrology, and land use (Figure 7).

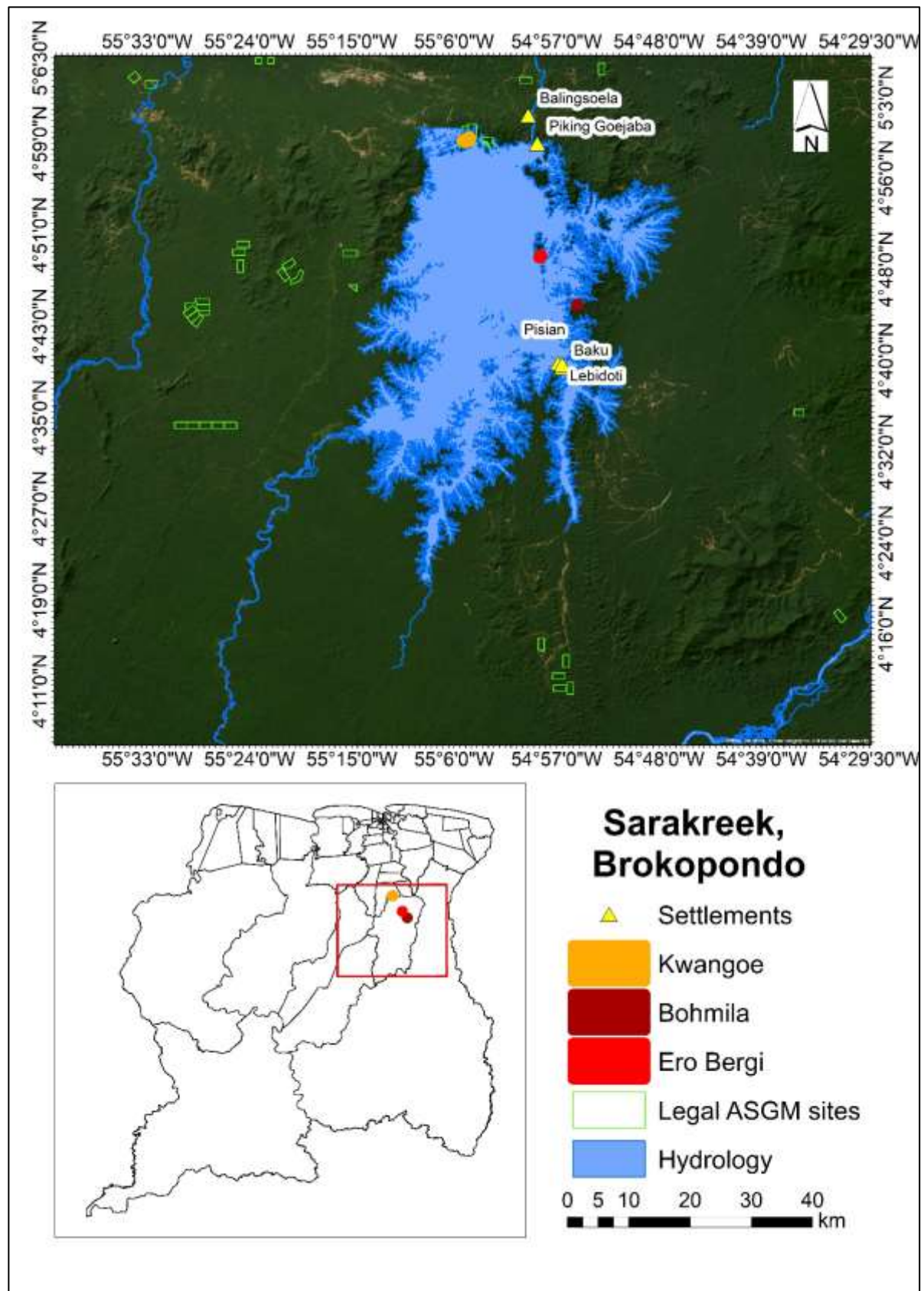


Figure 7. Locations of study sites within Sarakreek Resort, Brokopondo (created by the authors)

- *Accessibility and safety:* Field sites were chosen based on accessibility during both dry and wet seasons, as well as on-site safety conditions to facilitate consistent data collection and minimize fieldwork disruptions.
- *Stakeholder relevance:* Sites were selected based on research purpose, input from local authorities, environmental agencies, and community stakeholders to reflect areas of public concern and regulatory interest.

The selected sites provide a representative cross-section of the environmental conditions associated with ASGM in Suriname. This strategic approach ensures that the findings from soil, water, and barren solution sampling, as well as the subsequent risk assessments, are generalizable to broader ASGM-impacted regions. By including both heavily impacted and relatively undisturbed reference areas, the study design also enables differential analysis and improves the reliability of cause-effect interpretations regarding mining-related pollution.

2.3 ASGM Sites Description

The selected sites – Bohmila, Ero Bergi, and Kwangoe – are located in the Sarakreek resort area of the Brokopondo district (Figures 8 – 10). Heap leaching is the primary gold extraction technique at Bohmila. The process utilizes tailings sourced from upstream hammer mill – sluice box operations, which are further processed via hydraulic mining before leaching.

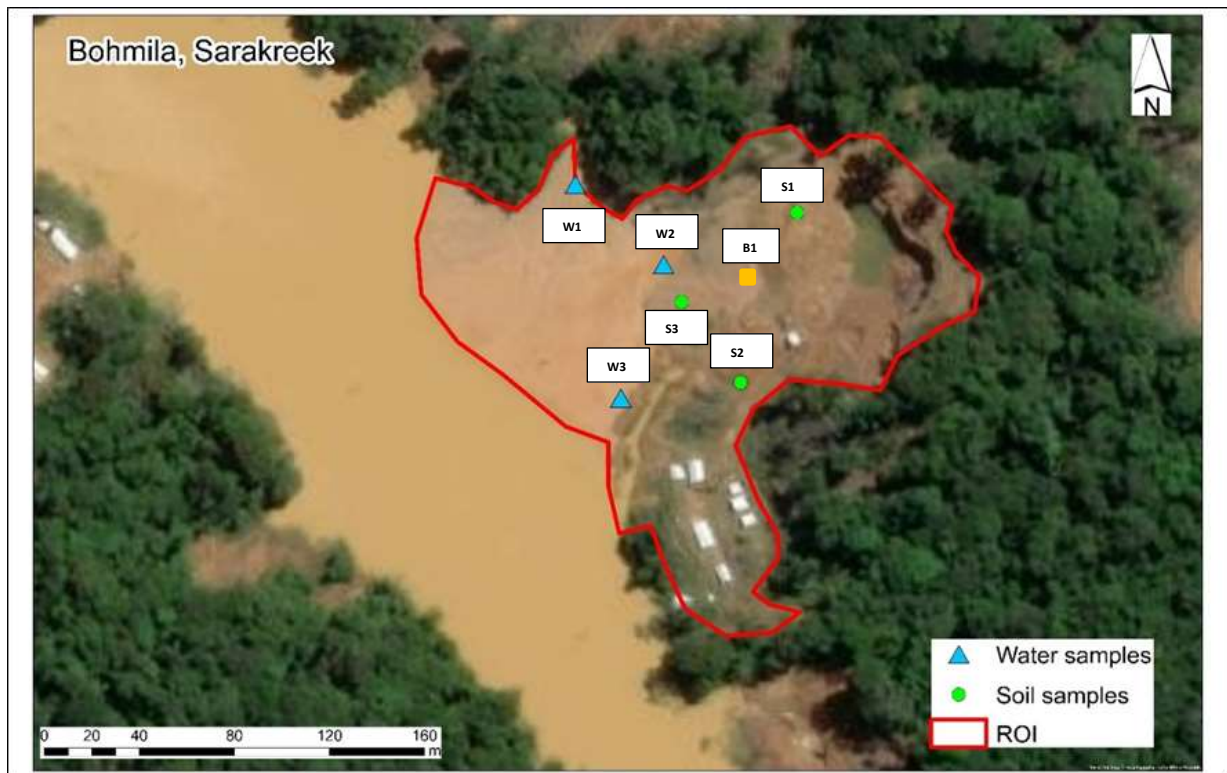


Figure 8. **Scheme of sample collection within the Bohmila site** (site area – 2.5 hectares)
W1–W3 – water samples location, S1–S3 – soil samples location, BS – barren solution sample location

Step-by-step workflow:

1. *Tailing's reprocessing (hydraulic mining):*

- Tailings from hammer mill – sluice box operations are disaggregated using *high-pressure water jets*, creating a slurry (*pulp*).
 - A *gravel/sand pump* transports the pulp to a secondary sluice box for: (i) removal of residual clays and fine sediments; (ii) concentration of gold-bearing sand particles.

2. *Heap leaching preparation:*

- The cleaned, gold-concentrated sand is stacked into engineered heaps (typically 1 – 3m height).
- *Jinchan lixiviant* (a non-cyanide, thiourea-based solution) is applied via drip irrigation systems.
- The lixiviant percolates through the heap, dissolving gold into solution over 30 – 60 days.

3. *Gold recovery:*

- Pregnant leach solution (PLS) is collected at the heap base.
- Gold is recovered from PLS using activated carbon adsorption.

For more information about Bohmila site see Appendixes A.1 and A.2.

The Ero Bergi site is situated within the eastern shore line of Afobaka Lake. For more information about this site see Appendixes A.3 and A.4.

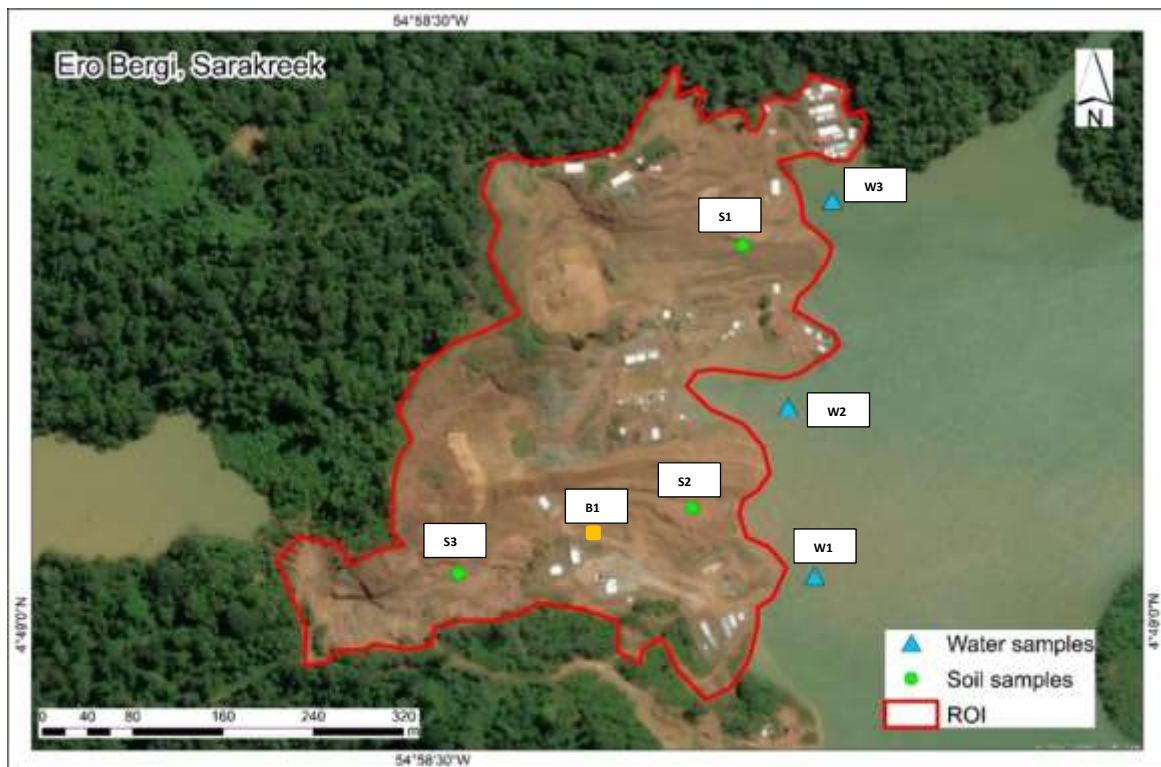


Figure 9. **Scheme of sample collection within the Ero Bergi site** (site area – 15 hectares)

W1–W3 – water samples location, S1–S3 – soil samples location, BS – barren solution sample location

Mining methods applied within the limits of this site include the following:

Mining: Open-pit mining is used to extract gold-bearing material.

Processing: The extracted ore is processed using a hammer mill and sluice box system.

- The *hammer mill* crushes and grinds the material into smaller particles, liberating some of the gold.
- The *sluice box* concentrates part of the free gold, using *mercury amalgamation*.
- The remaining material, which includes unliberated gold, residual free gold, and gangue minerals, is discharged as tailings.

Amalgamation: Amalgamation is carried out on the sluice box concentrate to recover gold by separating it from the remaining materials using mercury.

Chemical extraction of gold:

- The tailings from the hammer mill – sluice box operation is transported via truck and front-end loader to a heap leach stockpile.
- According to site personnel, the tailings are mixed with *cement* and *caustic soda* prior to heap formation.
- *Heap leaching* is conducted using a chemical agent called *Jinchan dressing agent* for gold extraction.

Leaching terminology: *pregnant solution* – the gold-rich solution obtained after the leaching process; *barren solution* – the solution remaining after metal extraction, containing little to no valuable metals.

The Kwangoe site is located along northern part of Afobaka Lake shore within the limits of legal ASGM activity. For more information about this site see Appendixes A.5 and A.6.



Figure 10. **Scheme of sample collection within the Kwangoe site** (total site area – 44 hectares; area available for investigation – 10.23 hectares) W1–3 – water samples location, S1–S3 – soil samples location

Mining methods applied within the limits of this site include the following:

Mining: Open-pit mining is applied to extract gold-bearing material from the site. This method involves the removal of overburden and excavation of surface material to access gold-rich ore bodies.

Processing: The extracted ore is processed using a *hammer mill – sluice box operation*. The *hammer mill* crushes and grinds the mined material into smaller particles, liberating some of the gold. These free gold particles are then partially recovered using a *sluice box*, where *mercury* is used to form an *amalgam* with the gold. However, not all gold is recovered at this stage. A significant portion of both free and associated (bonded) gold, along with other minerals and gangue material, remains in the tailings.

Amalgamation occurs both within the sluice box and during the subsequent separation of the sluice concentrate. The concentrate is further treated to isolate gold from the remaining material.

Chemical extraction of gold: The tailings from the hammer mill–sluice box operation, which still contain a mix of unrecovered free gold, gold associated with other minerals, and waste material, are transported by *trucks and front-end loaders* to the *heap leaching stockpile* and the *tank leaching unit*.

Both *heap leaching* and *tank leaching* methods are used for chemical extraction of gold, utilizing *Jinchan gold dressing agent*, an alternative to cyanide-based leaching reagents. Gold from the pregnant solution is recovered by *adsorption onto activated carbon*, which selectively binds the dissolved gold from the solution.

Notably, heap leaching is employed at the Bohmila site, whereas at the Ero Bergi site both amalgamation and heap leaching are applied for gold recovery. Within the Kwangoe site, amalgamation, heap leaching, and tank leaching are utilized as chemical extraction methods for gold.

2.4 Field Sampling Design and Protocols

The field sampling design was developed to ensure systematic, representative, and high-quality data collection across potentially contaminated ASGM sites. Sampling strategies were guided by the principles outlined in *BS 10175:2011+A2:2017*, with specific adaptations for the environmental and logistical context of Suriname. A *stratified random sampling approach* was selected as the most appropriate technique to ensure compliance with ISO/ASTM requirements while optimizing costs. This approach was used to capture both spatial variability and known high-risk zones, such as ore processing areas, tailings deposits, chemical storage sites, and drainage pathways. Sampling locations were selected based on the conceptual site model, with considerations for contamination sources, surface water flow, and prevailing land use. The sampling protocol workflow is illustrated in Figure 11.

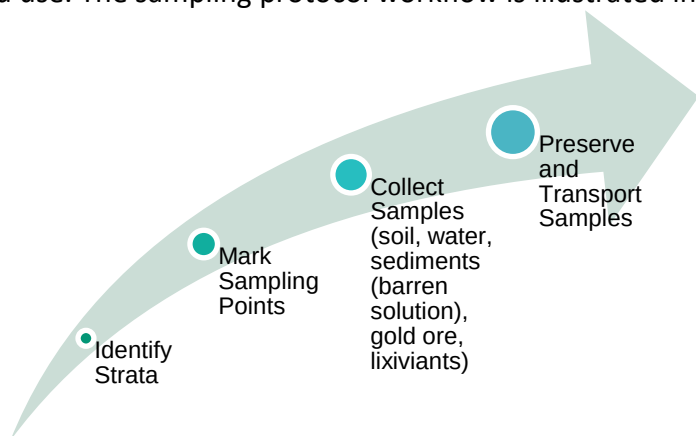


Figure 11. **Sampling protocol workflow** (Developed by authors)

When selecting sampling locations and determining sample quantity, the following considerations were applied:

- According to ISO 18400-203 §6.4 requirements, *a minimum of three collective samples is mandated for areas ≤50 ha* to achieve representative results;
- *Priority was given to high-risk zones*; background (reference) sampling was intentionally omitted;
- *Each key stratum* – including tailings dumps, processing zones, wastewater collectors, and adjacent water bodies – *was assigned at least one soil sample*;
- *High-risk zones* were assigned *two soil samples* each to ensure adequate representation.
- At each sampling location, *three separate soil subsamples* were collected: one for *cyanide (CN⁻)* analysis; one for *mercury (Hg)* analysis; one for the detection of *other pollutants*.
- *Barren solution samples* were collected (if possible) at the *same locations as water samples* to support integrated analysis.
- *At least three water samples* were collected from each site to ensure spatial variability is captured.

Detailed information on the number and distribution of samples across the three selected ASGM sites is presented in Table 9.

Table 9. Site sampling: number of collective samples

Site name	Number of samples			
	Soil	Water	Barren solution	Heap material from tailing dump
Bohmila	3	3	1	-
Ero Bergi	3	3	1	1
Kwangoe	3	3	—	-
Total	9	9	2	1

Note: One collective soil sample is consisted of at least 5 spot samples.

Samples were stored in pre-labelled, contamination-free containers and preserved according to the requirements of targeted laboratory analyses (e.g., mercury, cyanide, pH). Field protocols also included the use of *field blanks*, *duplicates*, and *chain-of-custody documentation* to maintain data integrity and traceability. All sampling activities were conducted in compliance with health, safety, and environmental protection guidelines.

2.4.1 Soil Sampling

Cluster sampling was selected to collect soil samples. This sampling type involves the collection of a representative sample composed of multiple small incremental point samples taken within a defined area – typically around 1 m² – to form what is known as a cluster disturbed sample (as referenced in BS 10175:2011+A2:2017, section 7.7.2.4). The material was sampled from within the same soil strata, ensuring consistency in the sample composition. This method is particularly useful for determining the distribution and concentration of specific elements or contaminants, especially in environmental investigations involving disturbed soils.

Soil sampling were conducted in accordance with the following normative protocols:

- ISO 18400-101:2017 Soil quality – Sampling Part 101: Framework for the preparation and application of a sampling plan;
- ISO 18400-104:2018 Soil quality – Sampling Part 104: Strategies;
- ISO 18400-107:2017 Soil quality – Sampling Part 107: Recording and reporting;
- ISO 18400-102:2017 Soil quality – Sampling Part 102: Selection and application of sampling techniques;
- ISO 18400-203:2018 Soil quality – Sampling Part 203: Investigation of potentially contaminated sites.

All soil samples were collected from the topsoil layer (0–20 cm) using auger and hand tools, following clean sampling procedures to prevent cross-contamination.

Soil samples weight: for CN⁻ testing – 1.0 kg; for Hg testing – 0.5 kg; for other pollutants testing – 1 kg.

2.4.2 Water Sampling (Surface)

Water sampling was conducted following a structured and standardized approach to ensure data reliability, minimize contamination risks, and maintain sample integrity throughout the process in accordance with the protocol of U.S. Environmental Protection Agency (EPA). (2020). Quick guide to drinking water sample collection. EPA Office of Water. The procedure was divided into three key phases: *preparation before fieldwork, field sampling, and post-sampling handling and documentation.*

Phase 1. Preparation before fieldwork. Prior to field deployment, all necessary planning and preparation were completed to ensure efficient and safe sample collection:

- Sampling locations were identified using maps, local knowledge, and GPS tools. Access permissions were secured in advance, and safety protocols were reviewed;
- The following items were prepared:
 - a) Water sampling bottles: glass bottles for mercury analysis and HDPE (high-density polyethylene) bottles for other tests. All bottles were pre-labelled with sample ID, date, time, and location to avoid confusion and ensure traceability;
 - b) Field notebook for recording observations;
 - c) GPS-enabled smartphone;
 - d) Cooler box with ice packs for sample preservation;
 - e) Labels and waterproof markers;
 - f) (PPE), including gloves.

Phase 2. Field sampling procedure. In the field, care was taken to prevent contamination and ensure consistent sampling technique across all sites:

- Clean gloves were worn at all times during sampling to avoid sample contamination;
- Samplers approached water bodies gently to avoid disturbing sediments or altering the water composition near the sampling point.

Sample Collection:

- Sampler positioned on the *downstream side* of the sampling location to minimize disturbance;
- The bottle was submerged facing *upstream*, approximately *10–20 cm below the water surface*;
- Bottles were filled slowly, minimizing air bubbles, and capped immediately after collection;
- The above steps were repeated for each pre-identified sampling point.

Phase 3. Post-sampling handling and documentation

After collection, samples were handled with care to maintain integrity until laboratory analysis:

- All samples were placed immediately in a cooler with ice packs to maintain a temperature of approximately 4°C, protecting samples from sunlight and heat;
- Samples were delivered to the laboratory within 24 hours, while maintaining a cool temperature during transit.

Water samples for cyanides identification were preserved with 1.0 ml of NaOH 30%, water samples for other pollutants identification were preserved with 0.5 ml of nitric acid HNO₃.

2.4.3 Barren Solution Sampling

A barren solution is the residual liquid that remains after gold has been extracted from ore through heap leaching. This solution typically contains unreacted lixiviants (such as cyanide), reaction by-products, and potentially toxic elements like arsenic, mercury, and lead. Barren solution sampling was carried out in accordance with ISO 5667-10:2020 — Water Quality – Sampling – Part 10: Guidance on Sampling of Waste Water.

Grab sampling was selected as the sampling method, which is particularly suitable for artisanal and small-scale gold mining sites and for rapid assessments of contamination. The sampling and preservation procedures followed the same protocol as those used for water sampling, ensuring that samples were collected, stored, and transported under controlled conditions to maintain analytical integrity.

2.4.4 Sampling of Heap Material from a Tailings Dam

Cluster sampling was selected to collect heap material samples from tailing dam. All samples were collected from the subsoil layer (20–50 cm) using auger and hand tools, following clean sampling procedures to prevent cross-contamination. Samples weight: for CN⁻ testing – 1.0 kg; for Hg testing – 0.5 kg; for other pollutants testing – 1 kg.

2.4.5 Sampling of Jinchan lixiviant

The investigation of the gold ore dressing product, Jinchan, included a detailed chemical analysis of a representative sample, which was combined with the five-point samples. The measured concentrations of elements such as Al, As, B, Ba, Be, Ca, Cd, Cl, Co, Cr, Cu, Fe, F, Hg, K, Mg, Mn, NO₂, NO₃, SO₄, PO₄, and CN (total and free) were compared with reference materials (SS2, OREAS 550, OREAS 603C) and with the components listed in the SDS.

2.5 Laboratory Testing and Analytical Methodology

Laboratory testing of collected samples – including soil, water, and barren solution – was conducted in a certified laboratory to quantify contamination levels, evaluate gold recovery rates, and assess the environmental impact of ore dressing agents. The analyses included cyanides, mercury and heavy metal assessments.

Detection limits for water samples testing, ug/l: As – 0.050; Cd – 0.010; Co – 0.050; Cu – 0.500; Ni – 0.500; Pb – 0.050; Sb – 0.010; Zn – 1.000; CN- (mg/l) – 0.010.

Detection limits for soil samples testing, ppm: As – 0.100; Cd – 0.010; Co – 0.050; Cu – 0.500; Ni – 0.100; Pb – 0.050; Sb – 0.050; Zn – 1.000; CN- (mg/l) – 0.100.

Detailed information on the analyzed components and analytical methodologies applied is presented in Table 10.

Table 10. Sample analysing: methodology

Analyzed environment	Analyzed component	Methodology
Water and barren solution	Cyanides	ISO 6703-1:1984 Water quality — Determination of cyanide Part 1: Determination of total cyanide
	Arsenic, antimony, mercury	ASTM D5673-16 Standard test method for elements in water by inductively coupled plasma – Mass spectrometry ASTM D1976-20
	Cobalt, nickel, copper, zinc, cadmium and lead	Standard Test Method for elements in water by inductively-coupled plasma atomic emission spectroscopy
Soil	Mercury	EPA Method 7473 (SW-846): Mercury in solids and solutions by thermal decomposition, amalgamation, and atomic absorption spectrophotometry
	Cyanides	ASTM D2036-09(2022) Standard test methods for cyanides in water (are often adapted for soil matrices after NaOH extraction)
	Arsenic, antimony	ISO 22036:2024 Environmental solid matrices — Determination of elements using inductively coupled plasma optical emission spectrometry
	Cobalt, nickel, copper, zinc, cadmium and lead	ISO/TS 16965:2013 – Soil quality – Determination of trace elements using inductively coupled plasma mass spectrometry (ICP-MS)

2.6 Risk Assessment Methodology Framework

This section outlines the comprehensive methodology employed to assess *ecological and human health risks* associated with ASGM activities in the study area. The framework integrates:

- Ecological risk assessment using geochemical indices to quantify contamination levels and ecological threats from heavy metals in soil;
- Human health risk assessment based on US EPA guidelines, evaluating non-carcinogenic and carcinogenic risks for local populations via ingestion, inhalation, and dermal exposure pathways.

2.6.1 Ecological Risk Assessment Methodology

2.6.1.1 Soil Ecological Risk

To evaluate ecological risk, several indices were calculated (Hakanson, 1980; Cheng et al., 2018; Zhou et al., 2022):

- Geo-accumulation index (I_{geo});
- Contamination factor (C_i^f);
- Potential ecological risk index (E_i^r);
- Modified degree of contamination (mCd);
- Nemerow comprehensive index (P_i);
- Potential ecological risk index (RI).

The *geo-accumulation index* (I_{geo}) is a widely used tool for assessing the degree of contamination of soils or sediments by heavy metals. It compares current concentrations of metals to pre-industrial or natural background levels, helping to evaluate anthropogenic influence and is expressed as:

$$I_{geo} = \log_2 \left(\frac{C}{k \cdot B_n} \right) \quad (1)$$

where C is measured heavy metal content; B_n – background value of heavy metal content (Table 11); k – the petrogenesis effect, usually set to 1.5 (Zhou et al., 2022).

Table 11. Background values of some trace elements for Suriname, mg/kg

Element	Range/Mean	Source	Notes
As	0.1–10 / 5	Jimenez et al. (2023)	Higher near gold mining belts
Sb	0.2–4.5 / 2.35	Gibbs & Barron (1983)	Lateritic soils near gold-mining zones
Cd	0.05–0.3 / 0.18	Kubier et al. (2019)	Baseline for tropical soils
Co	5–20 / 12.5	Kabata-Pendias (2011)	Typical median ranges (no local data)
Cu	20–80 / 50	Gibbs & Barron (1983)	Lower in sandy coastal soils
Hg	– / 0.15	Kroonenberg et al. (2022)	Up to 0.8 mg/kg in mining zones
Ni	10–85 / 47.5	Kabata-Pendias (2011)	Higher in lateritic soils
Pb	15–40 / 27.5		Elevated in urban areas
Zn	50–120 / 85		Zn availability and mobility are strongly influenced by soil pH, organic matter content, and Fe/Mn oxide presence

I_{geo} degrees are classified as follows (Förstner et al., 1990):

$I_{geo} \leq 0$ – uncontaminated

$0 < I_{geo} < 1$ – uncontaminated to moderately contaminated;

$1 \leq I_{geo} < 2$ – moderately contaminated;

$2 \leq I_{geo} < 3$ – moderately to heavily contaminated;

$3 \leq I_{geo} < 4$ – heavily contaminated;

$4 \leq I_{geo} < 5$ – heavily to extremely contaminated;

$5 < I_{geo}$ – extremely contaminated.

The *contamination factor* (C_i^f) is a simple and widely used method for evaluating the level of contamination of soil by individual trace elements. It is especially useful in environmental risk assessments to compare current concentrations of a contaminant with its natural or baseline background level. The contamination factor (C_i^f) is expressed as:

$$C_i^f = \frac{C_i}{C_n^i} \quad (2)$$

where C_i is the measured value of trace element i in the soil sample (mg/kg) and C_n^i is the geochemical background value¹⁶ of trace element i (Table 5).

C_f^i values are divided into four categories (Cheng et al., 2018):

- $C_f^i < 1$ – low contamination;
- $C_f^i < 3$ – moderate contamination;
- $C_f^i < 6$ – considerable contamination;
- $C_f^i > 6$ – very high contamination.

The *potential ecological risk index* (E_r^i) provides a quantitative measure of the ecological risk posed by individual trace elements in soil. It combines the contamination level with the toxicity of the element, making it useful for assessing both pollution extent and potential ecological impact. Potential ecological risk index (E_r^i) is expressed as:

$$E_r^i = C_f^i * T_r^i \quad (3)$$

where C_f^i is the contamination factor of trace element i and T_r^i is the toxicity coefficient of element i (Table 12).

Table 12. **Toxicity coefficient values of some trace elements** (Xu et al., 2008)

Trace element	As	Sb	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn
Toxicity coefficient	10	10	30	5	2	5	40	5	5	1

E_r^i degrees are classified as follows (Cheng et al., 2018):

- $E_r^i < 40$ – low risk;
- $40 \leq E_r^i < 80$ – moderate risk;
- $80 \leq E_r^i < 160$ – considerable risk;
- $160 \leq E_r^i < 320$ – high risk;
- $E_r^i \geq 320$ – very high risk.

Modified degree of contamination (mC_d) is a comprehensive metric used to assess the overall level of heavy metal contamination in a soil sample. It accounts for the combined effect of multiple contaminants by averaging their individual contamination factors and is expressed as:

$$mC_d = \frac{\sum_{i=1}^N C_f^i}{N} \quad (4)$$

where N is the number of elements analyzed and C_f^i is the contamination factor of trace element i .

mC_d degrees are classified as follows:

- $mC_d < 1.5$ – unpolluted soil;
- $1.5 \leq mC_d < 2$ – slightly polluted soil;
- $2 \leq mC_d < 4$ – moderately polluted soil;
- $4 \leq mC_d < 8$ – considerably polluted soil;

¹⁶ Statistical characteristics of the total (natural pedo-geochemical and anthropogenic) content of a substances in soil (ISO 19258:2018 Soil quality — Guidance on the determination of background values).

- $8 \leq mC_d < 16$ – highly polluted soil;
- $16 \leq mC_d < 32$ - strongly polluted soil;
- $mC_d \geq 32$ – extremely polluted soil.

Nemerov comprehensive index (P_i) is a metric used to quantify the overall pollution pressure in a specific location by combining the average and maximum contamination levels of multiple trace elements and is expressed as:

$$P_i = \sqrt{\frac{(mC_d)^2 + (C_{fmax}^i)^2}{2}} \quad (5)$$

where mC_d is the modified contamination degree and C_{fmax}^i is the maximum value of the contamination factor.

P_i degrees are classified as follows: (i) $P_i \leq 0.5$ – uncontaminated; (ii) $0.5 < P_i \leq 1$ – slightly contaminated; (iii) $1 < P_i \leq 2$ – moderately contaminated; (iv) $2 < P_i \leq 3$ – moderately to heavily contaminated; (v) $3 < P_i \leq 4$ – heavily contaminated; (vi) $4 < P_i \leq 5$ – heavily to extremely contaminated; (vii) $P_i > 5$ – extremely contaminated.

Potential ecological risk index (RI) is a widely used indicator to evaluate the cumulative ecological risk of multiple heavy metals in environmental media (soil, water, air). It accounts for both the contamination level and the toxicity of each metal and is expressed as:

$$RI = \sum_{i=1}^N E_r^i \quad (6)$$

where E_r^i is the monomial potential ecological risk associated with element i .

RI degrees are classified as follows for nine pollutants¹⁷: (i) $RI < 170$ – low ecological risk; (ii) $170 \leq RI < 340$ – moderate ecological risk; (iii) $340 \leq RI < 680$ – considerable ecological risk; (iv) $680 \leq RI < 1360$ – high ecological risk; (v) $RI > 1360$ – very high ecological risk.

2.6.1.2 Water Ecological Risk

To evaluate ecological risk, the laboratory results on water pollutant concentrations were compared with reference values established by the US EPA. These reference values include:

- Water life (chronic exposure): thresholds for protecting aquatic ecosystems (chronic pollution)¹⁸;
- Water + organism: limits applied when people both use the water and consume aquatic organisms;
- Organism only: limits applied when people do not use the water directly but consume aquatic organisms from it¹⁹;
- Drinking water: standards for safe human consumption²⁰.

¹⁷ The original classification was based on eight pollutants. If a study considers a different number of pollutants, the classification thresholds should be proportionally adjusted using a weighted average correction method.

¹⁸ Source: <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table>

¹⁹ Source: <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table>

²⁰ Source: <https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#one>

2.6.2 Health Risk Assessment Methodology

2.6.2.1 Exposure Dose

In this study, the risk assessment methodology introduced by the Environmental Protection Agency of the United States (US EPA) was utilized to evaluate the health risks in relation to the concentration of heavy metals in soil and water within the limits of ASGM sites. According to the Exposure Factors Handbook (US EPA, 2011), the Average Daily Dose (ADD) of *soil pollutants* (expressed in mg/kg/day) for the three *exposure pathways* — *ingestion*, *dermal contact*, and *inhalation* — was estimated using Equations (7) to (9) (Miletić et al., 2023).

$$ADD_{ing} = \frac{C \cdot R_{ing} \cdot EF \cdot ED}{BW \cdot AT} \cdot CF \quad (7)$$

$$ADD_{inh} = \frac{C \cdot R_{inh} \cdot EF \cdot ED}{PEF \cdot BW \cdot AT} \quad (8)$$

$$ADD_{derm} = \frac{C \cdot SA \cdot SL \cdot ABS \cdot EF \cdot ED}{BW \cdot AT} \cdot CF \quad (9)$$

where ADD_{ing} is daily exposure number of heavy metals and metalloids through ingestion (mg/kg/day), ADD_{inh} is daily exposure number of metals through inhalation (mg/kg/day), and ADD_{derm} is daily exposure number of pollutants through inhalation (mg/kg/day). The exposure factors for these models are shown in Table 13 with reference to the US EPA and environmental site assessment guidelines. The values of these factors include the standards from US EPA and concrete data from this study.

Table 13. **Exposure factors for dose models that were used for this study**

Factor	Definition	Unit	Value (Children)	Value (Adults)	Reference
C	Concentration of an element in soil or water (UCL ²¹ 95%)	mg/kg or mg/l	–	–	This study
R _{ing}	Ingestion rate of soil	mg/day	200	100	US EPA (1989)
IR	Ingestion rate of water	l/day	1	2	US EPA (1989)
EF	Exposure frequency	days/year	180	180	US EPA (2001a)
ED	Exposure duration	years	6	30	US EPA (2001)
BW	Average body weight	kg	15	70	US EPA (1989)
AT	Average time	days	365 × ED	365 × ED	US EPA (1989)
CF	Conversion factor for soil	–	1 × 10 ^{−6}		–
	Conversion factor for water		1 × 10 ^{−3}		
R _{inh}	Inhalation rate	m ³ /day	7.6	20	Zheng et al. (2010)
PEF	Particle emission factor	m ³ /kg	1.36 × 10 ⁹	1.36 × 10 ⁹	US EPA (2001)
SA	Surface area of the skin that contacts the dust and water	cm ²	2800	5700	US EPA (2001)
SL	Skin adherence factor for the dust	mg/cm ²	0.07	0.2	US EPA (2001)
ABS	Dermal absorption factor (chemical specific)	–	0.03 for As, 0.001 for other pollutants		US EPA (2001)
AT	Average time carcinogenic	days	10,950 for non-carcinogenic risk		US EPA (2001)
			25,550 for carcinogenic risk		

²¹ Upper Confidence Level

For water pollutants risk was assessed for two main exposure pathways: *direct ingestion of river water* and *dermal contact during bathing or domestic use*. The average daily dose for ingestion exposure (ADD_{ingH2O}) and dermal exposure ($ADD_{dermH2O}$) was calculated using standard US EPA equations (14) – (15):

$$ADD_{ingH2O} = \frac{c * IR * EF * ED}{BW * AT} \quad (14)$$

$$ADD_{dermH2O} = \frac{c * SA * Kp * ET * EF * ED * CF}{BW * AT} \quad (15)$$

Where Kp (cm/hour) is a dermal permeability coefficient (specific to the chemical)²² and ET is exposure time per event (hours/day) (Table 14).

Table 14. **Exposure time values** (US EPA, 2004)

Scenario	ET (Exposure Time per Day)
Incidental dermal contact (e.g., bathing, domestic use)	1.0 hour/day (default)
Recreational water use (e.g., swimming)	0.33 to 2.0 hours/day
Children playing in shallow water or bathing	0.5–1.5 hours/day

The rest exposure factors for these models are shown in Table 7.

2.6.2.2 Non-Carcinogenic Risk Assessment

After the calculation of ADD, a *hazard quotient (HQ)* based on the non-carcinogenic toxic risk can then be calculated by dividing the daily dose by a particular reference dose (RfD), as in Equation (10):

$$HQ = ADD / RfD \quad (10)$$

Using the reference dose (RfD) as a threshold, it is possible to assess whether exposure to a substance may pose adverse health effects to humans. When the estimated average daily dose (ADD) is lower than the RfD, adverse health effects are not expected to occur (US EPA, 1993). A hazard quotient (HQ) value below 1 indicates no significant risk of adverse health effects, whereas an HQ greater than 1 suggests a potential for adverse health impacts (US EPA, 1986).

The *hazard index (HI)* can then be calculated by adding HQs of a mix of metal elements:

$$HI = \sum_{i=1}^n HQ \quad (11)$$

The hazard index is the sum of individual Hazard Quotients (HQs) and represents the overall non-carcinogenic risk posed by a single pollutant. An HI value less than or equal to 1 ($HI \leq 1$) indicates that there is no significant risk of non-carcinogenic health effects. However, when HI exceeds 1 ($HI > 1$), there

²² U.S. Environmental Protection Agency (EPA). (2004). Risk Assessment Guidance for Superfund (RAGS): Volume I, Part E – Supplemental Guidance for Dermal Risk Assessment (EPA/540/R/99/005). Office of Superfund Remediation and Technology Innovation. <https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part-e>

is a potential for adverse non-carcinogenic effects, with the likelihood of such effects increasing as the HI value rises (US EPA, 2001).

2.6.2.3 Carcinogenic Risk Assessment

Carcinogenic risk assessment estimates the probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen. It typically emphasizes long-term exposure and relies on both toxicological and epidemiological data. In this study, the lifetime average daily dose (LADD) was used to evaluate carcinogenic risk.

According to the classification system developed by the International Agency for Research on Cancer (IARC), heavy metals and metalloids were assessed for their carcinogenic potential. The LADD for the selected metals was calculated using standard equations provided by the U.S. Environmental Protection Agency (US EPA, 1989; 2001; 2001a):

$$LADD = \frac{c*EF}{AT} \times \left(\frac{CR_{child}*ED_{child}}{BW_{child}} + \frac{CR_{adult}*ED_{adult}}{BW_{adult}} \right) \quad (12)$$

where all the variables are the same as in Equations (7) – (9).

The lifetime *carcinogenic risk* (CR) was calculated using:

$$CR = LADD * SF \quad (13)$$

where SF is the corresponding slope factor²³.

Information about carcinogenic risk assessment criteria presented in Table 15.

Table 15. **Carcinogenic risk assessment criteria** (US EPA, 1989)

Risk level	Lifetime risk
High (<i>De Manifestis</i>) - unacceptable for industrial conditions and population. Measures to eliminate or reduce risk are necessary	$>10^{-3}$
Medium - permissible for industrial conditions; dynamic control and in-depth study of sources and potential consequences of harmful effects on the entire population are necessary to address risk management measures	$10^{-3} - 10^{-4}$
Low - acceptable risk (the level at which hygiene standards are usually established for the population)	$10^{-4} - 10^{-6}$
Minimal (<i>De Minimis</i>) - desired (target) level of risk during health and environmental protection measures	$<10^{-6}$

²³ Slope Factor (SF) is defined as an upper-bound estimate of the probability of developing cancer per unit of chemical intake (typically expressed in mg/kg/day) over a lifetime.

2.7 Quality Assurance / Quality Control Plan

Ensuring the integrity and reliability of collected data is essential to the success of this research. The Quality Assurance/Quality Control Plan was developed in line with internationally accepted standards to maintain accuracy, reproducibility, and validity across all stages of the study – from field sampling to laboratory analysis and data interpretation. This chapter outlines the key QA/QC measures applied during site investigations, sampling activities, laboratory testing, and risk assessment procedures.

2.7.1 QA/QC in Field Sampling

All field sampling (soil, surface water, and barren solution) was conducted following consistent protocols outlined in Section 1.4 to reduce variability due to human error or environmental factors. All field instruments (e.g., GPS devices) were calibrated daily using certified standards to ensure accurate and reproducible measurements. To assess sampling precision, at least 10% of soil and water samples were collected in duplicates. Additionally, triplicate samples were obtained at randomly selected sites to evaluate field variability. Each sample was labelled with a unique identifier including location, date, time, and sample type. A strict chain-of-custody protocol was followed to prevent tampering or loss of sample integrity during transport to the laboratory.

2.7.2 QA/QC in Laboratory Testing

All analyses were performed in a certified laboratory, adhering to ISO/IEC 17025 standards for analytical competence. Laboratory protocols followed US EPA-approved methods for heavy metal analysis, leaching tests, and ore dressing agent assessments. Method blanks, procedural blanks, and matrix spikes were included in each batch of laboratory analyses to detect potential contamination and assess accuracy. Laboratory replicates (at least 10%) were analyzed to verify reproducibility. Certified reference materials were used to calibrate instruments and validate analytical procedures for all target analytes. The detection limits for all analytes were documented and compared to relevant regulatory thresholds. Instrumental precision was routinely checked using control samples and recalibration as necessary.

2.7.3 QA/QC in Data Management and Risk Assessment

Raw field and laboratory data were cross-checked for completeness, consistency, and accuracy. Outliers and anomalous values were flagged and investigated. To account for variability in exposure parameters and analytical measurements, sensitivity analyses were incorporated into the risk assessment models. This approach helps quantify the robustness of risk estimates. Risk assessment methodologies (Sections 1.6.1 and 1.6.2) were subjected to internal peer review to ensure scientific rigor. All assumptions, equations, and input parameters were documented to enable reproducibility.

3. LABORATORY ANALYSIS RESULTS

3.1 Water Pollution Assessment Results

3.1.1 Mercury Concentration in Water

It was established that mercury concentrations in water samples did not exceed the reference limits set by the World Health Organization (WHO; 0.006 mg/L) or the U.S. Environmental Protection Agency (EPA; 0.002 mg/L) (Tables 16–18). This observation aligns with the well-documented behaviour of mercury in aquatic systems, where it tends to partition into sediments due to:

- Adsorption to organic matter and clay particles;
- Sedimentation of particulate-bound mercury (Hg^0 or Hg^{2+}).

The results completely correspond with the data obtained by NMA.

Table 16. Statistical characteristics of Hg content (mg/l) in water samples, n=18

Min	Max	Median	Mean
0.0000971	0.00106	0.00030	0.00041

Table 17. Statistical characteristics of Hg content (mg/l) in water relative to WHO reference concentration

Min	Max	Median	Mean
0.004	0.18	0.05	0.07
Reference concentration: 0.006 mg/l ²⁴			

Table 18. Statistical characteristics of Hg content (mg/l) in water relative to EPA reference concentration

Min	Max	Median	Mean
0.012	0.53	0.15	0.21
Reference concentration: 0.002 mg/l ²⁵			

3.1.2 Cyanide Concentrations in Water and Barren Solution

To evaluate potential environmental and human health risks from cyanide exposure, the measured concentrations in water and barren solution samples were compared to U.S. EPA guidelines:

- Aquatic life (chronic exposure): 5.2 $\mu\text{g/L}$ ²⁶
- Water + organism (human consumption of water and aquatic organisms): 4.0 $\mu\text{g/L}$ ²⁷
- Organism only (consumption of aquatic organisms only): 400 $\mu\text{g/L}$ ⁹

²⁴ Source: Preventing disease through healthy environments exposure to mercury: a major public health concern <https://www.who.int/publications/i/item/9789240023567>

²⁵ Source: <https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#one>

²⁶ Source: <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table>

²⁷ Source: <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table>

- Drinking water standard (MCL²⁸): 0.2 µg/L²⁹

The cyanide concentrations detected in water samples were mostly below the reference limits (Table 19).

Table 19. Statistical characteristics of cyanide concentrations in water relative to EPA reference levels

Reference level	Min	Max	Median	Mean
Water life	0.0017	0.052	0.025	0.020
Water + organism	0.0023	0.068	0.033	0.026
Organism only	0.000022	0.00068	0.00033	0.00026
Fresh water	0.045	1.36	0.65	0.52

While all values were within safe limits for environmental and food safety exposure, the drinking water threshold of 0.2 µg/L was exceeded in one sample taken within the Ero Bergi site. This suggests no acute ecological or dietary threat, but potential concern for direct human consumption if untreated surface water is used. These results suggest that cyanide is not widespread in natural water sources, and contamination is likely localized and linked to site-specific discharges.

Cyanide concentrations in barren – liquid residues from ore processing – were considerably higher (Table 20).

Table 20. Cyanide concentrations in barren solution relative to reference levels

Site	Water life	Water + organism	Organism only	Fresh water
Ero Bergi	0.092	0.12	0.0012	2.4
Bohmila	8.097	10.53	0.105	210.54

The Bohmila site exhibited extremely elevated cyanide concentrations in barren solution, greatly exceeding all EPA reference values. This indicates serious risks to aquatic ecosystems, public health, and downstream water quality. At Ero Bergi, cyanide levels also surpassed the safe drinking water limit by more than tenfold, although they remained considerably lower than those at Bohmila. Despite ongoing gold mining activities at this site, cyanide was not consistently present in natural water samples. Most concentrations were well below environmental thresholds, with occasional exceedances of the drinking water safety standard. Barren solution samples, particularly from Bohmila, indicate severe cyanide contamination, with potential environmental and human health implications if untreated effluents reach surface or groundwater systems.

Notably, cyanide forms very strong complexes with mercury. During cyanidation, both elemental mercury (Hg⁰) remaining in tailings and oxidized mercury (Hg²⁺) react with CN⁻ to form soluble complexes – most commonly Hg(CN)₂ (neutral), [Hg(CN)₃]⁻, and [Hg(CN)₄]²⁻. The dominant species depends on free cyanide concentration and pH, with higher CN⁻ levels favouring [Hg(CN)₄]²⁻ (Matlock et al., 2002; Silva da & Guimarães, 2024).

Elemental mercury can be converted in situ under cyanidation conditions. Laboratory and field studies demonstrate that Hg⁰ reacts under aerobic conditions to produce [Hg(CN)₄]²⁻ and related complexes, greatly increasing mercury solubility and mobility (Seney et al., 2020). These Hg–CN complexes facilitate

²⁸ Maximum Contaminant Level (MCL) - The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.

²⁹ Source: <https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#one>

mercury transport in alkaline, high-cyanide leach solutions. However, when solutions move downstream, pH decreases and dilution may destabilize the complexes, releasing Hg^{2+} (bioavailable for methylation) and free CN^- , thereby amplifying ecological and human health risks (Pure Earth, 2023).

2.1.3 Heavy Metal Concentrations in Water and Barren Solution

To assess the environmental and health implications of heavy metal concentrations detected in water and barren solution samples, results were compared with U.S. EPA reference criteria. All heavy metals detected in natural water samples were well below EPA limits for aquatic life, drinking water, and human exposure through water and aquatic organisms (Table 21).

Table 21. Statistical characteristics of heavy metal concentrations in water

Parameter	As mg/l	Cd mg/l	Co mg/l	Cu mg/l	Ni mg/l	Pb mg/l	Sb mg/l	Zn mg/l
Min	0.00005	0.000009	0.00005	0.0005	0.0005	0.00005	0.00001	0.001
Max	0.00100	0.00003	0.04288	0.0151	0.01301	0.00642	0.00015	0.015
Median	0.00013	0.00001	0.0014383	0.0084	0.00364	0.00334	0.00001	0.006
Mean	0.00025	0.000014	0.01296	0.0079	0.00443	0.00372	0.00003	0.007
<i>Reference levels, mg/l</i>								
¹⁾ For water life chronic	150	1.8 (acute)	1.0 ³⁰	-	52	2.5	-	120
²⁾ Water + organism	0.018	-	-	1300	610	-	5.6	7400
²⁾ Organism only	0.14	-	-	0	4600	-	640	26000
³⁾ Fresh water	0.01	0.005	0.11 ³¹	1.3	—	0.01	0.006	—

Source:

¹⁾ - <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table>;

²⁾ - <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table>;

³⁾ - <https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#one>

Lead (Pb) and arsenic (As) levels remained under the drinking water thresholds (0.01 mg/L and 0.01 mg/L, respectively). Cobalt (Co) concentrations were well below established reference values. These levels do not suggest contamination and are not expected to pose ecological or human health risks under current standards.

Copper (Cu) concentrations in barren solution exceeded the freshwater standard of 1.3 mg/L at both Ero Bergi and Bohmila, indicating a risk to drinking water sources or freshwater organisms if the solution is not contained (Table 22).

Table 22. Heavy metal concentrations in barren solution

Site	As mg/l	Cd mg/l	Co mg/l	Cu mg/l	Ni mg/l	Pb mg/l	Sb mg/l	Zn mg/l
Ero Bergi	0.00874	0.00048	2.71	2.75	0.87	0.00138	0.00003	0.00645
Bohmila	0.01587	0.00064	3.59	3.825	1.71	0.04464	0.00075	0.18367

Note: for reference levels see Table 21.

³⁰ B.C. Ministry of Water, Land, and Resource, Stewardship, 2025. Cobalt Water Quality Guidelines – Freshwater Aquatic Life. Water Quality Guideline Series, WQG-26. Prov. B.C., Victoria B.C.

³¹ Toxicological profile of Cobalt <https://chatgpt.com/c/68a0f8e3-afe0-8332-817b-3e7f74b42a97>

Lead (Pb) concentration at Bohmila (0.0447 mg/L) also exceeded the safe limit (0.01 mg/L). Other metals remained below EPA reference thresholds, though Cobalt was high without formal EPA standards for comparison.

Natural water samples show no signs of heavy metal contamination and remain within safe ecological and human health limits. Barren solutions, particularly at Bohmila, show elevated levels of Cu and Pb, which exceed safety thresholds and present potential risks if not properly managed.

The findings reinforce the importance of strict handling and disposal measures for barren solutions and regular monitoring of process water discharges, especially in artisanal gold mining settings.

3.2 Soil Pollution Assessment Results

3.2.1 Mercury Concentration in Soil

The Table 23 shows the extent of mercury (Hg) enrichment in soils across three sites – Bohmila, Kwangoe, and Ero Bergi – expressed as multiples of the natural background level. The background concentration of mercury in Surinamese soils is established at 0.15 mg/kg (Kroonenberg et al., 2022)³².

Table 23. **Statistical characteristics of Hg content (mg/kg) in soil relative to background concentration**

Site	Min	Max	Median	Mean
Bohmila	0.53	0.61	0.55	0.57
Kwangoe	0.19	1.01	0.50	0.55
Ero Bergi	0.30	29.7	1.57	10.17

At Bohmila, soil mercury concentrations are moderately elevated but remain below the background threshold (i.e., <1), indicating no significant contamination. At Kwangoe, although one sample slightly exceeds the background level, the majority fall below or near the baseline, suggesting localized contamination. In contrast, Ero Bergi shows clear evidence of significant contamination, with soil samples far exceeding background levels. The high mean value reflects the presence of extremely elevated concentrations, likely resulting from intensive artisanal and small-scale gold mining activities.

3.2.2 Cyanide Concentrations in Soil

No official EPA or WHO threshold exists for cyanide levels in soil; therefore, Canadian environmental standards³³ were used to assess cyanide concentrations at ASGM sites. These standards set reference limits of 0.9 mg/kg for residential or agricultural soils and 8.0 mg/kg for industrial or commercial soils. Among all soil samples collected, only one sample from Ero Bergi exhibited elevated cyanide (CN⁻) levels, measuring 5.04 mg/kg, which exceeds the residential/agricultural threshold but remains below the industrial limit. All other samples showed CN⁻ concentrations below 0.1 mg/kg, indicating no significant contamination.

³² Source: Kroonenberg S., Wong T., Bijnaar G., Finkie R., Goenopawiro K., Asneel S., Lin-Tsung M., Nanan R., Ramdas K., Sitaram P. (2022) Mercury background values in soils and saprolites in the gold-rich greenstone belt of Suriname, Guiana Shield: The role of parent rock and residual enrichment. Science of the Total Environment, 848, 157631. <https://www.sciencedirect.com/science/article/abs/pii/S0048969722047295?via%3Dihub>

³³ Source: https://support.esdat.net/Environmental%20Standards/canada/soil/rev_soil_summary_tbl_7.0_e.pdf

3.2.3 Heavy Metal Concentrations in Soil

Across all sites, most metal concentrations remained below background thresholds (i.e., values <1.0), indicating no widespread contamination. However, specific patterns of localized enrichment were observed (Table 24).

Table 24. Heavy metal content (mg/kg) in soil relative to background concentration

Site	As	Cd	Co	Cu	Ni	Pb	Sb	Zn
Bohmila	0.47	0.05	2.06	1.28	2.27	0.12	0.16	0.43
Bohmila	0.74	0.05	0.89	1.23	2.70	0.16	0.13	0.59
Bohmila	0.85	0.05	3.05	1.28	2.62	0.10	0.13	0.51
Ero Bergi	0.71	0.05	4.19	2.42	2.30	0.10	0.13	1.07
Ero Bergi	0.70	0.05	3.45	1.20	0.94	0.06	0.06	0.33
Ero Bergi	0.45	0.05	0.36	0.82	1.02	0.01	0.18	0.31
Kwangoe	0.49	0.05	0.15	0.23	0.11	0.35	0.15	0.30
Kwangoe	0.29	0.05	0.23	0.40	0.37	0.64	0.14	0.45
Kwangoe	2.46	0.05	0.59	2.71	3.74	0.07	0.16	0.48
Background	5	0.18	12.5	50	47.5	27.5	2.35	85

At Bohmila, cobalt (Co) and nickel (Ni) exhibited moderate elevation, with Co ranging from 0.89 to 3.05 times the background and Ni exceeding 2.0 times the background in all samples. This suggests moderate anthropogenic impact, likely related to mining activities. Other metals, including arsenic (As), copper (Cu), and zinc (Zn), were slightly elevated (up to ~0.85× background), while cadmium (Cd), lead (Pb), and antimony (Sb) remained consistently low ($\leq 0.16\times$).

Ero Bergi exhibited the highest contamination potential among the sites. Cobalt levels were notably elevated, reaching up to 4.19 times the background level, and copper concentrations exceeded twice the background in some samples. Nickel also showed moderate enrichment (0.94–2.30×), and one zinc measurement slightly surpassed the background level (1.07×). These elevated concentrations suggest significant localized contamination, likely linked to intensive ASGM (artisanal and small-scale gold mining) activities in the area. Nevertheless, arsenic, lead, and antimony levels remained low and well below background thresholds. In contrast, Kwangoe showed generally low contamination, with most metals under 0.5× background levels. However, one sample demonstrated a spike in arsenic (2.46×) and nickel (3.74×), suggesting isolated contamination events or natural geochemical variability.

Overall, cadmium (Cd) was consistently the lowest across all sites, remaining around 0.05 background, indicating no concern. Similarly, lead (Pb) and antimony (Sb) stayed well below 1.0, suggesting limited anthropogenic influence for these elements. These findings indicate that, while no systematic exceedances were found, certain sites – particularly Ero Bergi – exhibit localized enrichment of specific heavy metals, most notably Co, Ni, Cu and Zn, which may warrant further investigation and environmental monitoring.

The concentration of heavy metals in soil samples was also assessed against the Dutch target values³⁴

³⁴ Target Value: The maximum concentration of a pollutant in soil that is considered safe for humans, ecosystems, and sustainable land use. It's a goal to aim for during remediation or monitoring. If levels are below the target, no action is usually required. Soil is considered clean or unpolluted.

for soil quality, as outlined in the report by Tamis and Karman (2008)³⁵ (Table 25).

Table 25. Heavy metal content (mg/kg) in soil in relative to Nederland standard (target value)

Site	As	Cd	Co	Cu	Ni	Pb	Sb	Zn
Bohmila	0.08	0.01	2.87	1.78	3.09	0.04	0.13	0.26
Bohmila	0.13	0.01	1.23	1.71	3.66	0.05	0.10	0.36
Bohmila	0.15	0.01	4.24	1.78	3.56	0.03	0.11	0.31
Ero Bergi	0.12	0.01	5.81	3.36	3.12	0.03	0.10	0.65
Ero Bergi	0.12	0.01	4.80	1.67	1.28	0.02	0.05	0.20
Ero Bergi	0.08	0.01	0.51	1.14	1.39	0.00	0.14	0.19
Kwangoe	0.08	0.01	0.21	0.32	0.15	0.11	0.11	0.18
Kwangoe	0.05	0.01	0.32	0.56	0.50	0.21	0.11	0.27
Kwangoe	0.42	0.01	0.82	3.77	5.08	0.02	0.12	0.29
Target value	29	0.8	9	36	35	85	3	140

At Ero Bergi, cobalt again showed significant enrichment, particularly in one sample reaching 5.81× the target value. Copper was also elevated (up to 3.36×), and nickel levels ranged from 1.28 to 3.12×. These values point to moderate to high contamination, especially for cobalt. However, other elements such as arsenic, lead, and antimony remained below or near target values.

At Kwangoe, most metals were within safe limits, except for one sample showing elevated copper (3.77×) and nickel (5.08×), indicating isolated contamination. The rest of the samples displayed low proportions for all metals, with cobalt, arsenic, and lead far below threshold levels. Overall, cobalt, nickel, and copper were the primary contaminants across all sites, particularly at Ero Bergi and Bohmila, where exceedances were most pronounced. The spatial distribution suggests contamination likely associated with mining-related activities, especially in zones with historical or active ASGM operations.

In ASGM areas of Suriname's tropical forests, elevated concentrations of Cu, Zn, Ni, and Co in soil result from a combination of natural metal-rich geology, poorly controlled mining practices, waste dumping, and enhanced mobilization due to acidic or complexing conditions. These factors act together to raise metal levels well above both global reference standards and local pre-mining background levels.

3.3 Chemical Composition of Jinchan Lixiviant

3.3.1 Chemical Profile

The Jinchan gold lixiviant is characterized by an overwhelmingly sodium-rich composition (42%) and trace molybdenum (≈48 ppm), indicating a sodium – molybdate-based chemical structure consistent with the Jinchan reagent's known formulation.

The absence of arsenic, and major heavy metals, combined with only trace levels of mercury, lead, and cadmium, confirms that the lixiviant is chemically clean and non-toxic within analytical detection limits. Minor elements such as boron, manganese, nickel, and vanadium occur at low concentrations, likely derived from mineral contact or stabilizing additives (Table 26).

³⁵ Source: Tamis, J. E., & Karman, C. C. (2008). Soil and groundwater quality standards (Report No. CO11/08). Wageningen IMARES. <chrome-extension://mhjfbmdgcfjbbpaeojofohoefgiehjai/index.html>

Table 26. **Chemical profile of Jinchan lixiviant**

Category	Elements	Key Findings
Major Constituents	Na (42.14%), Fe (0.097%), Al (0.006%)	Sodium dominates – confirms the lixiviant’s strongly alkaline, salt-based nature. Other major elements minimal.
Minor/Trace Metals	Mn (13.65 ppm), Mo (47.61 ppm), Ni (21.21 ppm), Co (0.75 ppm), Cu (0.62 ppm), V (2.31 ppm), Sr (1.25 ppm)	All present at low levels. Mo, Mn, and Ni are slightly enriched – typical of reagent or process contact.
Toxic or Regulated Elements	Hg (0.034 ppm), Pb (1.69 ppm), Tl (0.80 ppm), As (<0.1 ppm), Cd (0.06 ppm), Sb (0.05 ppm)	All very low – far below hazardous waste thresholds. Hg presence still notable but minor.
Non-metals/Light Elements	B (29.11 ppm), Se (1.00 ppm), P (<0.005%)	B likely part of chemical structure; Se within normal trace levels.
Undetected (Below Quant. Limit)	Cr, Ba, Be, Mg, Sn, U, Sc	Confirms low background contamination and analytical cleanliness.

3.3.2 Ionic and cyanide composition

Jinchan lixiviant was analyzed to determine its principal ionic composition, cyanide speciation, and pH characteristics. The results (Table 27) indicate that the Jinchan lixiviant is a highly alkaline (pH = 12.0) and strongly saline solution, overwhelmingly dominated by chloride ions (271.44 g kg⁻¹). Such high salinity reflects the reagent’s formulation, which uses chloride-based stabilizers and sodium salts to maintain a controlled oxidative potential for gold dissolution.

Table 27. **Ionic and cyanide composition of Jinchan lixiviant**

Parameter	Unit	Quant. Limit	Result	Interpretation
Br	mg kg ⁻¹	5.00	< 5.00	Below detection limit
Cl	g kg ⁻¹	0.005	271.44	Dominant anion; highly saline solution
F	mg kg ⁻¹	0.50	1.86	Trace fluoride present
NO ₃	g kg ⁻¹	0.0001	2.23	Oxidizing nitrogen species
NO ₂	g kg ⁻¹	0.0001	5.13	Indicates redox-active medium
PO ₄	mg kg ⁻¹	0.10	< 0.10	Below detection limit
SO ₄	mg kg ⁻¹	5.00	569.00	Moderate sulphate concentration
CNT (Total cyanide)	mg kg ⁻¹	0.10	9333.44	High total cyanide load (≈ 0.93 %)
CNF (Free cyanide)	mg kg ⁻¹	0.10	6.50	Very low free cyanide; most CN complexed
pH	–	–	12.00	Strongly basic solution

Minor constituents include fluoride (1.86 mg kg⁻¹) and sulphate (569 mg kg⁻¹), while phosphate and bromide were below detection limits. The notable presence of nitrate (2.23 g kg⁻¹) and nitrite (5.13 g kg⁻¹) confirms the oxidizing – reducing (redox-active) character of the medium, consistent with the thiourea – nitrate chemistry typical of Jinchan-type lixiviants. These nitrogen oxides likely serve as catalytic oxidants in the gold complexation process.

Cyanide measurements are particularly important for environmental and occupational safety. The total cyanide concentration reached 9333.44 mg kg⁻¹ ($\approx$ 0.93 %), while free cyanide was only 6.50 mg kg⁻¹. This indicates that nearly all cyanide is chemically bound in complex or organocyanide forms rather than present as unbound CN⁻ ions. Under highly alkaline conditions, these complexes remain relatively stable and non-volatile; however, acidic or oxidative conditions could induce decomposition and release of toxic free cyanide.

Although free cyanide levels are low, the total cyanide burden remains substantial, warranting classification of Jinchan as a cyanide-bearing reagent. Safe management requires maintaining alkalinity above pH 11.5, preventing acid contact, and following standard cyanide management procedures.

Overall, the chemical profile demonstrates that Jinchan is a chloride – nitrate lixiviant containing complexed cyanide species. While its formulation reduces acute cyanide toxicity compared to conventional cyanide leach solutions, it still presents significant environmental risks under improper handling or disposal conditions.

3.3.3 Implications for Environmental Governance and Policy

The compositional results substantiate the need for regulatory oversight and technical safeguards in Suriname’s artisanal and small-scale gold mining sector. Despite being marketed as an “environmentally friendly” reagent, Jinchan contains high levels of total cyanide and reactive nitrogen species that can degrade under field conditions to form toxic by-products.

In the context of Suriname’s fragile riverine ecosystems and limited waste treatment infrastructure, the use of such reagent – particularly in informal or uncontrolled ASGM operations, typical for Suriname – poses a credible environmental and public health risk. These findings support the recommendation outlined in the National Code for the Management of Alternative Lixivants in Gold Mining (see Chapter 10), which advocates for:

- Prohibiting the use of Jinchan and similar reagents in artisanal tailings reprocessing or open leaching operations;
- Requiring centralized and licensed processing facilities for any experimental or pilot-scale applications;
- Establishing analytical monitoring protocols for total and free cyanide in effluents and residues.

Accordingly, the chemical analysis of Jinchan reinforces the conclusion that this lixiviant is not suitable for deployment within Suriname’s ASGM context and that its regulation should be explicitly integrated into national chemical management and mining policies.

3.4 Relationship Between Mining Practices and Environmental Contamination at ASGM Sites

Understanding the relationship between the duration and type of mining activity and the presence of contaminants is essential for assessing environmental risks and guiding mitigation strategies. Table 28 summarizes the data on the different types of contamination at ASGM sites with varying durations of mining activity. Notably, the contaminant patterns clearly reflect operational history, chemical usage, and the duration of activities.

At the Bohmila site, despite a relatively short-duration leaching operation (~6 months), the long-standing hammer mill–sluice box activity correlates with persistent heavy metals in soil and barren solutions.

Cyanide presence in the barren solution reflects chemical handling during recent leaching, but the limited duration has prevented widespread contamination in water or soil.

At Ero Bergie, longer-term and intermittent operations have led to cumulative contamination. Soil Hg reflects past mercury use, while the presence of CN⁻ and heavy metals across multiple media suggests both ongoing and residual impacts. The duration and intermittency of operations likely exacerbate contamination, particularly in soil.

Table 28. Summary of contaminant assessment at ASGM sites

Site	Duration of Activity	Contaminants							
		Hg in water	CN ⁻ in water	CN ⁻ in barren solution	Heavy metals in water	Heavy metals in barren solution	Hg in soil	CN ⁻ in soil	Heavy metals in soil
Bohmila	The leaching operation has been ongoing for about 6 months, whereas the hammer mill – sluice box operation has been in use for over 10 years.	No	No	Yes	No	Yes (As, Co, Cu, Pb, Sb)	No	No	Yes (Co, Cu, Ni)
Ero Bergie	The leaching operations have been ongoing intermittently over an extended period, with phases of inactivity followed by resumption. The hammer mill – sluice box operation has been active for more than 10 years.	No	Yes	No	No	Yes (Co, Cu)	Yes	Yes	Yes (Cu, Co, Ni, Zn)
Kwangoe	The leaching operation are applying for more than 6 years. The hammer mill – sluice box operation has been active for more than 10 years.	No	No	No	No	No	No	No	Yes (As, Cu, Ni)

At the Kwangoe site, long-term leaching without detectable Hg or CN⁻ suggests that chemical use was limited. However, heavy metals persist due to prolonged ore processing, highlighting cumulative impacts from non-mercury and non-cyanide sources, such as natural ore content or residual processing materials.

Overall, sites with longer mining activity (hammer mill–sluice box >10 years) consistently show heavy metal contamination in soil and barren solutions. Short-term leaching operations, such as at Bohmila, primarily affect barren solutions with limited environmental dispersion. Intermittent and long-duration leaching operations, such as at Ero Bergie, show contamination across multiple media – including water, soil, and barren solutions – with Hg and CN⁻ present. Hammer mill–sluice box operations contribute to heavy metal accumulation regardless of cyanide or mercury usage, whereas cyanide and Hg contamination are more dependent on chemical application during leaching.

4. RISK ASSESSMENT

4.1 Ecological Risk Assessment

The **geo-accumulation index (I_{geo})** results (Table 29) show that the degree of soil contamination by heavy metals differs across the various sites.

Table 29. The geo-accumulation index (I_{geo}) values

Site	As	Cd	Co	Cu	Ni	Pb	Sb	Zn	Hg
Bohmila	-1.671	-4.907	0.460	-0.230	0.600	-3.610	-3.187	-1.807	-1.454
Bohmila	-1.010	-4.907	-0.755	-0.286	0.848	-3.238	-3.559	-1.335	-1.297
Bohmila	-0.812	-4.907	1.025	-0.228	0.807	-3.856	-3.480	-1.555	-1.482
Ero Bergi	-1.073	-4.907	1.481	0.688	0.618	-3.918	-3.531	-0.486	-1.574
Ero Bergi	-1.097	-4.907	1.203	-0.320	-0.668	-4.720	-4.564	-2.198	-2.953
Ero Bergi	-1.730	-4.907	-2.042	-0.876	-0.553	-6.970	-3.029	-2.294	-0.648
Kwangoe	-1.611	-4.907	-3.345	-2.686	-3.752	-2.096	-3.361	-2.338	0.065
Kwangoe	-2.357	-4.907	-2.691	-1.901	-2.027	-1.235	-3.421	-1.749	4.255
Kwangoe	0.713	-4.907	-1.345	0.856	1.320	-4.336	-3.272	-1.655	-2.291

In Bohmila, most I_{geo} values for trace elements are negative, which generally indicates no significant accumulation and suggests that the soil is uncontaminated or uncontaminated to moderately contaminated for those metals. However, Co and Ni show some positive values (up to about 1.025 for Co and 0.848 for Ni), indicating a low to moderate accumulation of these elements in certain samples. Other elements like Cd, Pb, Sb, Zn, and Hg consistently show strongly negative values, pointing to minimal contamination or background levels.

Ero Bergi shows a similar pattern with predominantly negative I_{geo} values for most metals, particularly Cd, Pb, Sb, Zn, and Hg, which are well below zero, suggesting low contamination. Notably, Co exhibits positive values up to 1.481, indicating some moderate accumulation. Cu and Ni show mixed results with both negative and slightly positive values, pointing to variable contamination levels across samples. The very negative Pb values (down to nearly -7) suggest negligible lead contamination in the samples analyzed.

Kwangoe generally exhibits negative I_{geo} values for most metals, indicating low contamination. Exceptions include one positive value for As (0.713), Cu (0.856), Ni (1.320), and Hg (4.255), suggesting localized accumulation of these elements in specific samples. The extremely high positive value for Hg is particularly concerning, indicating heavy contamination or enrichment at that sampling point. Overall, most other metals such as Cd, Co, Pb, Sb, and Zn show low accumulation with negative values.

In summary, while most metals show low geo-accumulation across the study areas, some elements like Co, Ni, Cu, As and particularly Hg in Kwangoe, indicate localized low to moderate contamination. The elevated Hg in Kwangoe is a clear signal of potential heavy contamination needing further investigation. Bohmila and Ero Bergi generally appear less contaminated but still exhibit some accumulation of Co and Ni.

Based on the classification of **potential ecological risk index (E^i_r)** degrees (Table 30), most elements across all samples fall into the low-risk category ($E^i_r < 40$).

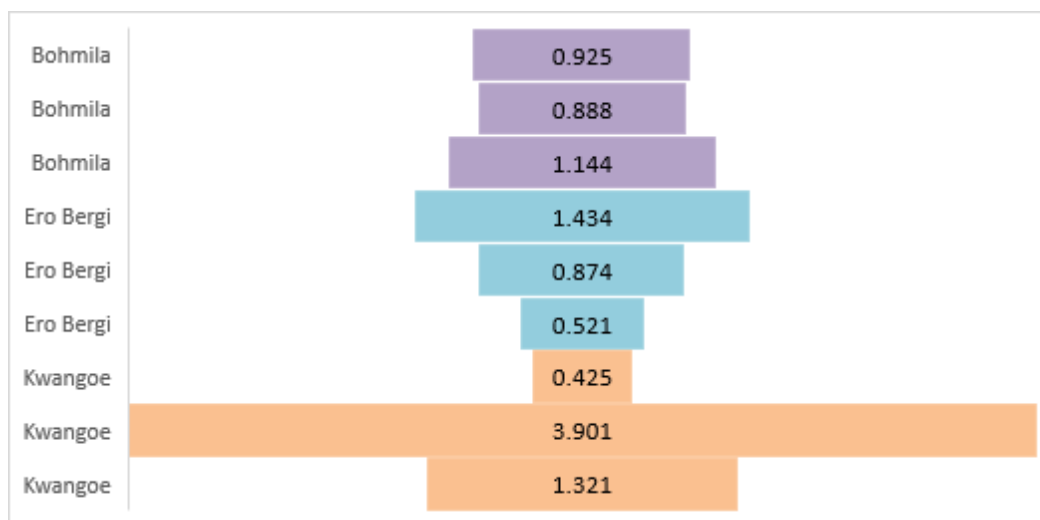
Table 30. The potential ecological risk index (E_i^r) degrees

Site	As	Cd	Co	Cu	Ni	Pb	Sb	Zn	Hg
Bohmila	4.71	1.50	10.32	6.40	11.37	0.61	1.65	0.43	21.91
Bohmila	7.45	1.50	4.44	6.15	13.50	0.80	1.27	0.59	24.41
Bohmila	8.54	1.50	15.27	6.40	13.12	0.52	1.34	0.51	21.49
Ero Bergi	7.13	1.50	20.93	12.08	11.51	0.50	1.30	1.07	20.15
Ero Bergi	7.01	1.50	17.26	6.01	4.72	0.28	0.63	0.33	7.75
Ero Bergi	4.52	1.50	1.82	4.09	5.11	0.06	1.84	0.31	38.29
Kwangoe	4.91	1.50	0.74	1.17	0.56	1.75	1.46	0.30	62.79
Kwangoe	2.93	1.50	1.16	2.01	1.84	3.19	1.40	0.45	1145.67
Kwangoe	24.60	1.50	2.95	13.57	18.72	0.37	1.55	0.48	12.26

For Bohmila, most E_i^r values for metals like As (4.71–8.54), Cd (1.50), Co (4.44–15.27), Cu (6.15–6.40), Ni (11.37–13.50), Pb (0.52–0.80), Sb (1.27–1.65), Zn (0.43–0.59), and Hg (21.49–24.41) all fall below 40, indicating a *low ecological risk* for these metals. Hg has the highest values but still remains in the low-risk category. In Ero Bergi, E_i^r values for As (4.52–7.13), Cd (1.50), Co (1.82–20.93), Cu (4.09–12.08), Ni (4.72–11.51), Pb (0.06–0.50), Sb (0.63–1.84), Zn (0.31–1.07), and Hg (7.75–38.29) mostly fall under the *low ecological risk category* as well. The highest Hg value (38.29) approaches the upper limit of low risk but does not exceed it. For Kwangoe, most metals show low risk levels (As 2.93–24.60, Cd 1.50, Co 0.74–2.95, Cu 1.17–13.57, Ni 0.56–18.72, Pb 0.37–3.19, Sb 1.40–1.55, Zn 0.30–0.48). However, Hg shows extremely high variation with values ranging from 12.26 to 1145.67. The values 12.26 and 62.79 correspond to low and moderate risk respectively, but 1145.67 far exceeds the threshold for very high risk (>320), indicating a severe ecological risk at this site due to mercury contamination.

In summary, most trace metals in all sites pose a low potential ecological risk based on their E_{ir} values. The only exception is mercury at Kwangoe, where one sample indicates a *very high ecological risk*, requiring urgent attention and remediation. Other metals, including arsenic, cobalt, and nickel, show varying but generally low ecological risks across the sites.

All **modified degree of contamination (mC_d)** values for Bohmila and Ero Bergi are below 1.5, indicating that soils at all sampling locations are classified as unpolluted (Figure 12).

Figure 12. Modified degree of contamination (mC_d) values

For Kwangoe, mC_d values are 0.42, 3.90, and 1.32. The first and third values are below 1.5, indicating unpolluted soil. However, the second value, 3.90, falls within the range of 2 to 4, which classifies it as moderately polluted soil.

In summary, most samples from Bohmila and Ero Bergi show unpolluted soils, while Kwangoe mostly has unpolluted soil except for one sample indicating moderate pollution. This suggests localized pollution in Kwangoe that may need further investigation.

The **Nemerov comprehensive index (P_i)** provides an integrated measure of overall pollution pressure at a given location by combining both the average and the highest contamination levels of multiple trace elements. It is calculated using the modified contamination degree (mC_d) and the maximum contamination factor (C_{fmax}). This approach ensures that the index reflects not only the general contamination status but also accounts for extreme pollutant concentrations that may pose elevated environmental risks. By incorporating both mean and peak contamination metrics, P_i offers a more balanced and realistic assessment of ecological stress, making it particularly suitable for evaluating spatial variations in soil quality and for identifying sites where high localized contamination may be masked by lower average levels (Table 31).

Table 31. The Nemerov comprehensive index (P_i) values

Site	Nemerov index	Contamination level
Bohmila	1.74	Moderately contaminated
Bohmila	2.01	Moderately contaminated
Bohmila	2.02	Moderately to heavily contaminated
Ero Bergi	3.13	Heavily contaminated
Ero Bergi	2.52	Moderately to heavily contaminated
Ero Bergi	0.81	Slightly contaminated
Kwangoe	1.15	Slightly contaminated
Kwangoe	20.44	Extremely contaminated
Kwangoe	2.81	Moderately to heavily contaminated

Bohmila shows P_i values ranging from 1.74 to 2.02. Two values (1.74 and 2.01) fall into the moderately contaminated category, while one value (2.02) borders the moderately to heavily contaminated level. This indicates Bohmila generally experiences *moderate pollution pressure* with some areas approaching higher contamination.

Ero Bergi's P_i values vary more widely, from 0.81 up to 3.13. One value (0.81) falls within the slightly contaminated category, indicating low pollution at that point. Two other values are higher: 2.52 classified as moderately to heavily contaminated, and 3.13 as heavily contaminated, showing significant variation and indicating some areas with substantial contamination.

Kwangoe's P_i values range from 1.15 to a very high 20.44. The lower value (1.15) corresponds to slightly contaminated soil, and 2.81 falls into the moderately to heavily contaminated category. However, regarding Kwangoe, it should be taken into account that the soil samples were selected outside the areas with high potential pollution. The extremely high value of 20.44 places that site in the *extremely contaminated category*, signalling a critical pollution hotspot requiring urgent attention.

The **potential ecological risk index (RI)** is a commonly used measure to assess the combined ecological risk posed by multiple heavy metals in environmental samples (Table 32).

Table 32. The potential ecological risk index (RI) values

Site	RI index	Contamination level
Bohmila	59	Low ecological risk
Bohmila	60	Low ecological risk
Bohmila	69	Low ecological risk
Ero Bergi	76	Low ecological risk
Ero Bergi	45	Low ecological risk
Ero Bergi	58	Low ecological risk
Kwangoe	75	Low ecological risk
Kwangoe	1160	High ecological risk
Kwangoe	76	Low ecological risk

For Bohmila, RI values are 58.89, 60.11, and 68.69. All are below 170, indicating a low ecological risk for this site. In Ero Bergi, RI values range from 45.50 to 76.17, also all below 170. This means Ero Bergi similarly experiences a low ecological risk. For Kwangoe, two RI values (75.17 and 76.01) fall below 170, indicating low ecological risk in those locations. However, one value is exceptionally high at 1160.14, which places it within the high ecological risk category (between 680 and 1360). This indicates a significant ecological threat in that specific area of Kwangoe.

In summary, Bohmila and Ero Bergi sites show low ecological risk overall. Kwangoe mostly shows low risk except for one location exhibiting high ecological risk, which requires urgent attention to prevent environmental harm.

In conclusion, the ecological risk assessment reveals notable spatial variability in heavy metal contamination across the three study sites. The geo-accumulation index (I_{geo}) results indicate that most soils in Bohmila and Ero Bergi are uncontaminated or show only low to moderate accumulation of certain metals such as Co and Ni. Kwangoe generally exhibits low contamination levels except for localized enrichment, particularly for mercury, where elevated values suggest heavy contamination in specific areas requiring further investigation.

The potential ecological risk index (E_{ir}) confirms that the majority of metals across all sites pose a low ecological risk, with the exception of mercury at Kwangoe, which reaches very high-risk levels in one sample, highlighting a critical environmental concern. Modified degree of contamination (mC_d) values further supports these findings, with Bohmila and Ero Bergi soils classified as unpolluted, while Kwangoe shows mostly unpolluted conditions except for one moderately polluted sample.

The Nemerow comprehensive index (P_i) provides an integrated measure of overall pollution pressure, reflecting moderate contamination in Bohmila, a wider contamination range in Ero Bergi, and generally low contamination in Kwangoe except for an extreme pollution hotspot. The potential ecological risk index (RI) largely indicates low ecological risk for Bohmila and Ero Bergi, whereas Kwangoe contains one site with a high ecological risk, underscoring the need for urgent attention and remediation efforts.

Overall, these assessments suggest that while Bohmila and Ero Bergi currently face relatively low ecological risks from heavy metals, Kwangoe presents localized but significant contamination issues, especially with mercury, which should be prioritized in future monitoring and management plans to protect environmental and public health.

4.2 Health Risk Assessment

4.2.1 Soil Pollution Health Risk Assessment

The hazard quotient analysis shows that ingestion is the dominant exposure pathway, with the highest values peaking at 0.0600. This suggests that accidental soil ingestion is the most significant route of exposure. Dermal contact presents a moderate but consistent risk, with values clustered between 0.0155 and 0.0158, indicating lower but notable concern for skin absorption. Inhalation of soil particles contributes the least, with values between 0.0001 and 0.0110, and therefore poses minimal non-carcinogenic threat (Figure 13).

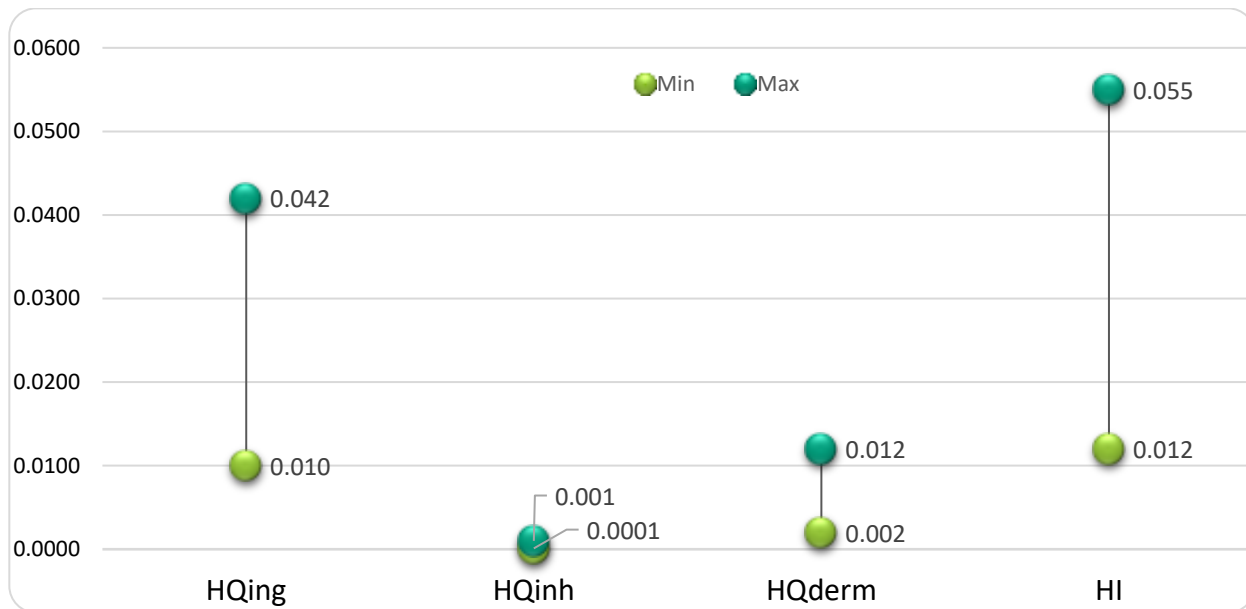


Figure 13. **Non-carcinogenic soil pollution risk**

(HQ_{ing} – ingestion hazard quotient; HQ_{inh} – inhalation hazard quotient; HQ_{derm} – dermal hazard quotient; HI – hazard index)

The hazard index, calculated as the sum of ingestion, dermal, and inhalation quotients, remains well below the EPA threshold of 1.0. The maximum observed value, approximately 0.0868, indicates that there is no significant health risk under current conditions. In terms of contribution, soil ingestion accounts for about 70 percent of the overall risk, dermal exposure contributes around 18 percent, and inhalation adds less than 2 percent, making it nearly negligible.

Overall, the results point to a low non-carcinogenic risk profile, with no immediate need for remediation. However, despite the low non-carcinogenic risk values observed for soil exposure, it is important to recognize that soil pollution is not the sole source of health risk for local residents in ASGM areas. Communities are simultaneously exposed to contaminated surface water and groundwater, mercury vapor released during amalgamation, chemical residues from lixiviants such as cyanide or sodium isocyanate, and heavy metal bioaccumulation through fish and crops. While soil pollution alone does not currently exceed health thresholds, it contributes to the broader cumulative risk profile when combined with these other exposure pathways. Therefore, its role should not be underestimated in evaluating

long-term health impacts and designing integrated risk management strategies.

The cancer risk assessment indicates that arsenic in soil poses the most significant concern, with ingestion values slightly above the acceptable threshold of 1×10^{-6} , suggesting a potential carcinogenic risk for exposed populations (Table 33).

Table 33. Carcinogenic risks for metal elements in soil collected from ASGM sites

Risk type	As	Cd	Pb	Ni	Co
CR _{ing}	5.18×10^{-6}	5.17×10^{-7}	3.63×10^{-8}	–	–
CR _{inh}	1.03×10^{-12}	–	–	3.70×10^{-10}	1.80×10^{-11}

Cadmium through ingestion presents a moderate but still sub-threshold risk, while lead contributes negligibly. Inhalation risks for arsenic, nickel, and cobalt are extremely low and unlikely to have meaningful health impacts. Overall, the results show that carcinogenic risk from soil exposure at ASGM sites is relatively low, but arsenic ingestion stands out as the primary pathway of concern. These findings underline the importance of continuous monitoring and considering soil exposure as part of the broader cumulative risk faced by local communities, who are also subject to additional environmental pressures from mercury emissions, contaminated water, and food chain accumulation.

4.2.2 Water Pollution Health Risk Assessment

Water pollution risk in artisanal and small-scale gold mining (ASGM) areas of Suriname was assessed for two main exposure pathways: (1) direct ingestion of river water and (2) dermal contact during bathing or domestic use. These pathways represent the most relevant exposure routes for local communities living in close proximity to mining sites, where untreated surface water is often used for drinking and daily household activities.

The hazard index (HI) was used to evaluate non-carcinogenic health risks. HI values were calculated separately for ingestion (HI_{ingestion}) and dermal exposure (HI_{dermal}), and then summed to estimate the total water pathway hazard index (HI_{water pathway}). An HI above the U.S. Environmental Protection Agency (EPA) threshold of 1.0 indicates potential health concerns. The calculated HI values for heavy metals, mercury, and cyanides in river water at the three studied sites (Bohmila, Ero Bergi, Kwangoe) are presented in Table 34.

Table 34. Non-carcinogenic water pollution risk

Site	HI _{ingestion}	HI _{dermal}	HI _{water pathway}
Bohmila	14.9–15.1	0.75–2.59	15.65–17.69
Ero Bergi	1.84–28.7	0.24–2.94	2.08–31.64
Kwangoe	1.21–14.5	0.20–0.51	1.41–15.01

Across all sites, water ingestion is the dominant exposure pathway driving elevated HI values, while dermal exposure provides a smaller but non-negligible contribution. Bohmila and Ero Bergi clearly exceed health-based safety thresholds, with Ero Bergi showing the highest variability and potential peak risks. Kwangoe demonstrates lower but still significant risk levels, particularly from ingestion.

The majority (97.4%) of the water pollution non-carcinogenic health risk is attributable to three

pollutants: cyanides (91%), lead (4.5%), and mercury (2%) (Figure 14).

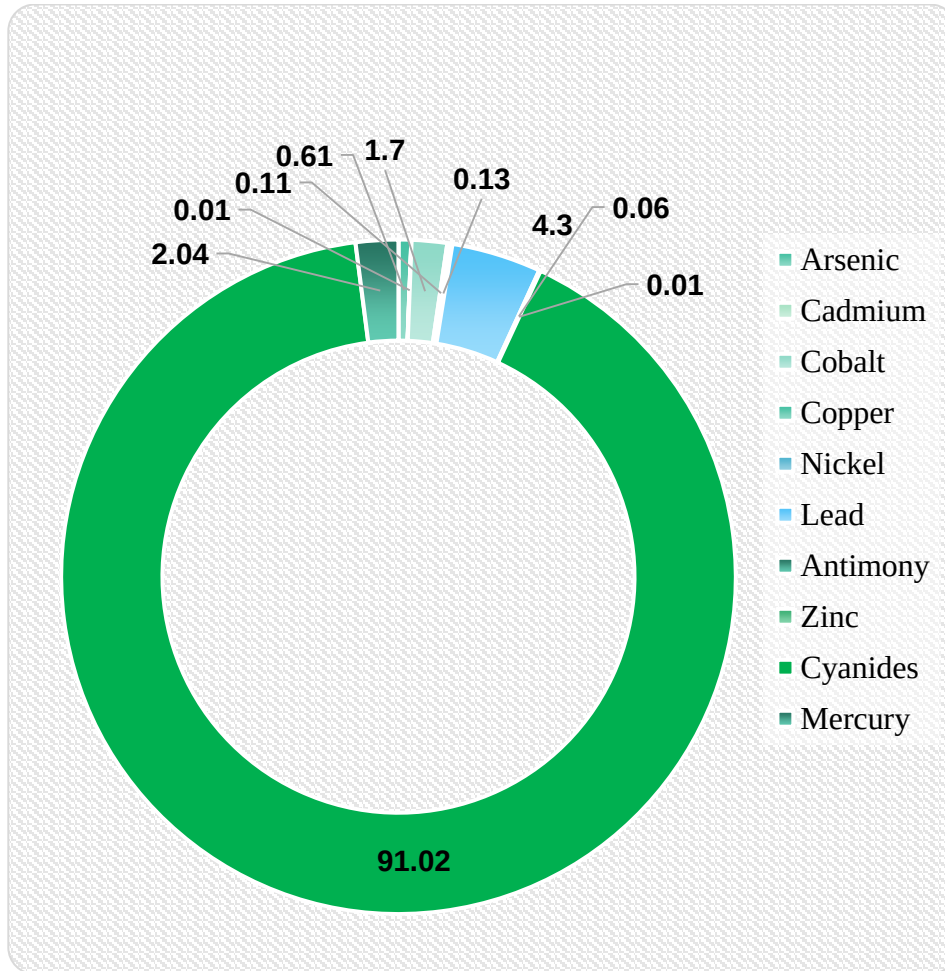


Figure 14. **Contribution of water pollutants to the non-carcinogenic health risk, %**

Cyanides overwhelming contribution indicates severe health implications. In non-cancer risk assessment (HI), the “critical effect” usually relates to thyroid and nervous system impacts, since those are the endpoints used to derive the oral reference dose for cyanide (0.0006 mg/kg/day).

For cyanides, the most sensitive target organs and systems (based on toxicological and clinical evidence) are:

- Central nervous system (CNS) → headache, dizziness, confusion, convulsions (cyanide interferes with cellular respiration in neurons).
- Cardiovascular system → arrhythmias, low blood pressure, cardiac arrest in acute cases.
- Respiratory system → rapid breathing, respiratory failure (due to tissue hypoxia).
- Thyroid gland → chronic low-level exposure can affect iodine uptake and thyroid hormone balance (especially from dietary cyanogenic glycosides).
- Liver and kidney → secondary damage due to detoxification processes and metabolic stress.

4.3 Overall Risk Assessment of Jinchan Use in ASGM

A review of available technical documentation, Safety Data Sheets (SDS), published case studies, and field observations indicates that the use of Jinchan is associated with several health, environmental, and operational risks. These risks, as well as the necessary conditions for their management, are summarized below to support a balanced regulatory assessment by the NMA.

1. Health Risks

- Potential chronic health effects associated with repeated or long-term exposure.
- Elevated health risks from water-related exposure, particularly through ingestion and dermal contact.
- Potential adverse effects on the central nervous, cardiovascular, respiratory, and thyroid systems, which may result in acute and/or chronic health outcomes.

2. Environmental risks

- Contamination of surface water and groundwater resulting from leakage, spills, or improper disposal of leach solutions and residues.
- Toxic effects on aquatic organisms in the event of uncontrolled discharge.
- Persistence of toxic compounds in tailings if residues are not adequately detoxified or neutralized.

3. Process and waste management risks

- Generation of hazardous leach residues requiring controlled handling, treatment, and storage.
- Risk of secondary pollution during tailings transport, heap dismantling, or residue reprocessing.
- Limited data on long-term behaviour of residues under tropical climatic conditions.

4. Operational and institutional risks

- Misuse or overuse due to inadequate understanding of chemical properties and process controls.
- Absence of standardized operating procedures and emergency response plans.
- Weak monitoring, inspection, and enforcement capacity in remote ASGM areas.

Necessary Conditions for Risk Management

If the use of Jinchan is to be considered for conditional authorization rather than prohibition, the following minimum conditions would be required:

- Mandatory training and certification of miners and operators in chemical handling, process control, waste management, and emergency response.
- Implementation of closed or well-contained leaching systems to prevent environmental releases.
- Mandatory neutralization, detoxification, and controlled disposal or storage of all leach residues and effluents.
- Development and enforcement of standard operating procedures, monitoring protocols, and incident reporting requirements.
- Regular oversight by competent authorities, including periodic site inspections and environmental monitoring.

In the absence of these conditions, the use of Jinchan presents significant and potentially unacceptable environmental and health risks in the ASGM context. The NMA may therefore consider either prohibition or strictly controlled, conditional use, based on the feasibility of enforcing the above requirements within Suriname's institutional and operational context.

5. STAKEHOLDER MAPPING

ASGM in Suriname is a complex and multi-stakeholder sector, involving diverse actors with varying levels of influence, interest, and engagement. Effective stakeholder mapping is essential to understanding power dynamics, fostering collaboration, and ensuring sustainable and inclusive mining practices. This chapter presents a comprehensive analysis of ASGM stakeholders in Suriname through three key frameworks:

- Power-Interest Stakeholder Analysis;
- Stakeholder Level of Engagement (RACI Matrix);
- Stakeholder Interconnection Analysis (Onion Diagram).

5.1 Rationale for Stakeholder Mapping

The ASGM sector in Suriname is characterized by fragmented governance, environmental challenges, and socio-economic disparities. Stakeholders range from high-power government agencies and international financiers to marginalized indigenous communities and informal miners. Mapping these stakeholders helps identify:

- Key decision-makers who shape policies and regulations.
- Influential but disengaged actors who may pose risks if not properly managed.
- Highly affected but low-power groups whose voices are often excluded from decision-making.
- Interconnections and gaps in collaboration that hinder sustainable development.

5.2 Methodological Approach

To identify and analyze key stakeholders, assess their interests and influence, and initiate meaningful engagement to foster collaboration and support for successful project implementation three different tools were used:

1. Power-Interest Matrix: Identifies stakeholders based on their ability to influence outcomes (power) and level of engagement (interest). This categorization informs engagement strategies – prioritizing active collaboration with high-power, high-interest actors (e.g., government ministries, international organizations) while monitoring those with low interest but high influence (e.g., banks, tax authorities).
2. RACI Matrix (Responsible, Accountable, Consulted, Informed): Clarifies stakeholder roles in critical ASGM processes, such as permitting, environmental compliance, and community development. The analysis reveals gaps in accountability, particularly in mercury pollution management and indigenous representation.
3. Stakeholder Onion Diagram: Visualizes stakeholder interconnections, highlighting strong internal ties among miners and trader but weak linkages with regulators and affected communities. The diagram also exposes institutional silos, such as misaligned priorities between revenue-focused agencies (Ministry of Natural Resources) and environmental regulators (National Environmental Authority).

5.3 Power-Interest Stakeholder Analysis

To systematically assess stakeholder influence and engagement in Suriname's artisanal and small-scale gold mining sector, a Power-Interest Matrix was employed (Figure 15). This analytical tool classifies stakeholders along two key dimensions:

- Power – The stakeholder's ability to influence policies, regulations, or operational outcomes in ASGM.
- Interest – The degree of attention and involvement the stakeholder has in ASGM-related issues.

This approach not only clarifies stakeholder dynamics but also informs strategic decision-making, ensuring that engagement efforts prioritize those with the greatest capacity to shape – or disrupt – sustainable ASGM development in Suriname.

High Power, High Interest stakeholder group includes the most influential stakeholders who both have decision-making power and a strong interest in the mining sector. Strategy: Prioritize active engagement, involve stakeholders in strategic planning, policy-making, and implementation.

Key stakeholders:

- Government Ministries (e.g., Natural Resources, Spatial Planning);
- Regulatory agencies (National Environmental Authority, Ministry of Natural Resources (Geological Mining Department);
- Financial institutions (Central Bank, Inter-American Development Bank);
- Mining industry actors (Suriname Gold Miners Association, Gold Traders);
- International organizations (UNDP, WWF Guianas).

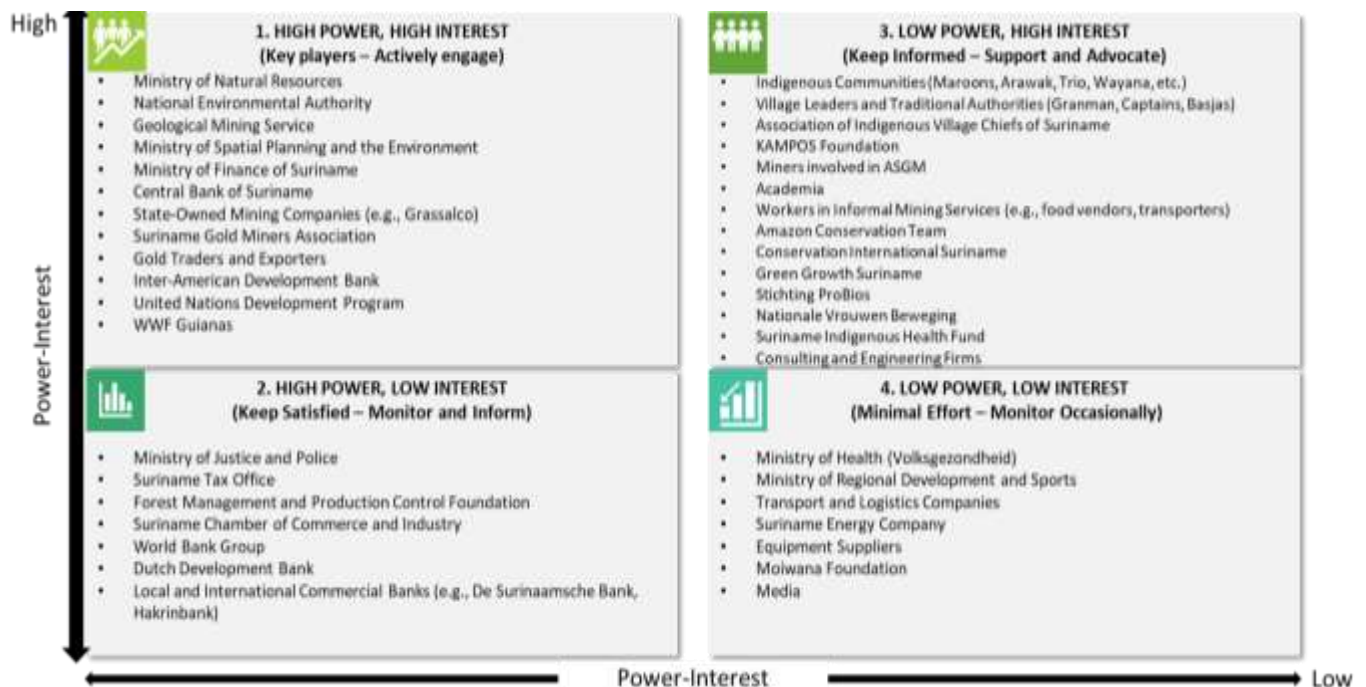


Figure. 15. **Power-Interest Matrix for stakeholders in artisanal and small-scale gold mining in Suriname** (developed by the authors)

High Power, Low Interest stakeholder group has significant influence but are not deeply interested in mining issues unless impacted directly. Strategy: Keep stakeholders from this group satisfied through regular updates and involve them selectively to avoid potential opposition.

Key stakeholders:

- Ministry of Justice and Police, Tax Office
- Commercial banks and development banks
- Suriname Chamber of Commerce
- Forest Management and Production Control Foundation
- World Bank Group.

Low Power, High Interest stakeholder group is highly interested, often due to direct social or environmental impacts, but lack institutional power. Strategy: Keep stakeholders well-informed and engaged as advocates or watchdogs; ensure their concerns are represented.

Key stakeholders:

- Indigenous communities and traditional leaders;
- Informal mining workers and community-based actors;
- NGOs (Amazon Conservation Team, CI Suriname, Green Growth Suriname);
- Academia and consulting firms.

Low Power, Low Interest stakeholder group are least affected and have minimal influence. Strategy: Monitor occasionally; no active engagement is needed unless circumstances change.

Key stakeholders:

- Ministry of Health, Transport companies
- Suriname Energy Company, equipment suppliers
- Media, Moiwana Foundation.

It is obvious that the project's viability depends on collaboration with high-power/high-interest stakeholders, particularly government bodies and international funders. Indigenous groups and NGOs can amplify pressure for ethical mining but need empowerment (e.g., via partnerships with high-power/high-interest stakeholders). Banks and regulatory agencies (e.g., Tax Office) could block progress if their low interest turns to opposition.

5.4 Stakeholders Level of Engagement Analysis

To build a RACI Matrix for the stakeholders involved in ASGM in Suriname, each stakeholder was categorized based on their role in different tasks associated with the mining process (Table 35). These tasks included:

1. Regulating mining permits
2. Environmental monitoring and compliance
3. Promoting sustainable mining practices
4. Health and safety regulations
5. Community engagement and development
6. Financing and investment in mining projects
7. Gold trade and export regulation
8. Mercury reduction and pollution management.

Table 35. RACI matrix for ASGM stakeholders (developed by the authors)

Stakeholders	Regulating Mining Permits	Environmental Monitoring and Compliance	Promoting Sustainable Mining Practices	Health and Safety Regulations	Community Engagement and Development	Financing and Investment in Mining Projects	Gold Trade and Export Regulation	Mercury Reduction and Pollution Management
Government Authorities								
Ministry of Natural Resources								
Ministry of Spatial Planning and the Environment								
National Environmental Authority								
Geological Mining Service								
Ministry of Finance of Suriname								
Central Bank of Suriname								
Suriname Tax Office								
Ministry of Health								
Ministry of Justice and Police								
Forest Management and Production Control Foundation								
Ministry of Regional Development and Sports								
Suriname Indigenous Health Fund								
Mining Industry Stakeholders								
Suriname Gold Miners Association								
Suriname Chamber of Commerce and Industry								
State-Owned Mining Companies								
Gold Traders and Exporters								
Miners involved in ASGM								
Equipment Suppliers								
Consulting and Engineering Firms								
Suriname Energy Company								
Transport and Logistics Companies								
Residents Living Near Mining Sites								
Indigenous Communities								
Village Leaders and Traditional Authorities								
Association of Indigenous Village Chiefs of Suriname								
KAMPOS Foundation								
Local Farmers and Fishers								
Small Business Owners								
Workers in Informal Mining Services								
Environmental and Social Advocacy Organizations								
Amazon Conservation Team								
WWF Guianas								
Conservation International Suriname								
Green Growth Suriname								
Stichting ProBios								
Nationale Vrouwen Beweging								
Moiwana Foundation								
ADEKUS								
Media								
International and National Financial Institutions								
Inter-American Development Bank								
World Bank Group								
United Nations Development Programme								
Global Environment Facility								
Dutch Development Bank								
Local and International Commercial Banks								

Key:

	Responsible
	Accountable
	Consulted
	Informed

RACI stakeholder matrix presents the level of engagement and positions of various groups in relation to key themes within the ASGM sector, including regulatory frameworks, environmental compliance, and community development.

Government Authorities are the most actively involved stakeholders, showing strong support for regulating mining permits, environmental monitoring, and promoting sustainable mining practices. However, their role is less prominent in managing mercury pollution and regulating gold and lixiviants trade and export.

Mining Industry Stakeholders show mixed levels of engagement. While they support sustainable mining and investment initiatives, they are opposed to stricter environmental and health regulations, indicating potential resistance to compliance requirements.

Residents Living Near Mining Sites are generally underrepresented in policy and decision-making processes. Their limited involvement is concerning given the direct impacts they face, especially regarding community development and pollution management.

Environmental and Social Advocacy Organizations are strongly supportive of environmental monitoring, sustainable mining, and pollution control. They are less engaged in trade and export matters, but their active stance on social and ecological issues suggests an important watchdog role.

International and National Financial Institutions focus primarily on investment and sustainable practices. They tend to remain neutral or uninvolved in local regulatory and social issues, pointing to a gap in localized stakeholder engagement.

Overall, the matrix reveals a need for more inclusive and balanced engagement, especially with local communities and industry actors on environmental and health-related themes. Strengthening cross-stakeholder collaboration could enhance sustainable and socially responsible mining practices.

5.5 Stakeholders Interconnection Analysis

The stakeholder interconnection analysis employs an onion diagram (Figure 16) to systematically map relationships within Suriname's ASGM sector through a four-tiered framework. This visualization tool categorizes stakeholders based on:

1. Operational Proximity – Their direct involvement in mining activities
2. Institutional Influence – Their role in governance and decision-making
3. Network Connectivity – The strength of their relationships with other actors.

The concentric layers represent:

- Core Operators: Direct mining actors (artisanal miners, equipment suppliers, local traders)
- Primary Influencers: Regulatory bodies and major industry players
- Secondary Engagers: NGOs, community organizations, and service providers
- Peripheral Observers: Media, academia, and international institutions.

Direct Operators (miners, traders, and equipment suppliers) demonstrate strong internal linkages within their own groups but maintain weak connections with regulators. Traders wield disproportionate influence, controlling market access and setting terms, while equipment suppliers act as gatekeepers; miners without capital often face exclusion or are forced into high-interest leasing arrangements. As a result, miners, despite being essential to the sector, are the most vulnerable and have the least formalized protections. Miners frequently rely on traders and suppliers for access to chemicals and equipment, typically through informal networks. Furthermore, there is limited engagement between

these operators and government agencies (e.g., NH, GMD), or with indigenous communities, especially when it comes to legal compliance, health, and safety standards.

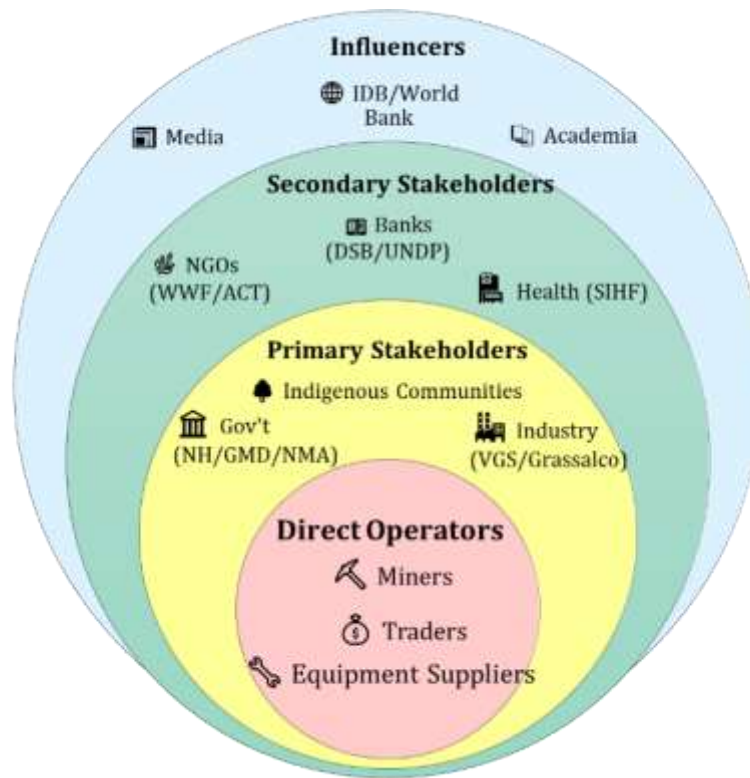


Figure. 16. **Stakeholder Onion Diagram for ASGM in Suriname**
(developed by the authors)

Primary stakeholders in Suriname's gold sector – including government agencies, indigenous communities, and industry actors – exhibit fragmented interconnections. While government bodies such as the Ministry of Natural Resources (NH), the Geological and Mining Department (GMD), and the National Environmental Authority (NMA) each play important regulatory roles, they often operate in silos. NH typically emphasizes revenue generation, whereas NMA focuses on environmental protection, leading to inconsistent policy enforcement and weak institutional coordination. Indigenous communities, although directly affected by mining activities, remain largely marginalized in governance processes. This is particularly concerning given the country's legal obligations under Free, Prior, and Informed Consent (FPIC) frameworks, which are not consistently upheld in practice. Meanwhile, industry actors such as VGS and Grassalco are influential in policy development through lobbying efforts, but they seldom collaborate with local communities. This lack of meaningful engagement further contributes to the disconnect between economic development goals and social and environmental justice.

Secondary stakeholders – such as NGOs like WWF and ACT Suriname, as well as health organizations like the Suriname Indigenous Health Fund (SIHF) – play a critical yet uneven role in addressing the impacts of artisanal and small-scale gold mining (ASGM) in Suriname. Their connections with local communities are strong, enabling them to provide essential support and advocacy in areas often neglected by state institutions. However, their engagement with government bodies remains weak, creating both opportunities and obstacles in advancing sustainable and inclusive mining governance.

These stakeholders act as key intermediaries for marginalized groups, particularly indigenous populations and communities directly affected by mining activities. Their contributions include:

- Providing mercury testing and healthcare outreach in remote regions where government services are absent.
- Advocating for environmental and human rights protections, often referencing international frameworks such as the Minamata Convention.
- Promoting alternative livelihood programs, including agroforestry initiatives, aimed at reducing community dependence on ASGM.

Despite their grassroots impact, NGOs and health organizations face significant structural barriers that limit their influence:

1. Exclusion from formal policy processes:

- Their data – such as contamination studies and community health assessments – is rarely integrated into government regulations.
- Health-focused organizations often lack representation on national decision-making bodies, such as the Ministry of Natural Resources' mining task forces.

2. Adversarial relationships with government and industry:

- Calls for stricter regulations, particularly around mercury use, frequently conflict with the governments and industry's economic priorities.
- Industry representatives, including those from the Association of Gold Miners in Suriname (VGS), often dismiss NGO findings as obstructionist, while government agencies regard them as external critics rather than partners.

3. Dependence on external funding:

- Many of these organizations rely heavily on international donors (e.g., UNDP, WWF Global), making their initiatives vulnerable to changing donor agendas and funding cycles.

Influencers as the stakeholders group shapes narratives and policies but operate with limited grassroots integration, creating a disconnect between high-level strategies and on-ground realities. International financial institutions such as the Inter-American Development Bank (IDB) and the World Bank play a significant role in shaping Suriname's approach to artisanal and small-scale gold mining (ASGM). However, their interventions often fall short due to a reliance on external frameworks. Many of the programs appear to replicate templates used in Africa or Asia, without fully accounting for Suriname's unique context, such as indigenous land tenure systems, the dominance of an informal economy where approximately 80% of ASGM remains unregistered, and the sector's reliance on mercury due to a lack of affordable alternatives. Furthermore, funding is frequently conditional, tied to rigid formalization targets that pressure stakeholders into rushed implementations. These institutions also tend to work primarily with government bodies, often excluding local NGOs and miners from meaningful involvement in project design and execution.

The media in Suriname plays a dual role in the ASGM landscape. On one hand, it has proven effective in exposing serious issues, and in amplifying the work of NGOs through documentaries on mercury poisoning and environmental harm. On the other hand, media coverage tends to be heavily urban-centric, with around 90% of reporting focused on Paramaribo, leaving the interior mining zones underrepresented. Coverage is also often sensationalized, favoring dramatic "gold rush" narratives over nuanced reporting that explores systemic issues or solutions. Moreover, the media rarely provides follow-up on the outcomes of policies or interventions they report on, limiting their impact on public accountability and sustained awareness.

Academia in Suriname plays an essential role in the ASGM landscape by producing critical research and training future regulators and engineers. However, academic contributions often remain confined to theoretical spaces. Many research findings never make their way to decision-makers. Access to meaningful field research is also limited. Conducting studies often requires mining permits and specialized equipment, pushing researchers to rely on industry partners, which may compromise independence. Additionally, the academic pace is slow, with peer review and publication timelines frequently lagging behind real-world events.

5.6 Stakeholder Engagement

The stakeholder engagement framework for Suriname's Artisanal and Small-Scale Gold Mining (ASGM) sector demonstrates a systematic approach to participatory research and governance reform (Table 36).

Table 36. **Stakeholder engagement process** *(developed by the authors)*

Task	Stakeholder Group	Engagement Process
1	2	3
1. Desktop Research	Government Authorities	Review existing policies, regulations, and environmental reports from ministries and agencies (NH, ROM, NMA, GMD, EMSAG).
	Environmental & Social Advocacy Organizations	Use published reports, data, and studies from NGOs (WWF, ACT, CI, ProBios).
	Financial Institutions	Analyze reports and project data funded by IDB, UNDP, World Bank, GEF, FMO.
2. Stakeholder Mapping & Initial Engagement	All Groups	Identify key actors, schedule introductory meetings, map influence and interest, distribute information briefs.
3. Fieldwork Preparation	Residents Near Mining Sites	Coordinate with village leaders and traditional authorities for access and logistical support.
	Government Authorities	Obtain permissions and align field plans with GMD and NMA protocols.
	Mining Industry Stakeholders	Contact VGS and miners for access to informal and formal mining zones.
4. Field Sampling and Testing	Residents Near Mining Sites	Collaborate with communities to identify sampling points and ensure local participation.
	Mining Industry Stakeholders	Work with ASGM miners and gold processing sites to access relevant sampling areas.
	Government Authorities	Engage NMA, GMD, and Ministry of Health to ensure compliance with health and environmental standards.
5. Comparative Analysis	Government Authorities	Compare field data with regulatory thresholds and environmental baselines.
	Environmental & Social Advocacy Organizations	Discuss findings in light of conservation targets and sustainable practices.
	Financial Institutions	Relate environmental impacts to funded project goals and due diligence requirements.

<i>Continuation of the Table 36</i>		
1	2	3
6. Stakeholder Interviews and Community Feedback	Residents Near Mining Sites	Conduct structured interviews and focus groups with community members, farmers, informal workers.
	Environmental & Social Advocacy Organizations	Hold consultative sessions with NGOs on social and ecological effects.
	Mining Industry Stakeholders	Interview miners, gold traders, and equipment providers on practices, challenges, and needs.
7. Regulatory and Environmental Assessment	Government Authorities	Analyze alignment of ASGM practices with laws, and involve ROM, NH, NMA in gap assessments. . Review of existing goldmining permit conditions and mineral agreements.
	Financial Institutions	Cross-check mining impacts with investment guidelines and environmental criteria.
	Mining Industry stakeholders	Discuss compliance challenges.
8. Reporting and Recommendations	All Groups	Share draft findings and tailored recommendations in stakeholder-specific briefs, request feedback.
9. Quality Assurance and Final Presentation	All Groups	Validate results with stakeholder feedback, present key findings in a joint forum or stakeholder workshop, including media coverage.

Phase 1: Foundational Research (Tasks 1-3)

The desktop research phase (Task 1) establishes a robust evidence base through triangulation of government regulatory documents (NH, NMA), NGO research (WWF, ACT), and financial institution reports (IDB, World Bank). This multi-source verification approach mitigates institutional bias in baseline data collection. Stakeholder mapping (Task 2) employs a snowball sampling technique to identify key actors, though the process would benefit from formal social network analysis to quantify influence pathways. Fieldwork preparation (Task 3) addresses critical ethical and logistical considerations through Free, Prior and Informed Consent (FPIC) protocols with indigenous communities, while simultaneously navigating bureaucratic requirements via government permitting processes.

Phase 2: Empirical Data Collection (Tasks 4-6)

Field sampling (Task 4) implements a community-based participatory research (CBPR) model, engaging local miners as co-researchers in environmental sample collection. This approach enhances data validity while building local capacity, though potential observer effects in mercury testing procedures should be controlled. The comparative analysis (Task 5) applies institutional theory to benchmark Suriname's regulatory framework against regional best practices, with financial institutions providing critical performance metrics. Stakeholder interviews (Task 6) employ mixed-methods design, combining structured questionnaires for industry actors (VGS, traders) with focus group discussions in mining communities to capture both quantitative operational data and qualitative lived experiences.

Phase 3: Policy Development & Validation (Tasks 7-9)

The regulatory assessment (Task 7) reveals significant policy implementation gaps through discordance analysis between formal regulations (NH, ROM) and observed practices (NMA monitoring data). According to the information presented in the NAP 2023, Suriname currently lacks legislation specifically targeting the ASGM (Artisanal and Small-Scale Gold Mining) sector. However, the 1986 Mining Decree

(Article 20) states that “Mining must take place with consideration of applicable standards on safety and health of staff in particular, and the community in general, as well as valid standards for the protection of ecosystems.” Furthermore, the Penal Code (Articles 226 and 227) establishes that “It is unlawful to knowingly or unknowingly be responsible for the sale, delivery, or distribution of goods that are harmful to life or health, without the buyer or recipient being made aware of the harmful nature of those goods.” Despite these existing general legal provisions, the NMA notes that ASGM activities have a significant negative impact on the environment (see paragraphs 4.8 and 4.9 of NAP 2023) and are often carried out in violation of even these basic legislative standards.

The reporting phase (Task 8) demonstrates innovative knowledge translation, producing tiered recommendations tailored to different literacy levels and stakeholder interests. Quality assurance (Task 9) incorporates deliberative democracy principles through consensus workshops, though power differentials in these forums require mitigation through neutral facilitation.

The process exhibits three notable strengths:

- 1) methodological pluralism combining document analysis, field measurements, and participatory techniques;
- 2) iterative validation loops with stakeholders;
- 3) explicit attention to marginalized voices through FPIC protocols.

5.7 Key Judgments

The stakeholder landscape in artisanal and small-scale gold mining (ASGM) is shaped by three critical dynamics.

First, *siloed operations* with minimal cross-tier collaboration create significant challenges. Stakeholders operate in parallel but disconnected tiers, leading to weak linkages between key groups. There is limited knowledge-sharing between direct operators – such as miners, traders, and suppliers – and NGOs or academia, particularly when it comes to sustainable practices. Additionally, government regulators and indigenous communities often remain at odds, with top-down policies failing to consider local input. The relationship between the industry (e.g., large mining companies) and miners is also marked by exploitative contracts and a lack of profit-sharing. This disconnection results in the duplication of efforts and inefficiencies, such as miners being unaware of mercury-free technologies, and NGOs lacking insight into the on-the-ground challenges miners face.

Second, *power asymmetry* dominates decision-making, with dominant actors holding the reins. The government (NH/GMD) and international bodies such as the IDB and World Bank conduct limited consultation with local communities. However, it remains an ongoing challenge to ensure deeper involvement of local people. Meanwhile, large mining corporations monopolize supply chains, sidelining artisanal miners.

Finally, *NGOs serve as critical but limited bridges* in the sector. Secondary stakeholders like WWF, SHIF, and ACT play key roles in connecting communities with vital resources. WWF and ACT link miners to sustainable technologies and certification programs, while SHIF provides healthcare access where government services fall short. However, the focus of these NGOs remains project-based, with efforts often limited to short-term training rather than addressing systemic change.

5.8 Key Recommendations

To strengthen interconnections within the artisanal and small-scale gold mining (ASGM) sector, several key recommendations are proposed.

First, *formalizing feedback loops* is crucial. Government and industry must be required to consult with indigenous leaders and miners when drafting policies, such as through initiatives like the National Gold Ore Dressing Agents Management Code. This ensures that policies reflect the realities of local communities and directly address their concerns.

Second, *cross-tier task forces* should be established to foster collaboration across different stakeholder groups. Mixed working groups – including miners, the National Environmental Authority (NMA), and NGOs like WWF – can co-design enforcement strategies, ensuring that regulations are practical, enforceable, and supported by all parties.

Third, creating *transparency platforms* can help align all stakeholders. Public dashboards that track chemical use, permits, and violations will provide visibility and accountability, making it easier for everyone involved to stay informed and make data-driven decisions.

Final Verdict: The current stakeholder network in ASGM remains hierarchical and disjointed, with NGOs often stepping in to compensate for institutional failures. Achieving systemic change requires mandating collaboration across tiers and redistributing power to marginalized groups, enabling a more inclusive and effective sector.

6. STAKEHOLDER INTERVIEWS AND COMMUNITY FEEDBACK

Artisanal and small-scale gold mining (ASGM) remains one of the most important livelihood activities in Suriname's interior. While it contributes significantly to income generation and local economies, it also presents serious environmental and health risks, especially due to the continued use of hazardous lixiviants like mercury and, to a lesser extent, cyanide. In recent years, there has been growing interest in transitioning to cleaner, safer, and more sustainable gold extraction methods. However, a shift of this magnitude requires a nuanced understanding of miners' current practices, motivations, constraints, and openness to change.

To inform evidence-based policy and guide technical support efforts, a structured questionnaire was developed and distributed among ASGM miners, Geological Mining Service Institutions and local residents across regions of interest in Brokopondo district.

6.1 Analysis of Survey Responses from Artisanal and Small-Scale Gold Miners

6.1.1 Analysis of Survey Responses

As a result of stakeholder mapping, miners involved in ASGM were identified as key actors responsible for mercury reduction and pollution management. To better understand their perspectives on the use of gold extraction chemicals – particularly mercury, cyanide, and alternative lixiviants – and to identify the barriers and enabling factors for adopting cleaner technologies in Suriname's ASGM sector, a targeted questionnaire was developed.

The questionnaire consisted of **12 questions**, grouped into **four thematic sections**:

1. **Current Practices and Chemical Use (3 questions)**

To determine which lixiviants are presently used and understand the underlying reasons behind their continued application, especially mercury.

2. **Cyanide and Non-Cyanide Alternatives (3 questions)**

To explore experiences, perceptions, and awareness regarding cyanide and other alternative gold extraction chemicals.

3. **Barriers to Technology Change (3 questions)**

To identify the main obstacles that hinder the transition to safer methods and gather insight into what types of support would be most effective.

4. **Policy and Future Outlook (3 questions)**

To collect miners' views on potential regulatory measures and to gauge expectations about the future direction of ASGM in Suriname.

The questionnaire results for the Current Practices and Chemical Use section are presented in Figures 17–19. In response to the question, *“Which lixiviants does your operation currently use for gold extraction?”*, a significant **90% of miners reported using mercury (Hg)** through amalgamation. This finding clearly confirms that **mercury remains the dominant chemical** in ASGM operations in Suriname. Its widespread use is likely attributed to its **low cost, ease of application, and long-standing familiarity** within the mining community (Figure 17).

In contrast, **none of the respondents reported using cyanide (NaCN/KCN)**. This complete absence suggests possible **barriers related to access, knowledge and technical feasibility** that make cyanide

unsuitable or undesirable for current ASGM operators.

Similarly, **borax – a mercury-free alternative used in gravity concentration – was not reported by any respondent**. This indicates that borax-based methods are **not adopted in practice**, likely due to **limited awareness, inadequate training, or perceptions that it is ineffective for the local ore types**.

When asked about nitric acid (HNO_3), **only 10% of miners confirmed its use**, while 90% reported not using it. This suggests that nitric acid plays a **minor and likely specialized role**, potentially limited to small-scale gold purification rather than primary extraction.

The survey also revealed that **0% of respondents use thiourea or thiosulfate**, two promising non-cyanide lixiviants. This finding confirms that **innovative, low-toxicity alternatives have not yet penetrated the field**, highlighting a substantial gap in **awareness, accessibility, and technical support** for their adoption. Interestingly, **60% of miners reported using other substances** in their operations. These include **cement (30%), cement combined with lime (15%), and battery acid (15%)**. The use of such non-conventional or improvised chemicals raises **serious environmental and health concerns**, particularly in the case of **battery acid**, which contains highly hazardous materials.

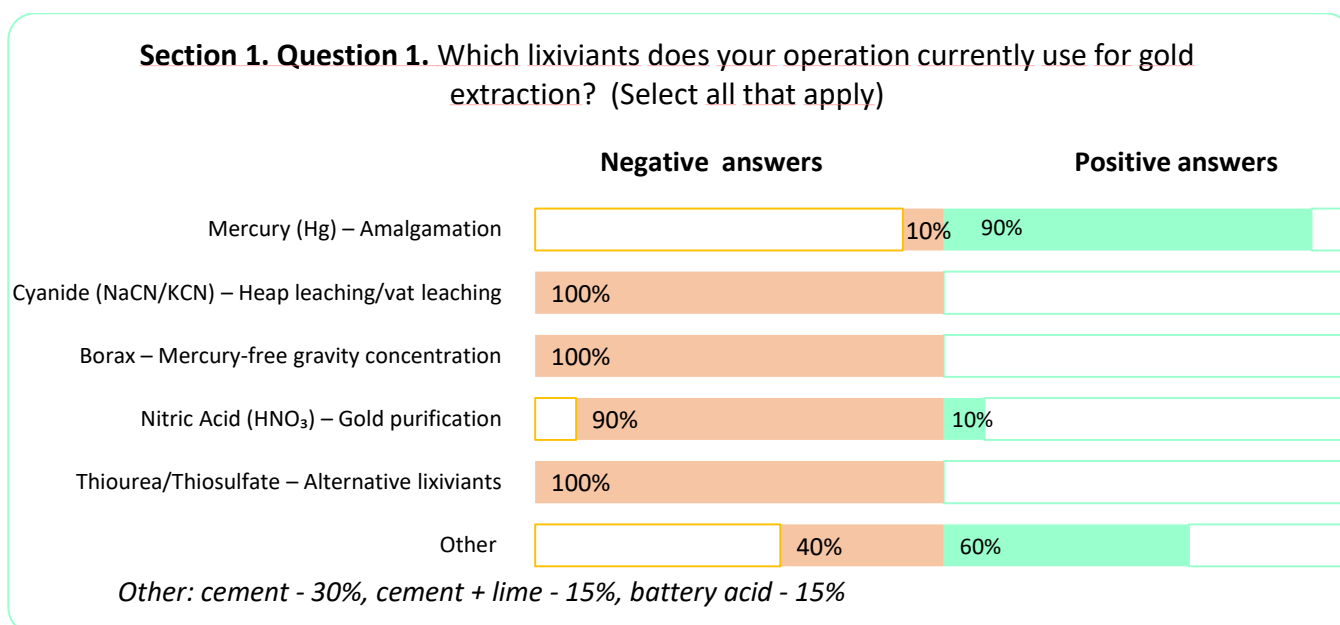


Figure 17. Survey responses to the Question 1 of Current Practices and Chemical Use section

Implications:

- The overwhelming use of **mercury (90%)** underscores the **critical need for targeted interventions**, including the **promotion of safer alternatives**, access to equipment, and **technical support** for mercury-free methods.
- The **complete absence of cyanide and non-cyanide alternatives** such as borax, thiourea, and thiosulfate highlights:
 - A **lack of technical capacity** and necessary **infrastructure**.
 - **Low awareness**, limited exposure, or **resistance to unfamiliar technologies** within the mining community.
- The reported use of **"other" substances**, particularly **hazardous chemicals like battery acid**, suggests **informal experimentation** in the absence of proper guidance, reflecting a **regulatory and informational vacuum** that could lead to **serious health and environmental risks**.

In response to the question on the main reasons for using mercury in gold extraction, the majority of miners identified the **simplicity and speed of the process** as the most important factor (Figure 18). Specifically, 50% of respondents ranked "fast and simple process (no complex equipment)" as their top reason. This clearly shows that ease of use is a critical driver for continued mercury use in ASGM operations. Additionally, **tradition and familiarity** with mercury methods were also influential, with 25% of miners ranking it as the most important factor and others assigning it high importance. This indicates that cultural and historical practices continue to shape technological choices in the sector.

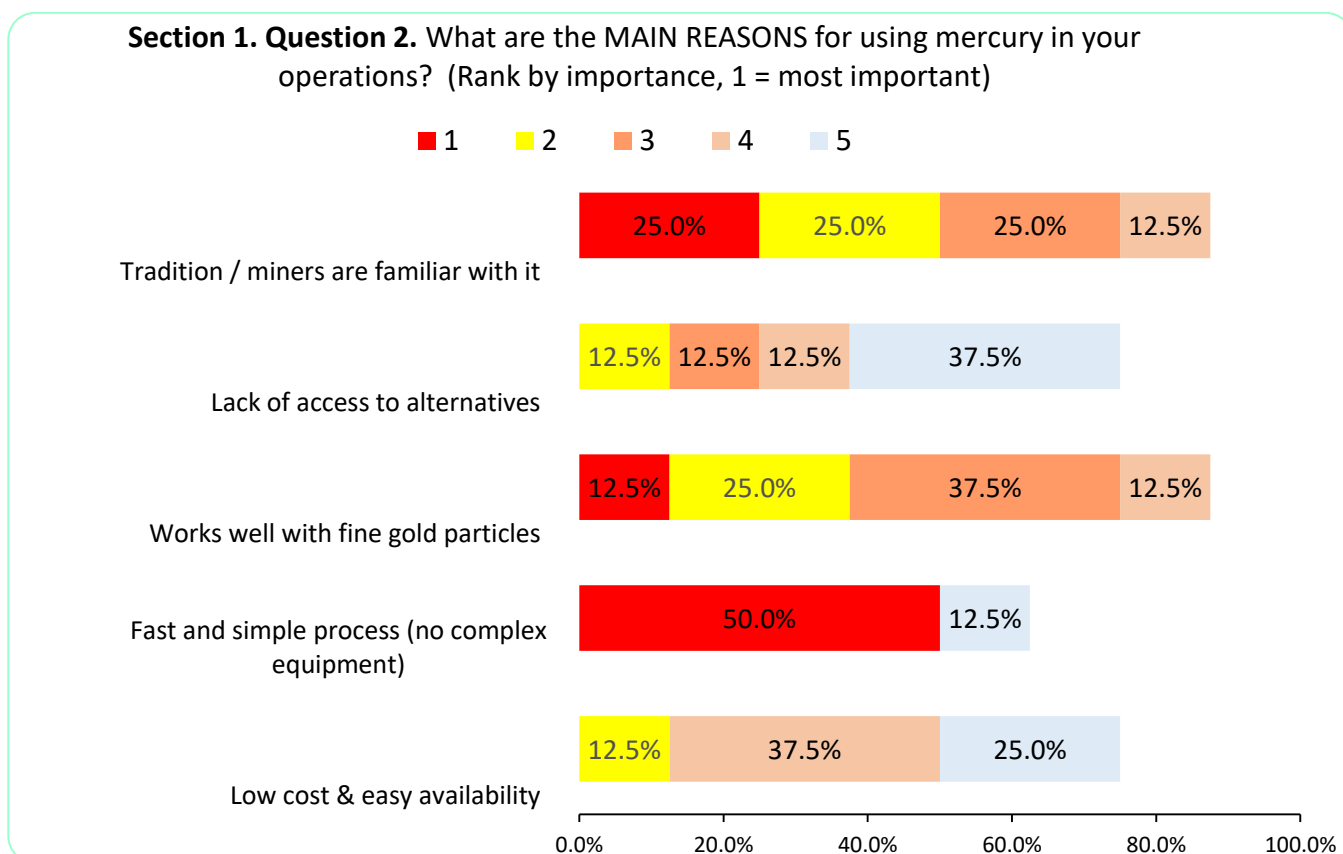


Figure 18. Survey responses to the Question 2 of Current Practices and Chemical Use section

Other considerations included **technical performance**, such as mercury's ability to work well with fine gold particles. While only 12.5% ranked this as the top reason, 37.5% considered it moderately important, suggesting that effectiveness for certain ore types is acknowledged, though not prioritized. Interestingly, **lack of access to alternatives** was ranked as the most important by only 12.5% of respondents, and 37.5% placed it as least important. This may indicate that while alternatives are not readily available, miners do not see this as the primary reason for continuing mercury use—perhaps due to limited awareness or experience with those alternatives.

Finally, **low cost and easy availability** were not considered the most important by any respondents, though they were ranked mid-level in importance by 37.5%. This implies that cost alone does not drive mercury use but remains a contributing factor. Overall, the results emphasize that **the simplicity, familiarity, and perceived efficiency of mercury-based methods are the main factors behind their continued use**, while barriers such as cost or access to alternatives are secondary. Therefore, any strategy to transition miners away from mercury must prioritize **developing and promoting alternative**

methods that are equally simple, efficient, and tailored to existing skills and conditions.

When asked about the main disadvantages of using mercury in their operations, miners most frequently identified **environmental pollution** and **health risks** as the top concerns (Figure 19). A significant 75% of respondents acknowledged the environmental impact of mercury, such as contamination of rivers and aquatic ecosystems, as a major disadvantage. An equal proportion – 75% – also recognized the **serious health risks** associated with mercury exposure, including neurological damage and poisoning. This indicates that there is a strong awareness among miners of the toxic effects mercury has on both ecosystems and human health.

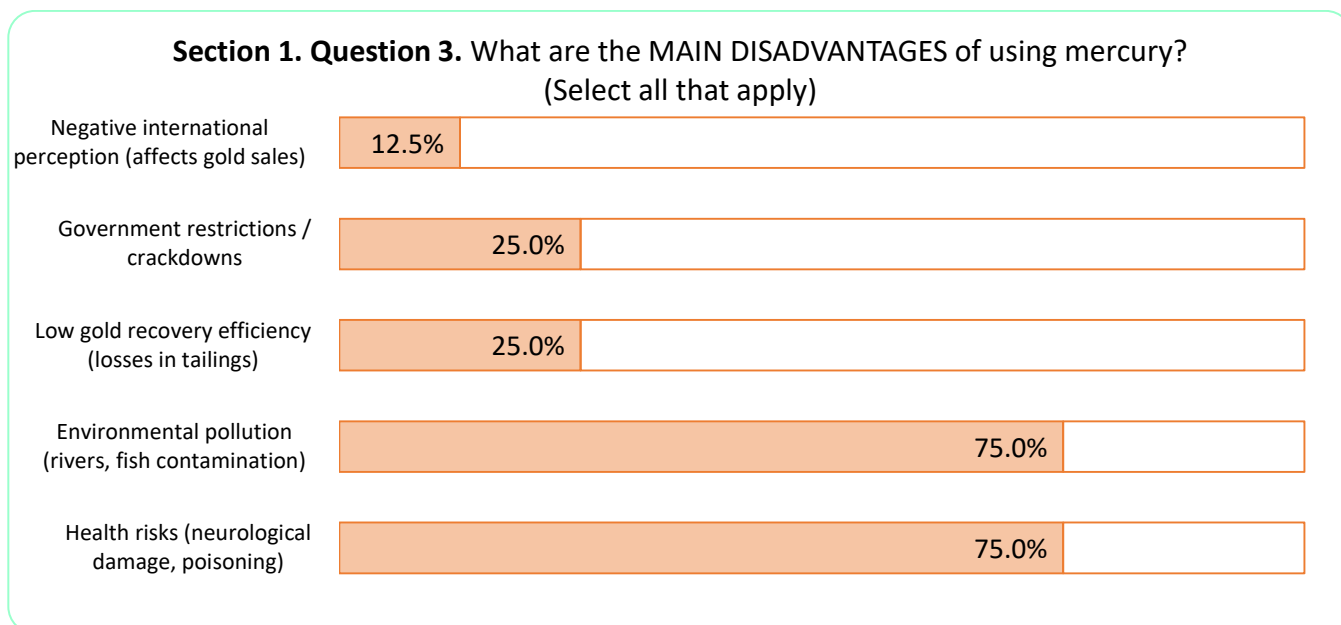


Figure 19. Survey responses to the Question 3 of Current Practices and Chemical Use section

In contrast, only 25% of respondents cited **government restrictions and crackdowns** as a disadvantage, suggesting that enforcement may either be weak or not seen as a major deterrent. Similarly, 25% noted **low gold recovery efficiency** – a technical drawback that highlights losses in tailings, which could be improved with alternative methods.

Surprisingly, only **12.5% of miners considered negative international perception** (which can affect gold sales) as a disadvantage. This suggests that market-related reputational risks have limited influence on the decisions of small-scale gold miners, possibly due to limited engagement with formal gold markets or lack of information about international standards.

Overall, the responses demonstrate a clear recognition of the **toxic legacy and dangers of mercury**, especially in terms of pollution and human health. However, **economic and enforcement-related factors appear to be of less concern**, emphasizing the need for more awareness on broader regulatory and market implications. Any efforts to reduce mercury use in ASGM must therefore build on miners' existing understanding of health and environmental harm while bridging gaps in market access, efficiency, and regulatory compliance.

The questionnaire results for the Cyanide and Non-Cyanide Alternatives section are presented in Figures 20–22. Survey results from Section 2 (Question 1) reveal key trends in the perceived suitability of cyanide for gold extraction. Among the operations surveyed, **75% believe that cyanide is not appropriate for their ore type, and none currently use it in their processes**. However, a notable **25% expressed interest**

in its potential application despite not using it at present. These findings underscore a general scepticism toward cyanide’s effectiveness in local geological contexts, while also highlighting a small but important openness to exploring alternative methods – provided that adequate information, training, and technical support become available (Figure 20).

Section 2. Question 1. Has your operation ever used CYANIDE for gold extraction?

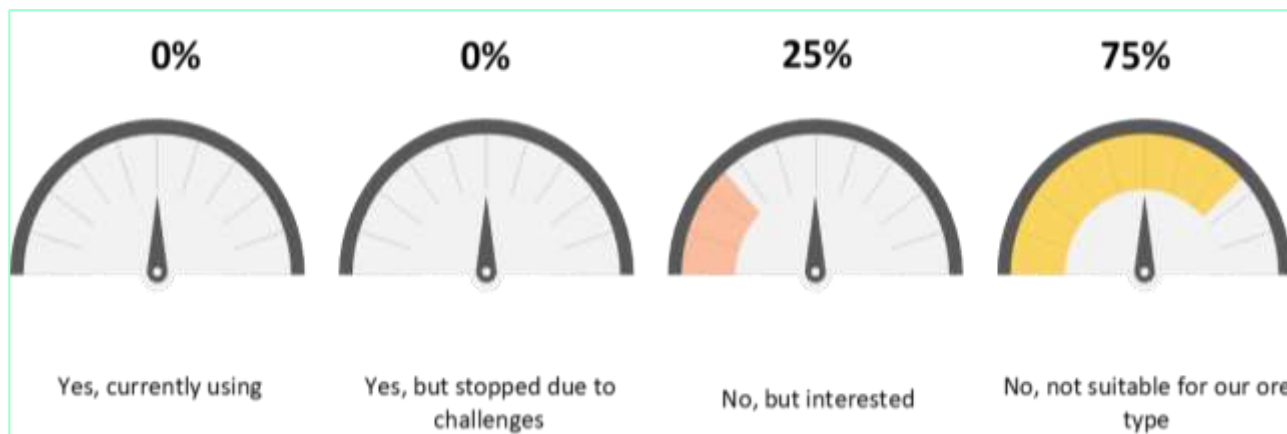
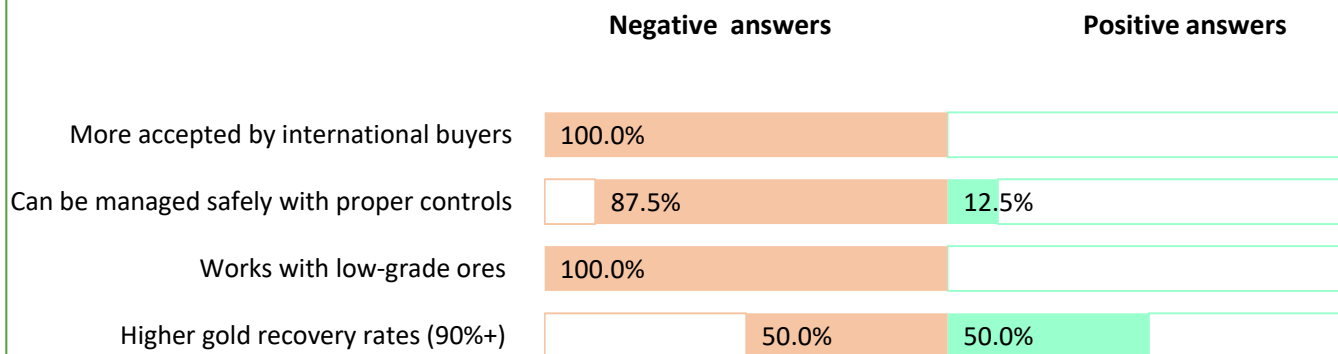


Figure 20. Survey responses to the Question 1 of Cyanide and Non-Cyanide Alternatives section

The survey results presented in Figure 21 demonstrate that among the respondents, **the most commonly acknowledged advantage of cyanide use in gold processing is its potential to achieve higher gold recovery rates** (90% or more), as indicated by 50% of participants. A smaller proportion (12.5%) recognized the possibility of safe management of cyanide under proper control measures as a potential benefit.

Section 2. Question 2. If using cyanide, what are the MAIN ADVANTAGES?
(Select all that apply)



Note: One respondent did not know what lixiviants are, and two respondents stated they did not want to use cyanide at all.

Figure 21. Survey responses to the Question 2 of Cyanide and Non-Cyanide Alternatives section

Conversely, there was an almost unanimous consensus rejecting two commonly cited industry advantages of cyanide use: its greater acceptance by international buyers and its suitability for processing low-grade ores. In both cases, 100% of respondents did not identify these as advantages, suggesting limited perceived economic or market-related benefits within Suriname's ASGM context.

Overall, these **results reflect a critical stance among respondents toward the use of cyanide, with only a minority acknowledging its technical strengths**, while the majority remain sceptical about its broader applicability and safety in artisanal and small-scale operations.

The survey results from **Section 2 (Question 3)** highlight four primary challenges associated with cyanide use in gold extraction, revealing both areas of unanimous concern and differences in stakeholder perception (Figure 22). None of the respondents identified the need for technical expertise in **pH control and process monitoring**, or the necessity of **strict waste management protocols** – including the proper construction of tailings ponds and implementation of detoxification procedures – as critical challenges. This finding suggests that respondents may lack sufficient knowledge or practical understanding of the technical and environmental complexities involved in the safe use of cyanide.

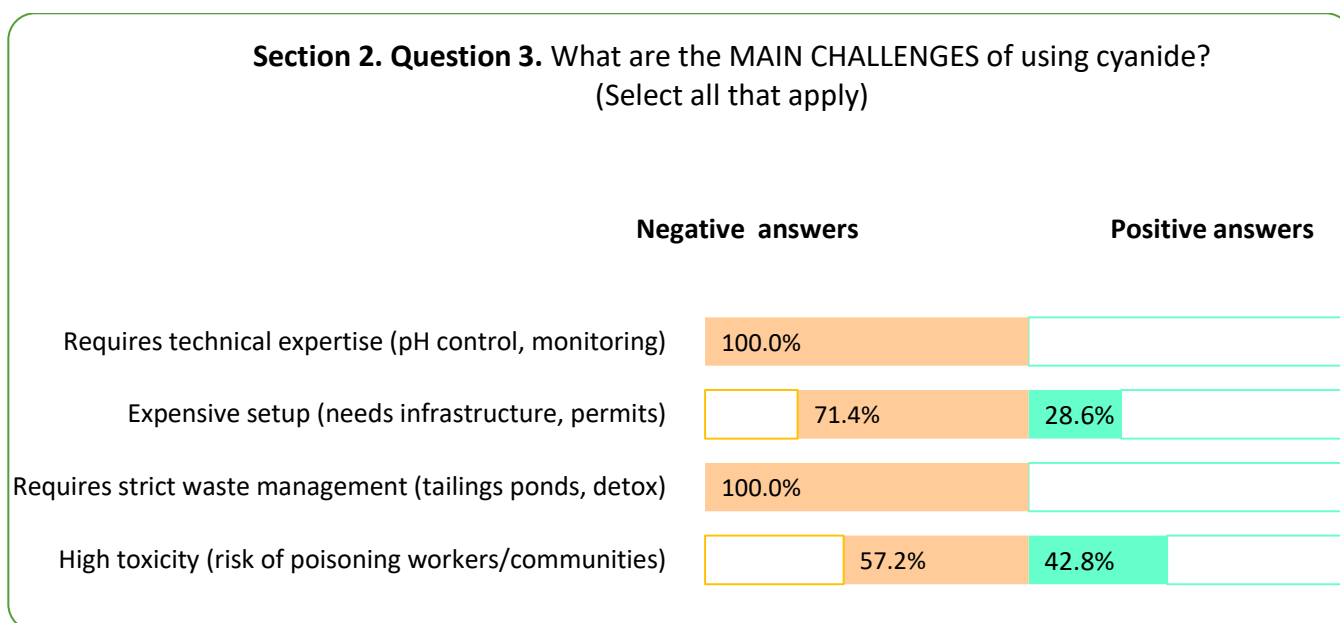


Figure 22. Survey responses to the Question 3 of Cyanide and Non-Cyanide Alternatives section

A majority of respondents (71.4%) did not view costs as a major challenge, suggesting that some operators may have access to cost-effective solutions or alternative financing strategies. However, **28.6% of participants cited high capital costs for infrastructure and permitting (licensing) as a significant barrier**, particularly for small-scale operations. Regarding cyanide's toxicity, opinions were split – 42.8% considered it a major concern, while 57.2% did not – indicating differing risk perceptions or varying levels of mitigation experience across operations.

Implications:

- Despite being universally recognized as essential prerequisites for the **safe use of cyanide**, both **technical expertise** and **robust waste management** were not identified as key challenges by respondents. This underscores a significant **knowledge gap** within the sector regarding the operational and environmental requirements for responsible cyanide management.

- **Financial constraints** appear to vary depending on the **scale and resources** of the mining operation. While larger or more organized entities may find the costs manageable, smaller-scale miners are likely to face substantial financial barriers to implementing cyanide-based processing systems.
- The **divided perception of cyanide toxicity** highlights the urgent need for:
 - Targeted **safety and environmental training programs**;
 - **Case studies** demonstrating effective risk mitigation and best practices; and
 - **Technology transfer and capacity-building initiatives** to assist smaller operations in adopting safer and more sustainable gold recovery methods.

The questionnaire results for the **Barriers to Technology Change** section are presented in Figures 23–25. The survey results presented in Figure 23 illustrate the level of awareness among respondents regarding non-cyanide gold extraction alternatives, such as thiourea, thiosulfate, and borax. The **data reveal a generally low level of familiarity and limited practical experience with these alternative lixiviants** within Suriname’s ASGM sector.

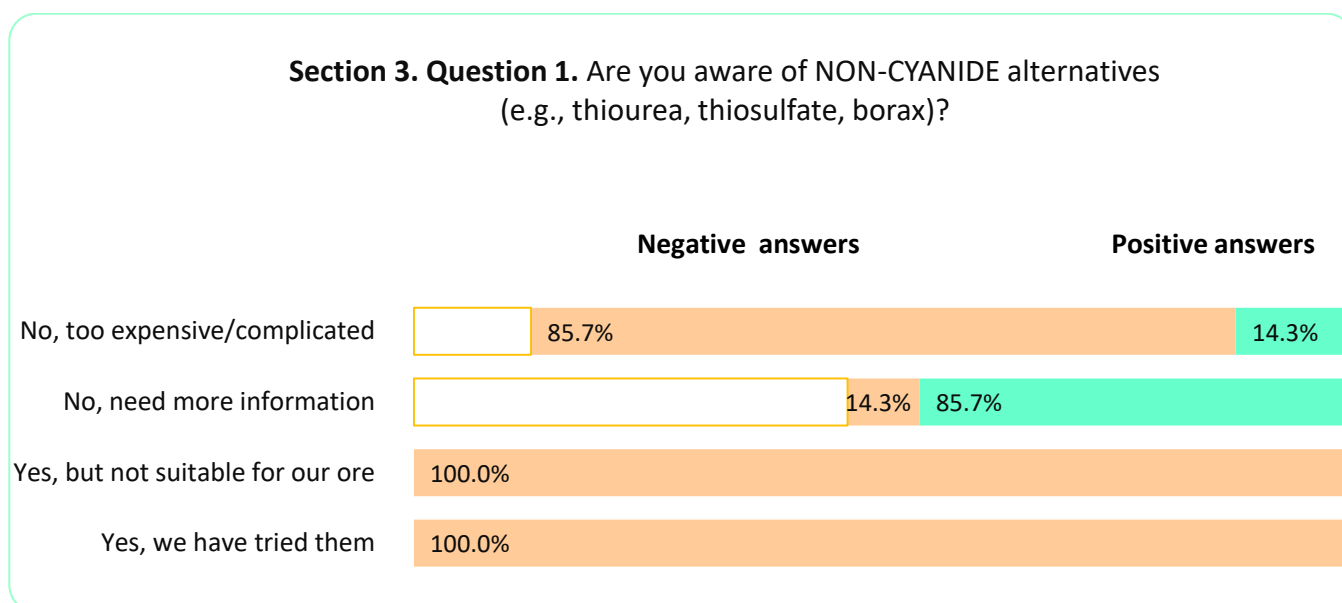


Figure 23. Survey responses to the Question 1 of Barriers to Technology Change section

A significant majority (85.7%) of **respondents indicated that they need more information about non-cyanide alternatives**, suggesting that knowledge gaps and limited technical outreach are major barriers to adoption. Similarly, **85.7%** of participants considered such alternatives **too expensive or complicated**, reflecting perceptions that these technologies are economically or operationally infeasible under local conditions. Notably, **none of the respondents** reported having tried these alternatives or found them unsuitable for their ore type, indicating that **practical experimentation and field testing** have not yet occurred within the surveyed group. This lack of direct experience further reinforces the notion that non-cyanide technologies remain **largely unfamiliar and inaccessible** to ASGM operators in Suriname. The survey results from **Section 3 (Question 2)** reveal a complex interplay between institutional, economic, and technical barriers that continue to hinder the transition from mercury-based gold extraction to cleaner, more safe processing technologies (Figure 24).

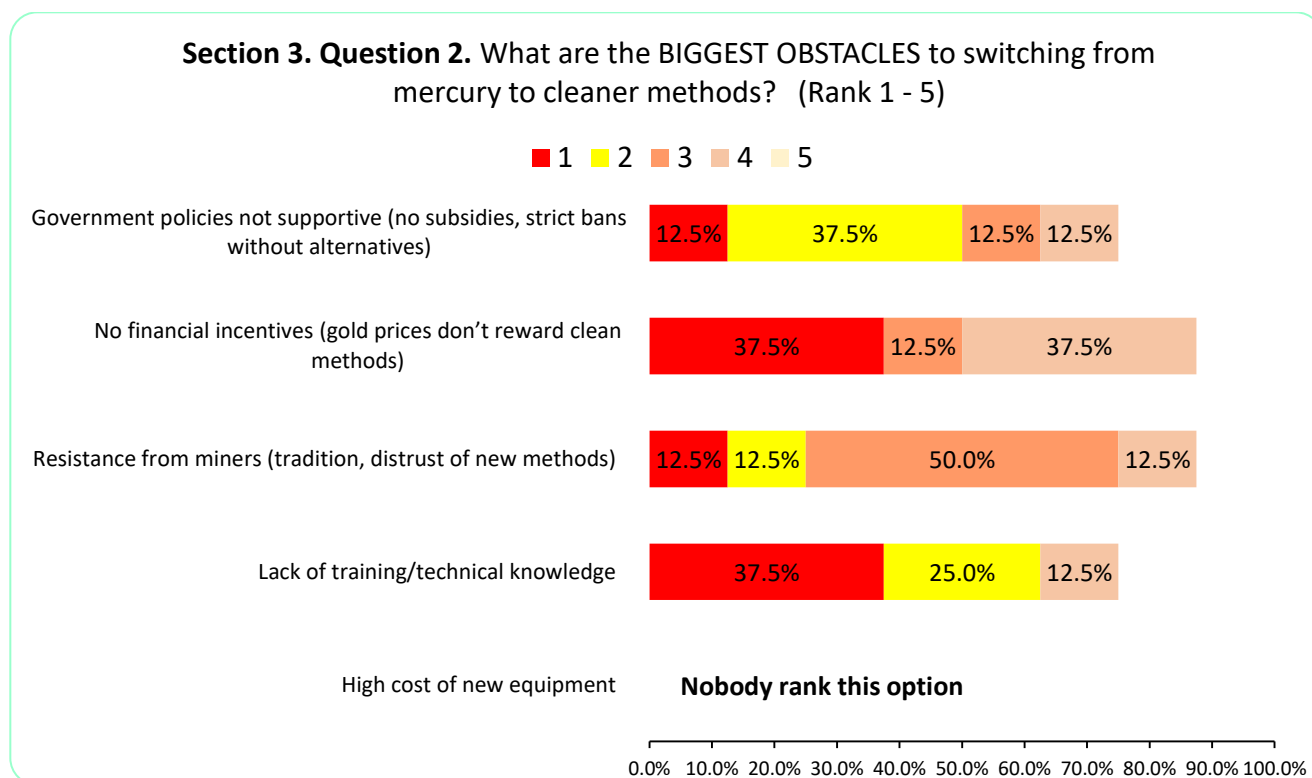


Figure 24. Survey responses to the Question 2 of Barriers to Technology Change section

Among the most frequently cited obstacles, **financial disincentives and lack of training or technical knowledge stood out prominently**. A significant proportion of respondents (37.5%) identified the absence of financial incentives or market premiums for mercury-free gold as the most critical barrier. **Without economic benefits** to offset the cost or effort of transitioning to alternative methods, **mercury remains the more attractive option for small-scale miners** operating on limited margins. An equal proportion (37.5%) highlighted knowledge gaps and insufficient training as the main constraint, indicating that **many miners lack the practical understanding or technical expertise** necessary to adopt and effectively apply cleaner technologies.

Miners' resistance to change also emerged as a notable issue. Half of the respondents **ranked** this behavioural barrier **as the third most important challenge**. This resistance is often rooted in cultural familiarity with mercury use and distrust toward unfamiliar extraction methods. Such social dynamics underscore the importance of trust-building and active engagement with mining communities when introducing new practices.

Government policies were widely viewed as either too restrictive or not sufficiently supportive. While **37.5% of respondents considered policy constraints the second most significant barrier**, others ranked it across different levels of importance. This dispersion suggests that **current regulatory approaches may be misaligned with the needs and capacities of artisanal and small-scale miners**. For example, bans on mercury use without simultaneous support for alternative solutions may unintentionally drive non-compliance or the use of unsafe practices.

Interestingly, **equipment costs were not cited by any respondents as a major barrier to the adoption of mercury-free technologies**. This finding contrasts with common assumptions that affordability of equipment is a primary concern and instead points to deeper, structural issues – such as lack of knowledge, inadequate incentives, and weak policy support – as the dominant limiting factors.

Taken together, these findings suggest that a **successful transition away from mercury requires more than technological solutions alone**. Efforts must simultaneously address economic conditions, knowledge gaps, community resistance, and policy frameworks. Simply **providing new equipment or imposing bans will likely be ineffective** unless accompanied by broader initiatives that make alternative methods practical, attractive, and socially acceptable to miners.

To **support this transition, targeted strategies are needed**. These include developing financial mechanisms that reward mercury-free gold production through premium pricing or tax incentives, implementing training programs and establishing demonstration sites to build capacity and confidence, reforming regulatory frameworks to be more supportive and participatory, and engaging trusted community leaders to influence behaviour and promote the health and safety benefits of cleaner extraction practices.

The survey results from **Section 3 (Question 3)** provide a clear picture of the types of support miners believe are most critical for transitioning away from mercury-based gold extraction. A strong consensus emerged around the need for immediate, practical assistance, with certain forms of support overwhelmingly favoured by respondents (Figure 25).

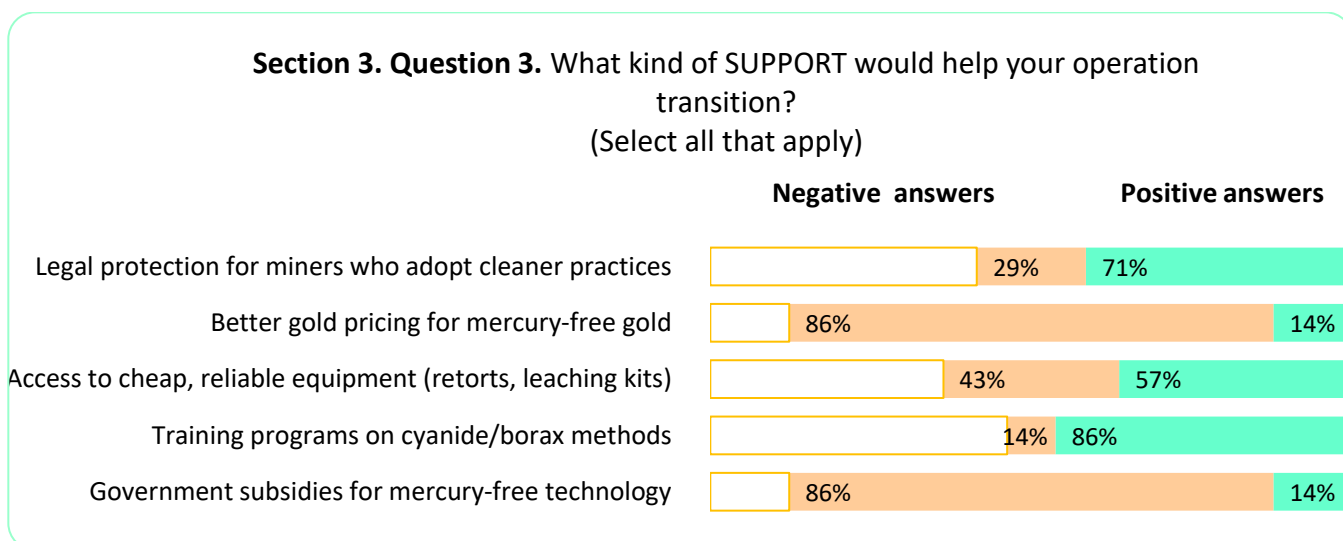


Figure 25. Survey responses to the Question 3 of Barriers to Technology Change section

The most widely requested forms of support were **training programs on alternative extraction methods** (such as cyanide or borax) reported by **86% of respondents**, and **legal protection for miners adopting cleaner practices**, cited by **71%**. These two priorities reflect miners' urgent need for both the **technical capacity** and **regulatory assurance** required to transition toward safer technologies.

The strong demand for training underscores a clear recognition that new extraction methods require **specialized skills and technical understanding**, while the call for legal protection highlights the **critical role of clear and supportive legislation** in fostering wider adoption of cleaner practices within the ASGM sector.

A **moderate level of importance** was assigned to **access to affordable equipment**, identified by **57% of respondents** as a priority. Although still valued, this factor appears less pressing than the need for training and financial support. This finding suggests that miners may already have some access to basic tools or perceive that equipment alone is insufficient without accompanying **technical knowledge and financial backing**.

At the lower end of the spectrum, only **14% of respondents** prioritized **better gold pricing** and **government subsidies for mercury-free technology**. This lower ranking does not necessarily imply that economic incentives are unimportant, but rather that miners are more immediately focused on **practical and tangible forms of support**. Legal or policy frameworks may be viewed as secondary to the more immediate challenges of implementation and economic survival.

Overall, these findings carry important implications for the design of future **transition and capacity-building programs**. Miners clearly favor interventions that provide **direct, hands-on assistance** – particularly those that build technical skills and reduce financial risks. The preference for training and practical support over purely regulatory approaches suggests that **top-down policies alone are unlikely to succeed** without complementary **grassroots-level engagement and empowerment initiatives**.

The questionnaire results for the **Policy and Future Outlook** section are presented in Figures 26–28. Survey results from **Section 4 (Question 1)** reveal important trends regarding stakeholder views on whether Suriname should implement a full ban on mercury use in artisanal and small-scale gold mining (ASGM). Among the respondents, **62% expressed support for a full ban**, but only on the condition that viable alternatives are made available to miners (Figure 26). This suggests a strong willingness to transition away from mercury, provided the shift is supported with practical solutions and adequate resources.

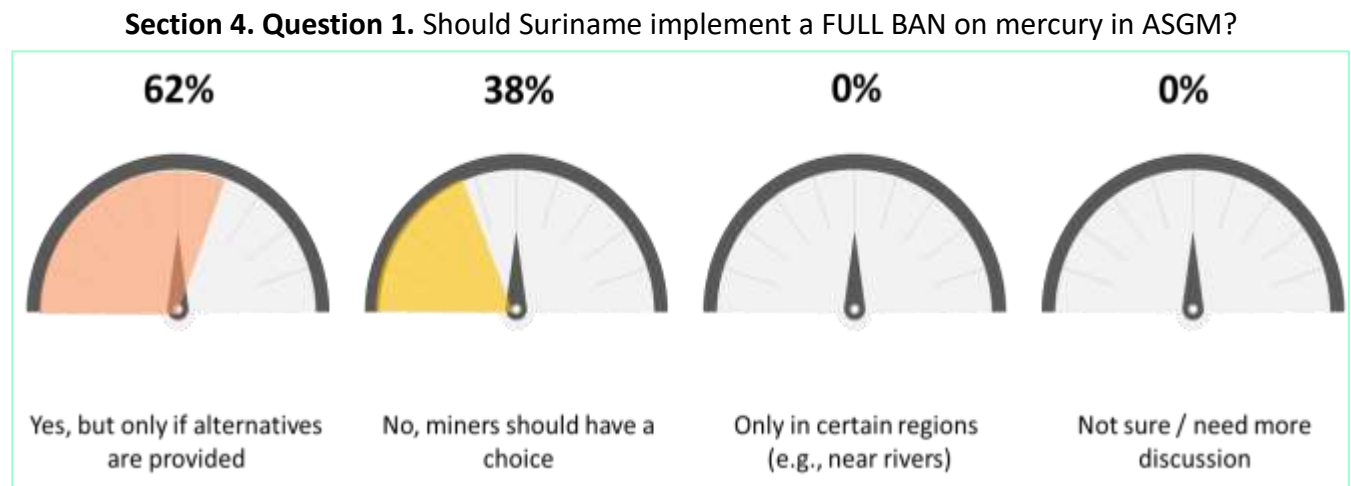


Figure 26. Survey responses to the Question 1 of Policy and Future Outlook section

In contrast, **38% of respondents opposed a complete ban**, arguing that miners should retain the freedom to choose their preferred processing method. This group **emphasized the importance of flexibility and individual decision-making in ASGM**, possibly reflecting concerns about livelihoods, autonomy, and the practicality of enforcing such a ban.

Notably, none of the respondents selected the options indicating that a ban should be limited to certain regions or that more discussion was needed, which suggests a clear polarization between conditional support for a ban and outright opposition.

These findings underscore the **critical importance of coupling any future regulatory action with robust support mechanisms**. A blanket ban without parallel investment in accessible, proven alternatives is likely to face resistance and may lead to unintended consequences such as non-compliance or increased informality. Conversely, well-designed transition strategies – grounded in consultation, training, and

economic incentives – could foster broad-based support for mercury phase-out efforts in Suriname. The visual analysis of responses to how the government should regulate cyanide use reveals clear preferences among stakeholders (Figure 27). Notably, **no respondents supported an approach that allows the use of cyanide but under regulated conditions and with mandatory training**. Similarly, **no participants favoured a completely unregulated approach**, suggesting a shared understanding of the need for oversight to prevent potential environmental or health risks.

Section 4. Question 2. How should the government regulate cyanide use?



Figure 27. Survey responses to the Question 2 of Policy and Future Outlook section

A small minority expressed support for strict regulation, reflecting cautious attitudes toward cyanide use. However, **the majority of stakeholders (86%) favoured a complete ban**, indicating that cyanide is not widely accepted as a mercury alternative. The **results suggest a prevailing consensus in favour of prohibiting cyanide's application**. Additionally, stakeholders seem to prioritize regulatory frameworks with punitive measures.

The survey reveals important insights into miners' perceptions of the drawbacks associated with mercury use in gold extraction. A single dominant concern stands out among the responses, painting a clear picture of how miners view the challenges and limitations surrounding the use of mercury (Figure 28).

A majority of respondents **(62.5%) identified the continued reliance on mercury due to the absence of viable alternatives as their primary concern**. This suggests that while miners are aware of the environmental and health risks associated with mercury, they feel effectively trapped by a lack of practical, accessible, and economically feasible options. The perceived inevitability of mercury use reflects both limited exposure to alternative technologies and a sense of resignation regarding the feasibility of making a change under current conditions.

A smaller proportion of respondents **(25.0%) noted the potential for a gradual shift toward cyanide-based extraction methods**, contingent on regulatory allowances. This **finding indicates** some awareness and **potential openness to alternative technologies**, but also underscores a dependency on supportive legal and policy frameworks for any transition to occur. The limited mention of cyanide suggests that even when alternatives are known, they are not yet viewed as broadly applicable or easily adoptable.

Interestingly, **none of the respondents cited industrial or large-scale mining takeover as a perceived disadvantage of mercury use**. This suggests that miners in the artisanal and small-scale gold mining (ASGM) sector do not currently view formalization or encroachment by industrial operations as a threat

to their livelihoods. This could reflect a strong sense of identity and resilience within the ASGM sector, or simply a prioritization of more immediate, practical concerns over longer-term structural shifts.

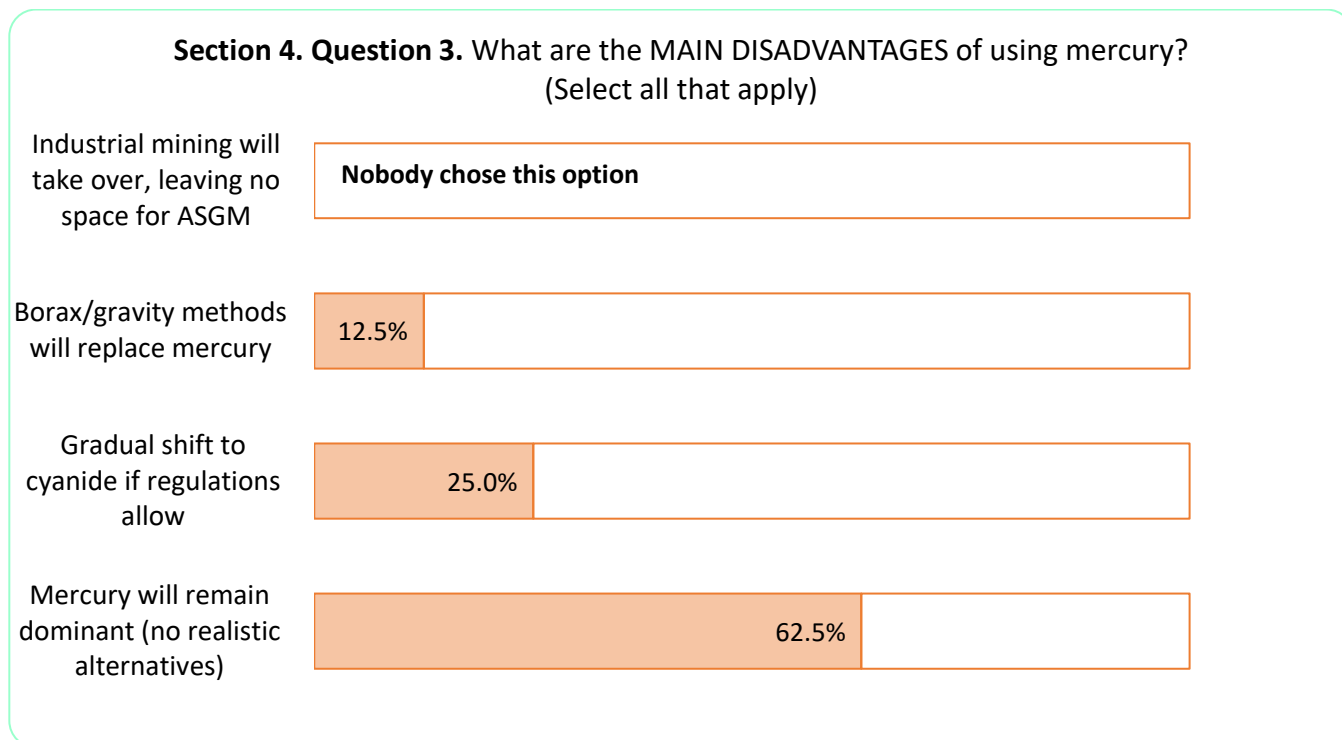


Figure 28. Survey responses to the Question 3 of Policy and Future Outlook section

The implications of these findings are significant. The **dominant perception of mercury's inevitability underscores the urgent need to increase the visibility, credibility, and accessibility of mercury-free alternatives**. Without strong demonstrations of technical and economic viability, miners are unlikely to voluntarily shift their practices. Furthermore, the openness to cyanide adoption by a minority of respondents suggests that regulatory reform could play a role in shaping the future of ASGM extraction methods.

6.1.2 Significance and Application of Results

The results of this questionnaire provide a nuanced understanding of the chemical practices, perceptions, and transition barriers among artisanal and small-scale gold miners in Suriname. They reveal that **mercury remains overwhelmingly dominant in gold extraction, with 90% of respondents reporting its use through amalgamation**. This finding underscores the deep-rooted reliance on mercury driven primarily by its simplicity, speed, and historical familiarity rather than by cost considerations or lack of alternatives. The near-total absence of cyanide and other non-cyanide lixiviants such as borax, thiourea, and thiosulfate highlights substantial technological, informational, and infrastructural gaps that continue to limit the diversification of extraction methods in the sector. The reported use of improvised and hazardous substances such as cement and battery acid further indicate a lack of technical guidance and regulatory oversight, posing significant risks to both human and environmental health. Despite the entrenched use of mercury, miners exhibit a high degree of awareness regarding its adverse

impacts. The majority recognize mercury's environmental pollution and health hazards, **indicating that resistance to change is not rooted in ignorance of its dangers but rather in the absence of feasible, trusted, and efficient alternatives**. This awareness presents an opportunity to design interventions that build on miners' existing understanding of health and environmental risks while addressing practical constraints that impede change.

Findings from the cyanide and non-cyanide alternatives section reveal that **most miners perceive cyanide as unsuitable for their ore types but acknowledge its global acceptance and efficiency when managed properly**. This combination of scepticism and conditional openness suggests that with appropriate training, regulatory guidance, and infrastructure for safe waste management, there may be a pathway for selective introduction of cyanide or other controlled alternatives in certain contexts. However, the absence of any current use and the strong support for strict regulation or complete prohibition underscore prevailing caution and the need for transparent, science-based policy frameworks before any widespread adoption.

The analysis of barriers to technology change highlights the multifaceted nature of challenges preventing the shift away from mercury. **High costs, technical complexity, lack of training, and limited financial incentives emerged as the most significant obstacles**. Moreover, miners' resistance to change and misaligned government policies were identified as additional impediments. These findings indicate that **technological innovation alone is insufficient – successful mercury reduction requires a coordinated, systemic approach** that addresses economic, technical, and behavioural dimensions simultaneously. Strategies must include training programs, demonstration projects, financial subsidies, and premium markets for mercury-free gold, supported by enabling policy environments that foster participation rather than penalization.

Equally important, miners emphasized the need for practical and immediate forms of support. The overwhelming demand for training and government subsidies, along with strong interest in market incentives such as better pricing for mercury-free gold, highlights those **miners are willing to adopt cleaner methods if the transition is economically and operationally feasible**. This finding underscores the importance of coupling environmental objectives with tangible livelihood benefits.

Finally, miners' responses regarding future policy directions reveal a conditional readiness for change. A **majority support a full ban on mercury use, but only if viable and accessible alternatives are provided**. The lack of support for unregulated or loosely controlled cyanide use demonstrates a strong preference for responsible oversight. The dominant perception that mercury use persists only because no viable alternatives exist signals both a problem and an opportunity: miners are aware of the issue and are open to change, but they need credible options, institutional backing, and clear incentives.

In summary, these findings have critical implications for policy and intervention design. Sustainable mercury reduction in Suriname's ASGM sector will require a multi-tiered approach that integrates (1) targeted training and technical assistance, (2) financial incentives and subsidies to offset transition costs, (3) rigorous yet participatory regulatory frameworks, and (4) community-based demonstration projects that prove the efficiency and practicality of cleaner technologies under real field conditions. By aligning environmental goals with miners' socio-economic realities and empowering them as key agents of change, these results provide a roadmap for advancing toward safer, more sustainable, and inclusive gold extraction practices in Suriname.

6.2 Analysis of Survey Responses from Suriname Geological Mining Service

6.2.1 Analysis of Survey Responses

As a result of stakeholder mapping, Suriname Geological Mining Service Institutions were identified as the most influential stakeholders who both have decision-making power and a strong interest in the mining sector. The objective of this questionnaire is to better understand GMD's perspectives on the regulation, enforcement challenges, policy gaps, and opportunities for improved governance related to the use of cyanide, mercury, and alternative lixiviants in artisanal and small-scale gold mining in Suriname. The questionnaire consisted of **13 questions**, grouped into **five thematic sections**:

1. Current Regulatory Framework (3 questions)

To identify existing laws, regulations, and institutional responsibilities governing the use of mercury, cyanide, and alternative lixiviants in Suriname's ASGM sector.

2. Enforcement and Compliance Challenges (3 questions)

To assess the practical challenges and limitations faced by GMD in monitoring, enforcing, and ensuring compliance with lixiviant-related regulations.

3. Gaps in Legislation and Policy (3 questions)

To determine key weaknesses and inconsistencies in Suriname's legal and policy framework for chemical management in ASGM activities.

4. International Collaboration and Capacity Building (2 questions)

To explore opportunities for international partnerships, technical support, and capacity-building initiatives to strengthen chemical governance in ASGM.

5. Future Recommendations (2 questions)

To collect miners' views on potential regulatory measures and to gauge expectations about the future direction of ASGM in Suriname.

The questionnaire results for the **Current Regulatory Framework section** are presented in Figures 29–31. Figure 29 presents the responses regarding the current regulatory status of various lixiviants used in ASGM. The results indicate that regulatory control varies significantly across different substances.

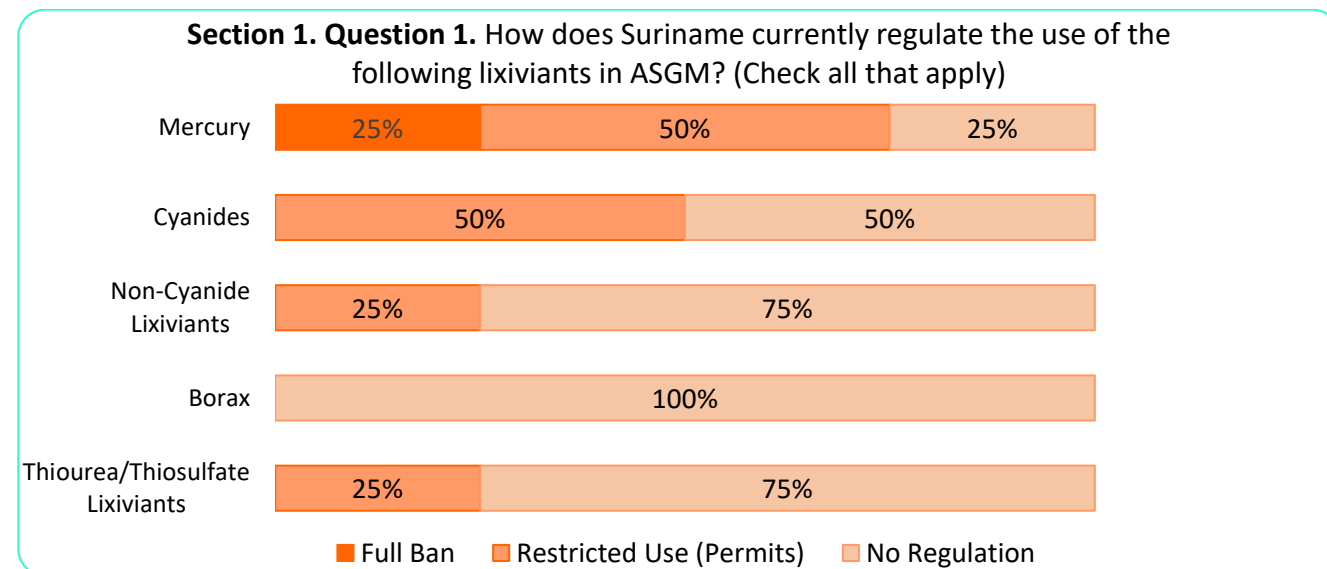


Figure 29. Survey responses to the Question 1 of Current Regulatory Framework section

Due to the respondent's opinion, mercury is subject to partial regulation, with **50% of responses indicating restricted use under permit**, while **25% reported a full ban** and another **25% noted the absence of specific regulations**. They noticed, that cyanide use is equally divided between **restricted use (50%)** and **no regulation (50%)**, suggesting inconsistency or limited enforcement of existing rules. At the same time respondents mentioned that non-cyanide lixivants and thiourea/thiosulfate are largely **unregulated (75%)**, with only **25% indicating restricted use**. This highlights a regulatory gap for emerging or alternative chemical agents that could replace mercury and cyanide. In contrast, **direct smelting (borax method) appears to be entirely unregulated (100%)**, despite being considered an environmentally benign alternative for gold extraction with mercury or cyanides.

Overall, the data suggest that **Suriname lacks a comprehensive and coherent regulatory framework for non-cyanide lixivants and alternative extraction agents**. This uneven regulatory landscape may hinder the transition toward safer, mercury- and cyanide-free technologies within the ASGM sector.

Figure 30 summarizes the responses regarding the main legal instruments that regulate the use of lixivants in Suriname's artisanal and small-scale gold mining sector. The results reveal that several legislative and regulatory mechanisms contribute to the governance of chemical use, but none appear to be dominant or fully comprehensive.

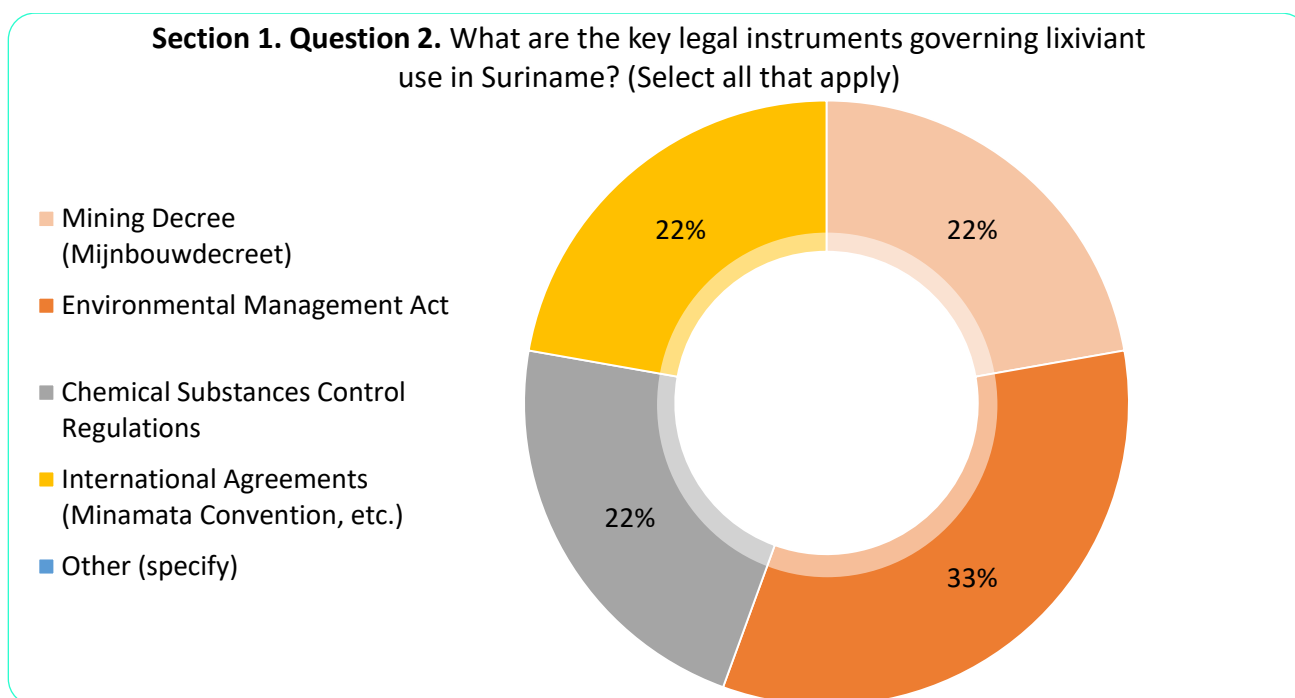


Figure 30. Survey responses to the Question 2 of Current Regulatory Framework section

The **Environmental Management Act** was identified by the largest share of respondents (**33%**) as a key legal framework, highlighting its central role in setting environmental standards and chemical control provisions. In contrast, the **Mining Decree (Mijnbouwdecreet)**, **Chemical Substances Control Regulations**, and **International Agreements** such as the **Minamata Convention** were each cited by **22%** of respondents, suggesting a more fragmented or overlapping distribution of authority.

The inclusion of **international conventions** among the key instruments indicates Suriname's recognition of global commitments to reduce mercury and other hazardous substances. However, the relatively

equal representation across multiple instruments suggests a **lack of clear institutional integration or a unified policy framework** for managing lixivants in ASGM.

Overall, the findings demonstrate that Suriname's regulatory foundation for chemical management in small-scale mining is **insufficient and dispersed**, potentially leading to enforcement inefficiencies and gaps in implementation.

Figure 31 illustrates responses regarding whether the Geological Mining Service conducts environmental impact assessments (EIAs) for ASGM operations that utilize cyanide or mercury. The results indicate a clear limitation in the application of EIAs within this sector.

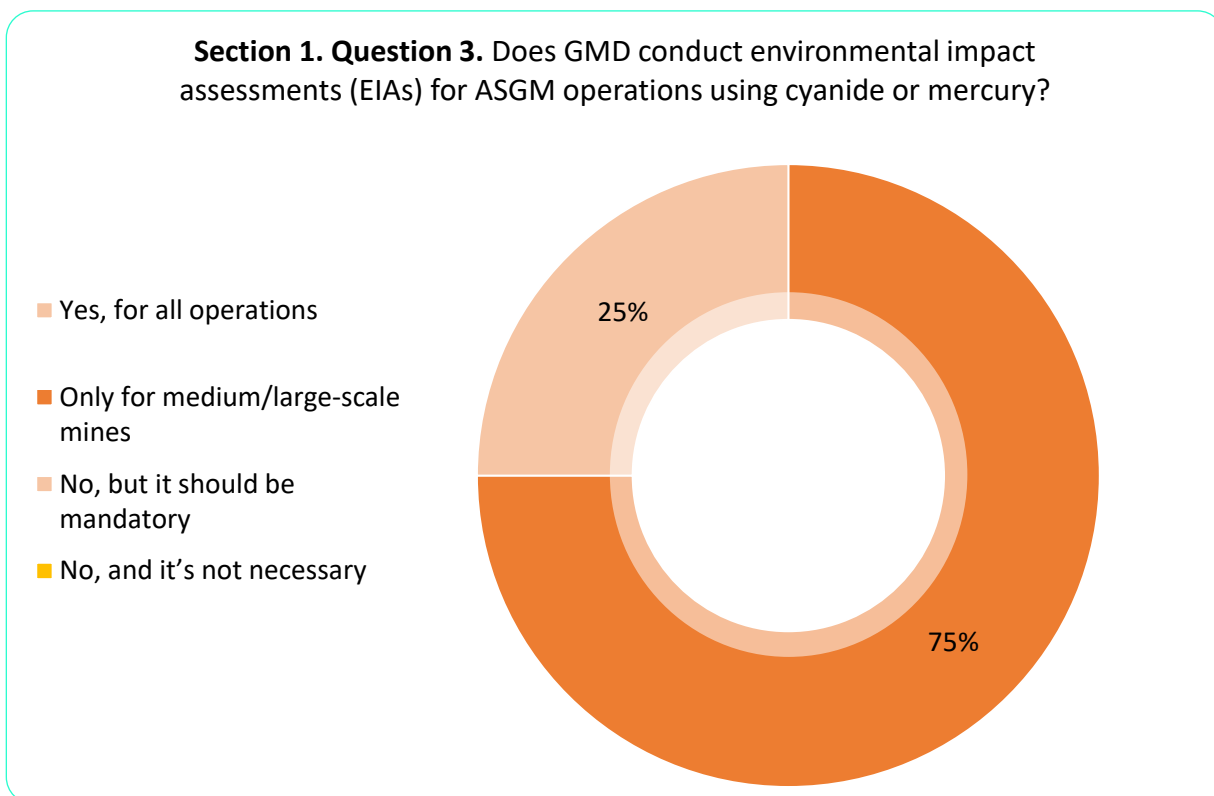


Figure 31. Survey responses to the Question 3 of Current Regulatory Framework section

A clear majority (**75%**) indicated that EIAs are carried out **only for medium- and large-scale mines**, while **25%** stated that EIAs are **not currently conducted for these operations but should be made mandatory**. No respondents reported that EIAs apply to all operations or that EIAs are unnecessary.

This distribution highlights a regulatory shortfall: formal environmental assessment procedures largely exclude artisanal and small-scale operations, even where hazardous chemicals are used. The one-quarter of respondents advocating mandatory EIAs underscores institutional recognition of this gap and a preference for strengthening oversight. Absent proportional assessment requirements or alternative simplified EIA mechanisms tailored to ASGM, small-scale operations remain a high-risk category for unassessed environmental and public-health impacts associated with mercury and potential cyanide use.

Implications for policy and practice include prioritizing (a) extension or adaptation of EIA requirements to ASGM through scaled/simplified assessment protocols, (b) capacity-building for implementation and monitoring at small scales, and (c) development of complementary measures (e.g., rapid environmental

screening, conditional permitting) to mitigate risks while accounting for sector informality.

The questionnaire results for the **Enforcement and Compliance Challenges** section are presented in Figures 32–34. Figure 32 summarizes GMD responses regarding the primary challenges to enforcing regulations on the use of lixivants in artisanal and small-scale gold mining. The results demonstrate that enforcement is hindered by a combination of institutional, operational, and social factors.

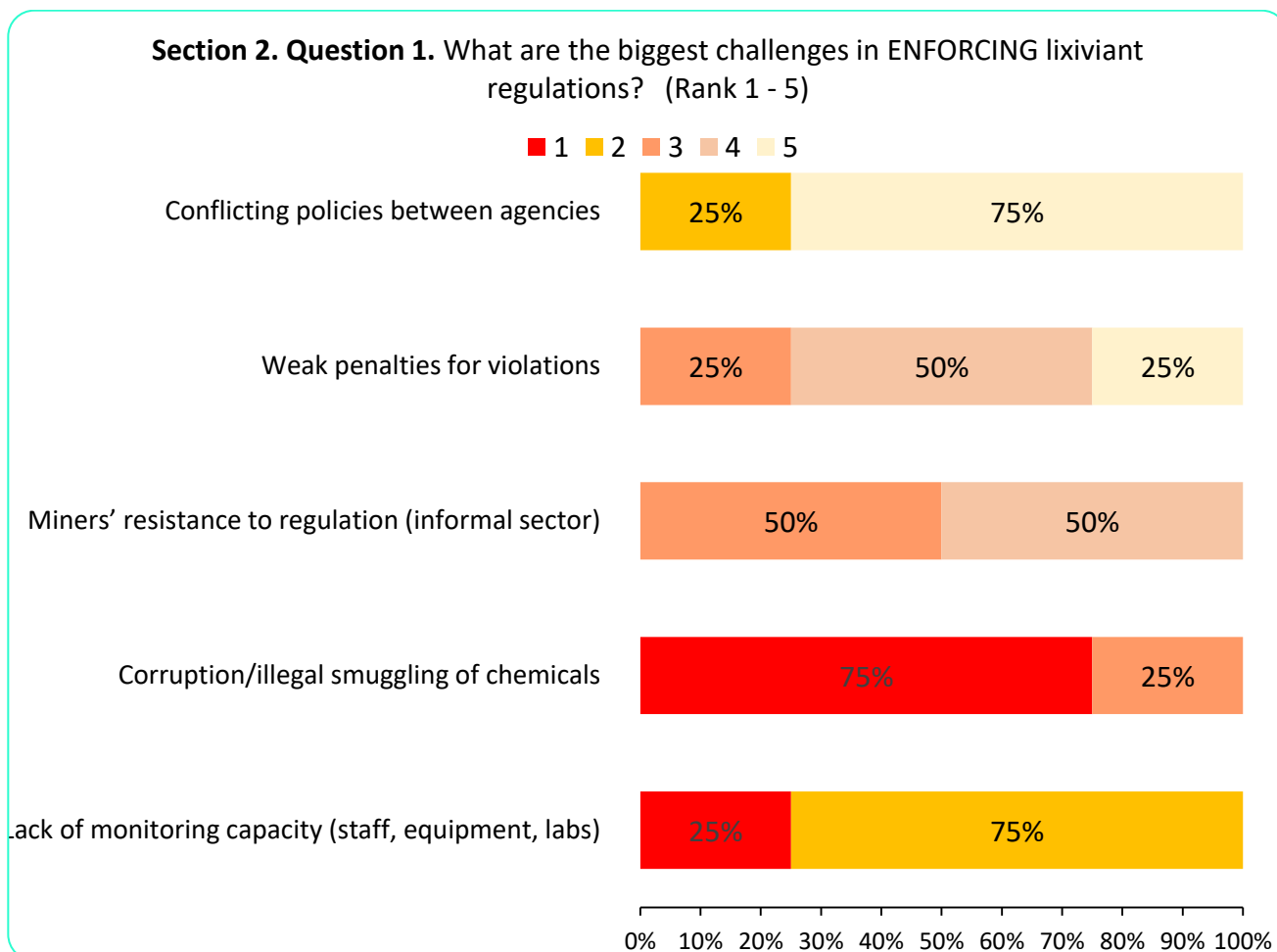


Figure 32. Survey responses to the Question 1 of Enforcement and Compliance Challenges section

The most critical enforcement constraint identified was **corruption and illegal smuggling of chemicals**, rated as the **top challenge by 75% of respondents**, followed by **lack of monitoring capacity** (staff, equipment, laboratories), which received high-priority rankings from all participants, with **25% rating it as the most severe challenge** and **75% ranking it second**. These findings indicate that institutional weaknesses and resource shortages severely limit regulatory effectiveness.

Miners' resistance to regulation – linked to informality and limited awareness – was ranked as a moderate obstacle, with **50% of respondents assigning it a medium level of importance (rank 3)** and the remaining **50% ranking it slightly lower (rank 4)**. Similarly, **weak penalties for violations** were distributed across middle to very low concern levels (25% rank 3, 50% rank 4, 25% rank 5), suggesting that existing sanctions are perceived as insufficient deterrents. **Conflicting policies between agencies** were viewed as the least pressing issue overall, with **75% ranking it lowest (rank 5)**, though it still reflects a degree of institutional overlap that can reduce coordination.

In summary, the data indicate that the **enforcement of lixiviant regulations in Suriname’s ASGM sector is constrained primarily by corruption, inadequate monitoring infrastructure, and limited institutional capacity**, while regulatory inconsistencies and miner non-compliance exacerbate these structural challenges.

Figure 33 illustrates how the Geological Mining Service currently verifies compliance with regulations governing the use of cyanide and mercury in Suriname’s artisanal and small-scale gold mining sector. The results highlight a major weakness in systematic environmental oversight.

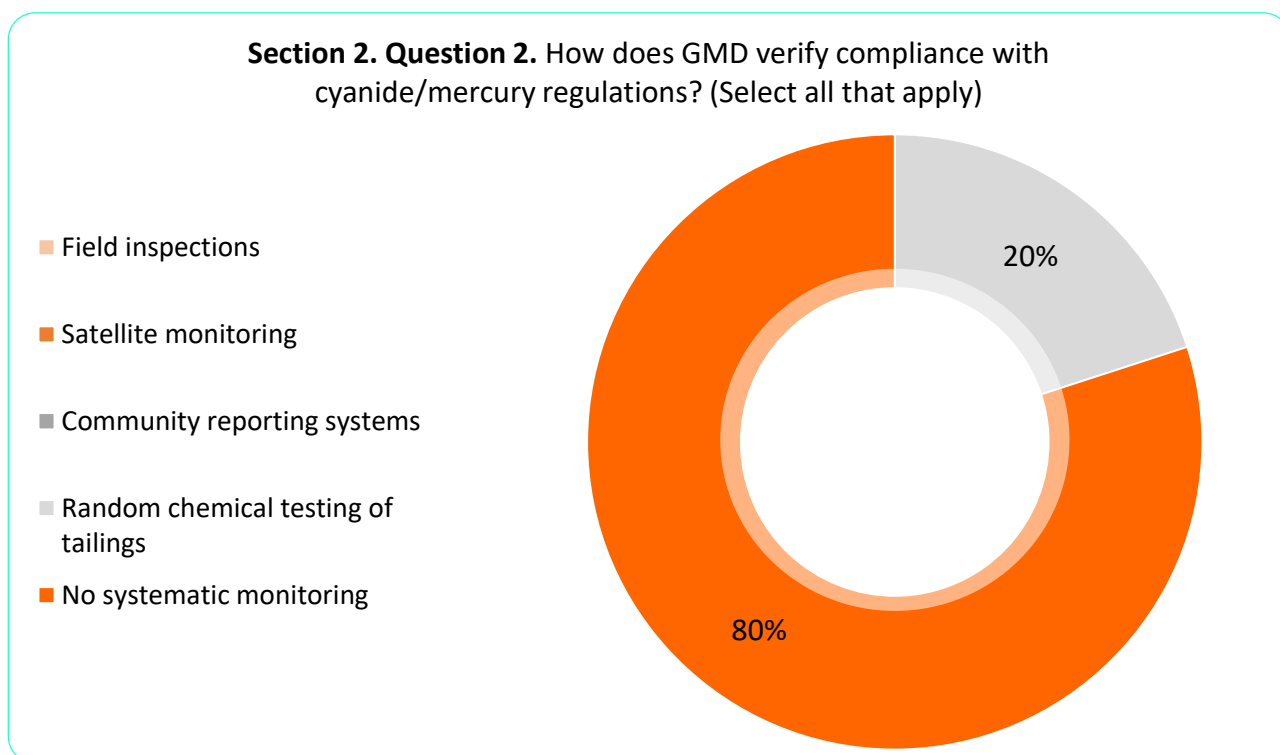


Figure 33. Survey responses to the Question 2 of Enforcement and Compliance Challenges section

The majority of respondents (80%) indicated that **no systematic monitoring** mechanisms are in place, while only 20% reported that **random chemical testing of tailings** is conducted as a means of verification. None of the respondents cited the use of **field inspections, satellite monitoring, or community reporting systems**, revealing an absence of structured or technology-based compliance methods.

These findings suggest that regulatory verification of chemical use in ASGM is **minimal and largely ad hoc**, with limited institutional capacity to routinely monitor environmental performance or detect non-compliance. The near-total lack of systematic oversight poses significant challenges for ensuring the safe management of hazardous substances and preventing contamination of surrounding ecosystems.

Figure 34 illustrates stakeholder perceptions regarding the spatial concentration of illegal lixiviant (e.g., mercury and cyanide) use within Suriname’s ASGM sector. The results indicate an even split in responses, suggesting significant uncertainty and information gaps on this issue.

Half of respondents (50%) confirmed the presence of specific **“hotspots”** where the illegal use of lixiviants is most severe. Although the chart does not specify exact regions, such responses imply localized patterns of environmental pressure likely associated with mining intensity, accessibility, and weak enforcement in remote areas. The remaining 50% of respondents reported that **no data are**

available, highlighting the absence of systematic spatial monitoring or record-keeping related to chemical use in ASGM.

Notably, **no respondents indicated that lixiviant use is evenly distributed** across mining regions, reinforcing the assumption that chemical pollution risks are spatially concentrated rather than uniform. These findings suggest that while stakeholders are aware of localized contamination risks, there remains a **critical lack of spatial data** to accurately identify and manage high-risk zones. This absence of verified information constrains evidence-based policymaking and the prioritization of environmental remediation efforts.

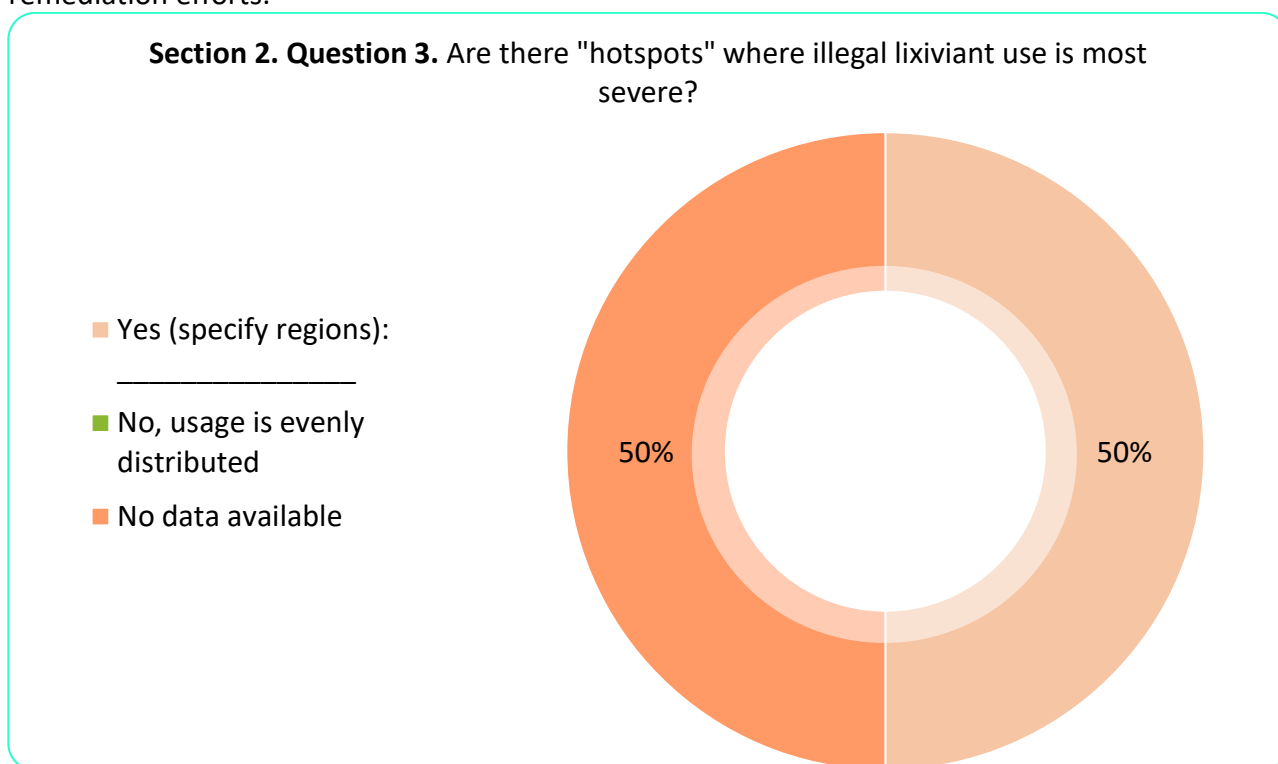


Figure 34. Survey responses to the Question 3 of Enforcement and Compliance Challenges section

The questionnaire results for the **Gaps in Legislation and Policy section** are presented in Figures 35–37. Figure 35 summarizes the main perceived deficiencies in Suriname's regulatory framework governing the use of mining chemicals, as identified by respondents. The results indicate that **weak control over chemical imports and sales** represents the most significant gap, cited by **29%** of respondents. This finding underscores the limited oversight and traceability of hazardous substances such as mercury and cyanide entering the artisanal and small-scale gold mining (ASGM) supply chain.

Two additional regulatory weaknesses were reported with equal frequency (**21%** each): the **absence of rehabilitation requirements for contaminated sites** and the **lack of a clear distinction between ASGM and industrial mining rules**. These gaps suggest that post-mining environmental management is not adequately enforced and that the regulatory framework does not sufficiently differentiate between the operational scales and environmental risks of small-scale versus industrial mining activities.

Meanwhile, **14%** of respondents identified a **lack of promotion for mercury-free alternatives**, indicating insufficient institutional or financial incentives to support the transition to cleaner technologies. Another **14%** highlighted **inconsistent enforcement across regions**, suggesting that regulatory implementation varies geographically, likely reflecting differences in institutional capacity and monitoring resources.

Section 3. Question 1. What are the biggest GAPS in Suriname's regulation of mining chemicals? (Select all that apply)

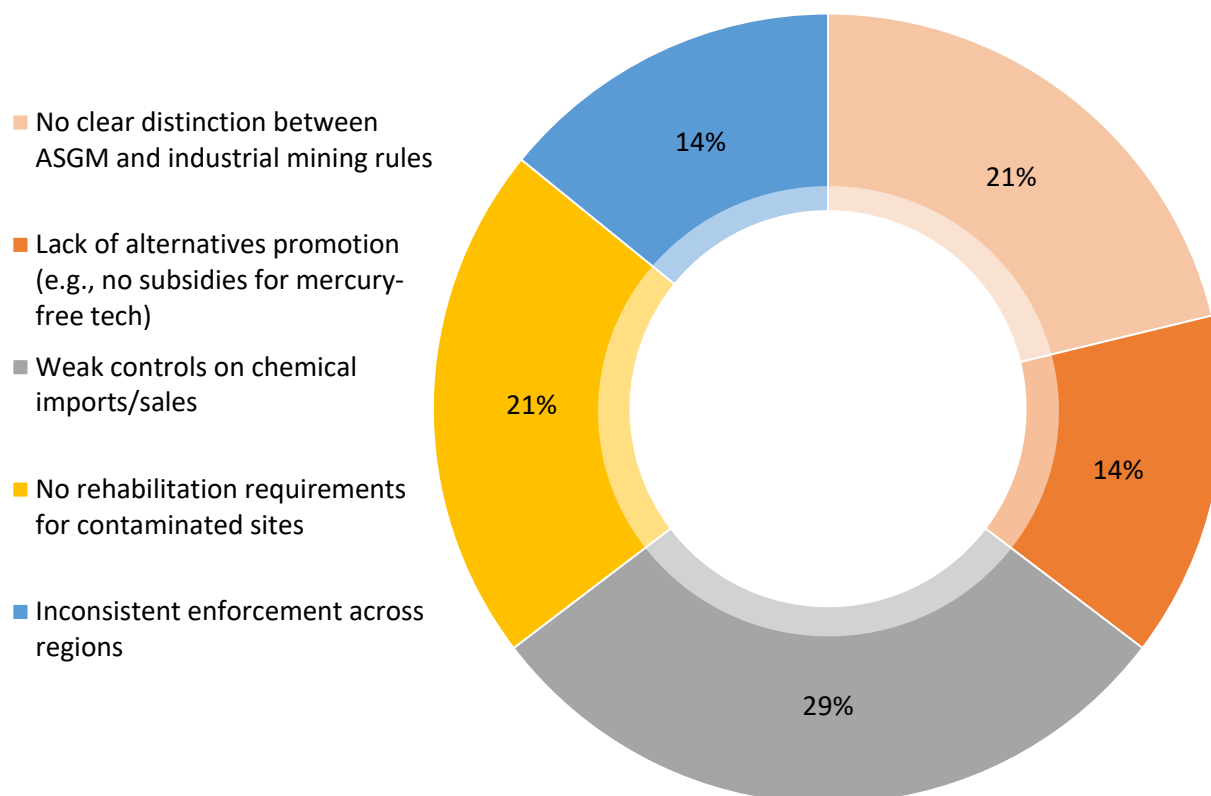


Figure 35. Survey responses to the Question 1 of Gaps in Legislation and Policy section

Figure 36 presents the results of a survey question regarding the potential adoption of stricter regulations on cyanide use in Suriname, specifically asking about mandatory detoxification and closed-loop systems.

Section 3. Question 2. Should Suriname adopt STRICTER rules on cyanide (e.g., mandatory detox, closed-loop systems)?

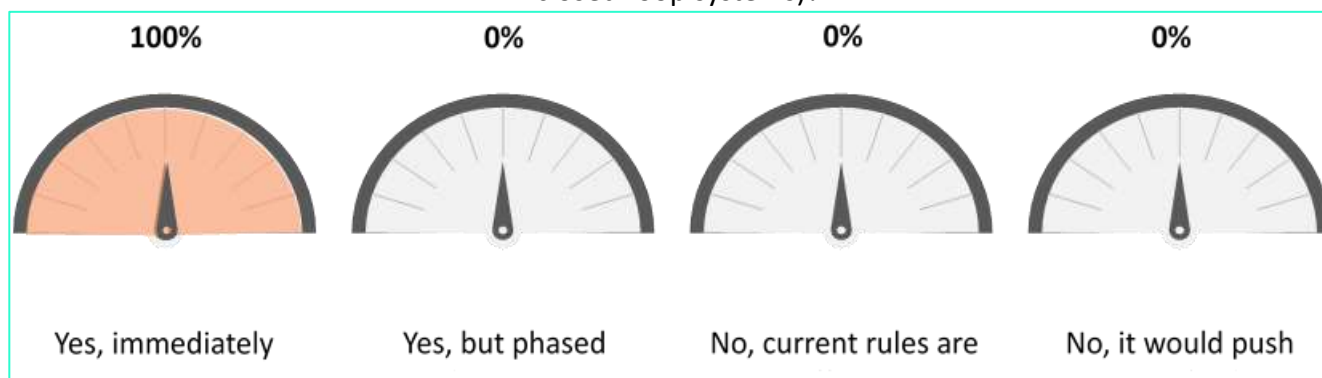


Figure 36. Survey responses to the Question 2 of Gaps in Legislation and Policy section

The data reveals a powerful and unambiguous mandate from the survey participants. The fact that 100% of respondents selected **"Yes, immediately"** indicates a profound consensus on the urgency and

necessity of strengthening cyanide regulations. This result suggests that stakeholders perceive the current regulatory framework as inadequate and that the associated environmental and health risks are significant enough to warrant immediate governmental action.

The absence of support for a phased approach ("**Yes, but phased**": 0%) underscores a preference for swift, decisive policy implementation over a gradual one. Furthermore, the complete lack of opposition (both "**No**" options at 0%) implies that, within this sample, concerns over potential economic drawbacks or the adequacy of existing rules are considered secondary to the imperative of implementing stricter environmental and safety controls.

Figure 37 presents the results of a survey question assessing whether the GMD or the relevant national body in Suriname has a strategy to phase out mercury use in alignment with its commitments under the Minamata Convention.

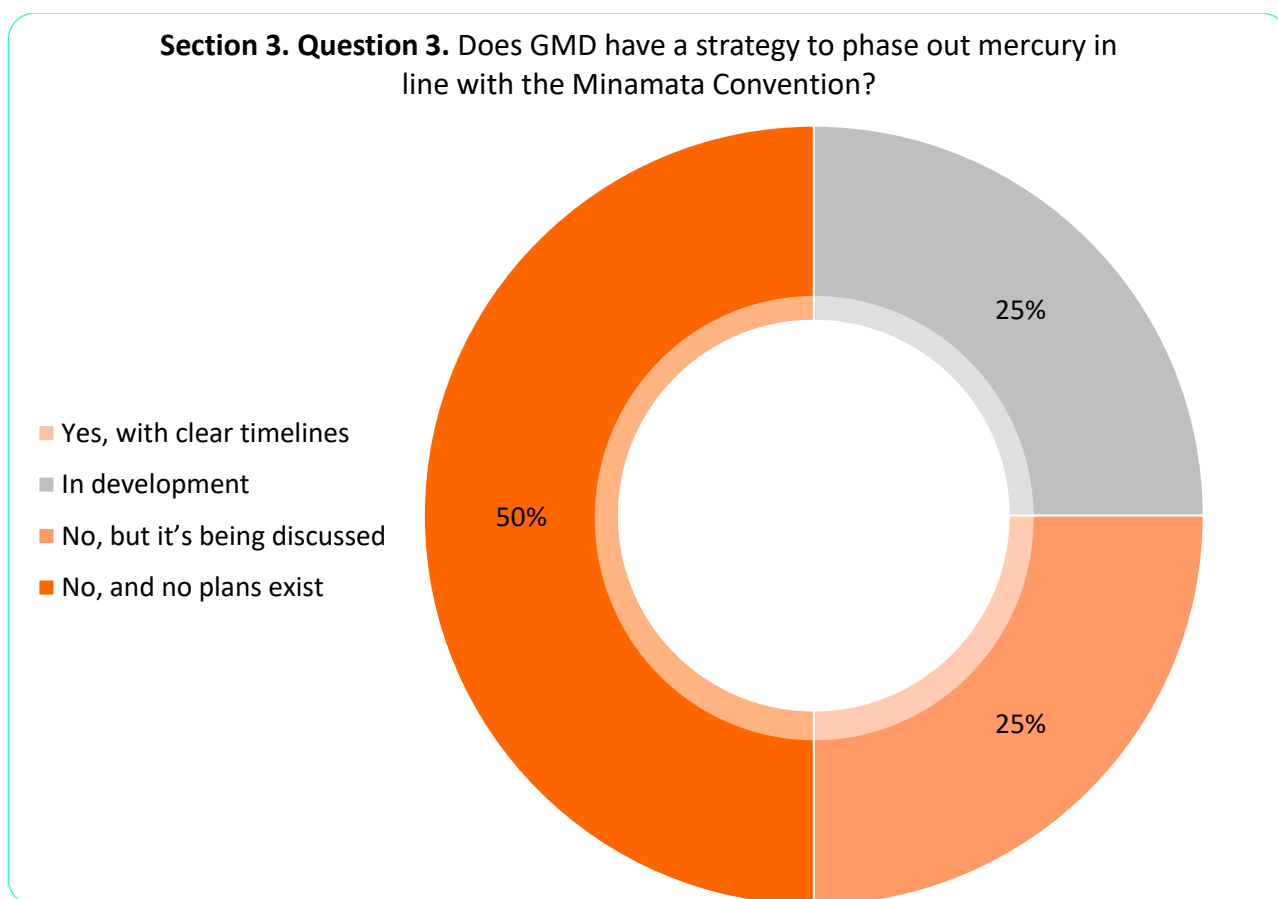


Figure 37. Survey responses to the Question 3 of Gaps in Legislation and Policy section

Crucially, only 25% of respondents believe a plan is "**In development**." This minority view, juxtaposed with the 75% who see no active development ("**No, but...**" and "**No plans**"), points to severe internal communication failures, a lack of transparent process, or starkly different perceptions of progress within the organization. It suggests that any development efforts are either in their earliest stages or are not being effectively communicated to the majority of stakeholders.

This result directly identifies a critical gap between Suriname's international commitment (as a party to the Minamata Convention) and its domestic regulatory action.

The questionnaire results for the **Gaps in International Collaboration and Capacity Building section** are

presented in Figures 38–39. Figure 38 presents the results of a survey question regarding the types of international support deemed most critical for improving lixiviant (e.g., cyanide, mercury) regulation in Suriname. Respondents were able to select all options they found applicable.

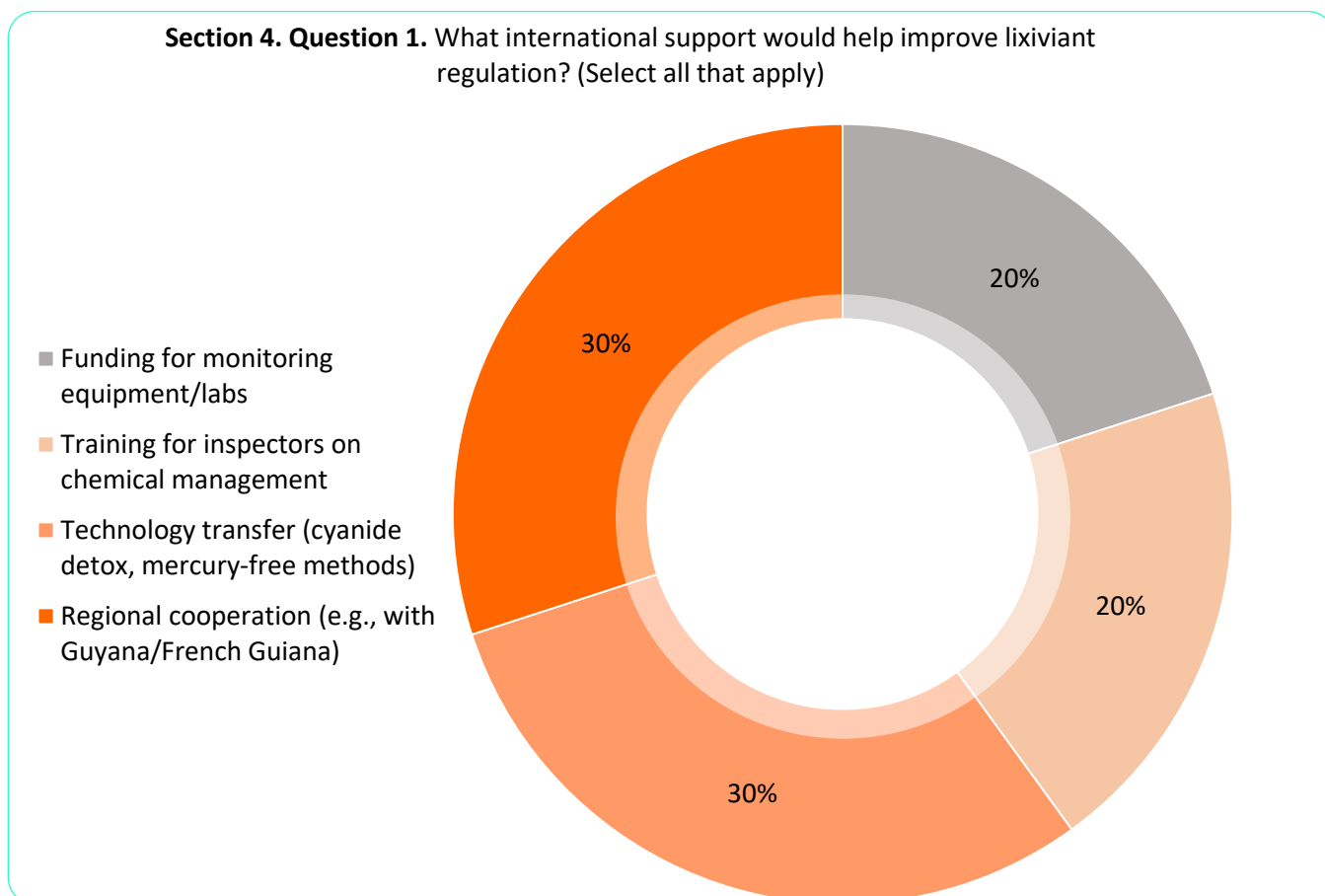


Figure 38. Survey responses to the Question 1 of Gaps in International Collaboration and Capacity Building section

The results reveal a clear and balanced prioritization among three key areas of international support, with a slightly lower priority placed on training alone. The equal weighting of **30% each for funding, technology transfer, and regional cooperation** indicates that stakeholders view these as interconnected and equally critical pillars for enhancing regulatory capacity.

The analysis of this survey data demonstrates that **stakeholders prioritize a multi-faceted approach to international support**. To significantly improve lixiviant regulation, efforts should be concurrently directed towards securing funding for foundational monitoring infrastructure, facilitating the transfer of cleaner technologies, and fostering robust regional cooperation, with capacity-building integrated within these initiatives.

Figure 39 presents the results of a survey question regarding the establishment of a centralized database for tracking lixiviant (e.g., cyanide, mercury) use in ASGM sector in Suriname. The data reveals a powerful and unambiguous mandate from the survey participants. The fact that **100% of respondents selected "Yes, with real-time tracking"** indicates a profound consensus on the need for the most robust and technologically advanced monitoring solution available.

Section 4. Question 2. Should Suriname establish a CENTRALIZED DATABASE for lixiviant use in ASGM?

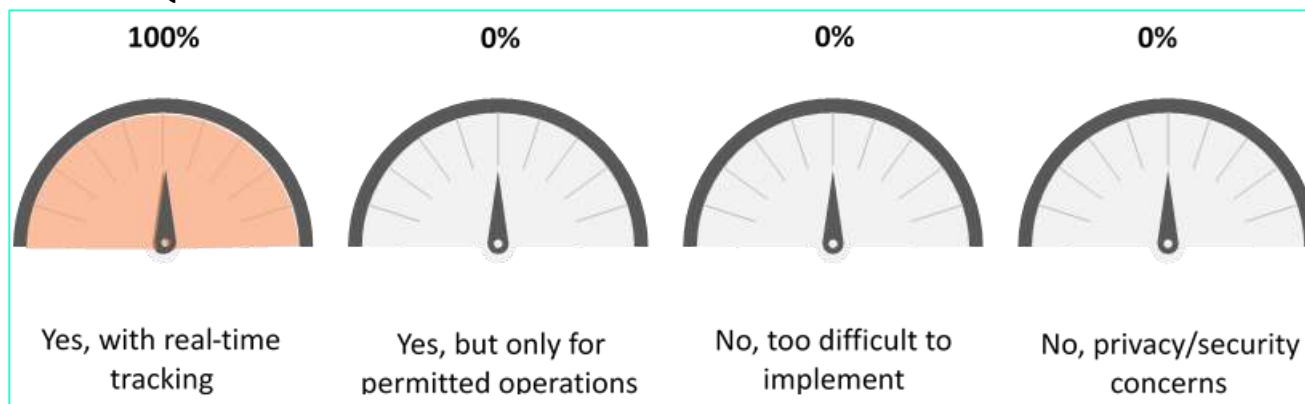


Figure 39. Survey responses to the Question 2 of Gaps in International Collaboration and Capacity Building section

The results demonstrate an overwhelming and specific demand from surveyed stakeholders for the Surinamese government to establish a centralized database with real-time tracking for lixiviant use in the ASGM sector. This finding points to a critical gap in current monitoring capabilities and provides a robust empirical basis for recommending the immediate development and implementation of this advanced technological solution.

The questionnaire results for the **Future Recommendations section** are presented in Figures 40–41. Figure 40 represents the results of ranking the reforms, needed for safer lixiviant use in Suriname.

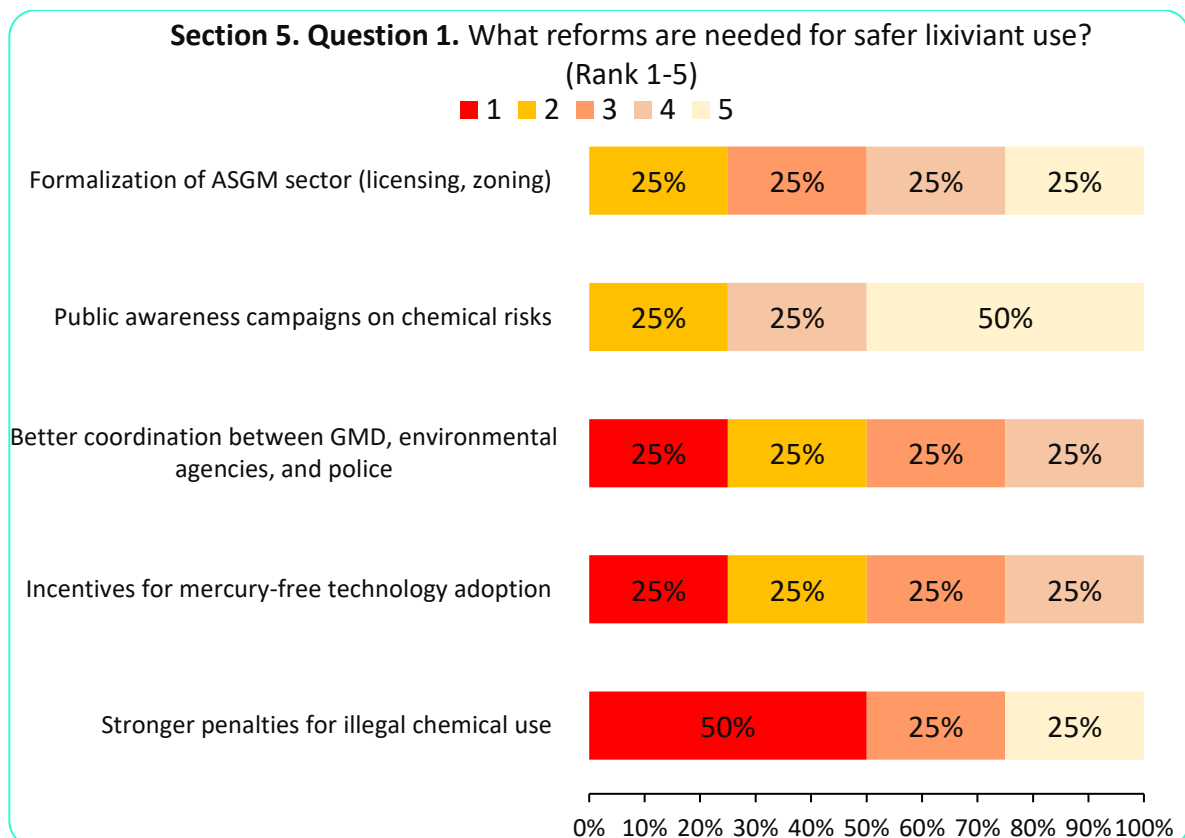


Figure 40. Survey responses to the Question 1 of Future Recommendations section

The data, collected through a ranking exercise, reveals a clear prioritization of institutional and punitive measures over awareness and incentives. The measure "Stronger penalties for illegal chemical use" was ranked as the top priority, receiving 50% of the first-place votes. This indicates a strong consensus among stakeholders that **enforcement and deterrence are the most critically needed actions**. The measures **"Formalization of the ASGM sector"** and **"Better coordination between government agencies"** demonstrated consistent importance across all ranking positions, each receiving an even distribution of 25% for ranks one through four. This pattern suggests these **are universally acknowledged as foundational, cross-cutting reforms essential for any effective regulatory framework**.

In contrast, the measure **"Public awareness campaigns on chemical risks"** was not selected as a first or second priority by any respondent. It received 50% of its votes in the third rank and 25% each in the fourth and fifth ranks, indicating it is **perceived as a necessary but secondary or supportive measure**. Similarly, "Incentives for mercury-free technology adoption" also showed an even distribution across ranks one through four, mirroring the pattern of formalization and coordination. **This positions technological incentives as a core component of reform, but not the single highest priority when compared to the immediate need for stronger enforcement.**

Figure 41 presents the stakeholders' priorities for policy reforms aimed at improving chemical management in the ASGM sector.

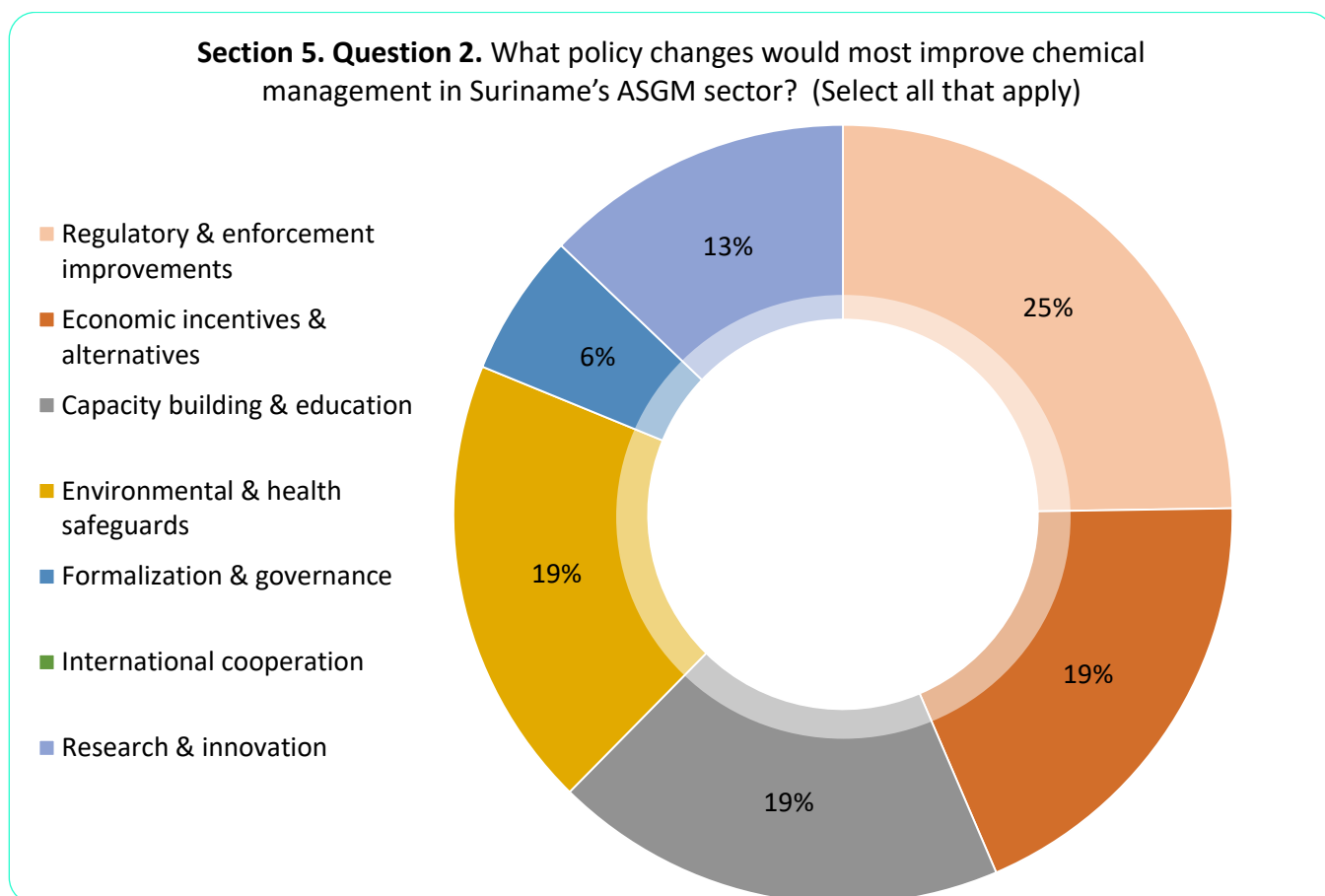


Figure 41. Survey responses to the Question 2 of Future Recommendations section

The data reveals a clear hierarchy of priorities among stakeholders. The most frequently selected policy change was **"Regulatory and enforcement improvements,"** which accounted for 25% of all responses, indicating it is **perceived as the single most critical area for intervention**. A group of three policy areas were tied as the next highest priorities, each receiving 19% of the responses: **"Capacity building and education,"** **"Environmental and health safeguards,"** and **"Formalization and governance."** This demonstrates that **stakeholders view investments in human capital, environmental protection, and structural sector reform as equally vital and interconnected pillars for improvement**. The policy of **"International cooperation"** received a lower but still notable priority at 13%, while **"Economic incentives and alternatives"** was selected least frequently at 6%. The option for **"Research and innovation"** received no selections, suggesting it is considered a lower priority relative to more immediate regulatory, governance, and capacity-building needs.

6.2.2 Significance and Application of Results

The results of the survey conducted among representatives of the Suriname Geological Mining Service provide valuable empirical evidence on the current state of chemical management governance within Suriname's artisanal and small-scale gold mining sector. The findings are particularly significant as they illuminate the structural, institutional, and policy deficiencies that currently impede the safe and sustainable use of lixivants such as mercury, cyanide, and emerging alternatives. The results reveal that the **existing regulatory framework is fragmented and unevenly enforced, with mercury and cyanide only partially regulated and non-cyanide lixivants almost entirely unregulated**. This fragmented control structure contributes to inconsistent oversight and hinders the transition to safer, mercury-free extraction technologies. Furthermore, the limited application of environmental impact assessments (EIAs) to only medium- and large-scale mining operations exposes a critical regulatory gap, as **small-scale miners continue to operate without adequate environmental screening or risk mitigation measures**. From an enforcement perspective, the survey highlights that **corruption, inadequate monitoring infrastructure, and lack of institutional capacity represent the most severe constraints to effective chemical governance**. The absence of systematic monitoring mechanisms – combined with reliance on occasional or random chemical testing – points to serious institutional weaknesses that undermine compliance verification. This deficiency not only increases environmental risks but also restricts the ability of regulatory bodies to detect and respond to illegal or unsafe practices. Moreover, the perception of localized "hotspots" of illegal lixiviant use, combined with the lack of spatial data, indicates the urgent need for an evidence-based approach to environmental surveillance and risk mapping.

The policy and legislative findings further emphasize the importance of reform. **Weak control over chemical imports and sales, absence of rehabilitation requirements, and the lack of differentiation between ASGM and industrial mining rules were all identified as significant regulatory gaps**. The unanimous support (100%) among respondents for immediate adoption of stricter cyanide regulations and the establishment of a centralized, real-time monitoring database demonstrates a strong institutional consensus and readiness for reform. These measures, if implemented, would mark a transformative step toward improving transparency, traceability, and accountability in chemical use.

In terms of practical application, these findings provide a robust foundation for designing targeted policy interventions and capacity-building programs. They support the development of a comprehensive national framework for chemical governance that integrates enforcement, monitoring, and education. Specifically, the results call for the adaptation of simplified or scaled EIA

procedures for ASGM, the introduction of stronger penalties for illegal chemical use, and the formalization of small-scale mining operations to facilitate oversight. The emphasis placed by respondents on international cooperation, technology transfer, and funding underscores the need for global partnerships to strengthen national capabilities and align Suriname's practices with international standards, such as those set forth under the Minamata Convention.

Ultimately, the significance of this study lies in its ability to translate stakeholder insights into actionable policy recommendations. **By addressing the identified gaps and prioritizing reforms in enforcement, institutional coordination, and environmental monitoring, Suriname can move toward a more sustainable, transparent, and responsible ASGM sector.** The application of these results will not only reduce environmental and health risks associated with mercury and cyanide use but also contribute to building a resilient governance system that supports green technologies, formalization, and long-term environmental stewardship in the mining sector.

6.3 Analysis of Survey Responses from Indigenous Communities and Traditional Leaders

6.3.1 Analysis of Survey Responses

The objective of this questionnaire is to understand the awareness, concerns, and perspectives of indigenous communities and traditional leaders regarding the use of lixiviants (such as mercury and cyanide) in ASGM and explore potential solutions.

The questionnaire consisted of **10 questions**, grouped into **three thematic sections**:

1. Awareness of Lixiviants Used in ASGM (4 questions)

To assess the stakeholders' level of knowledge and recognition of the specific chemicals used in artisanal and small-scale gold mining.

2. Perceptions on Regulation and Technology (3 questions)

To gauge stakeholder opinions on the effectiveness of current mining regulations and the availability and suitability of existing technologies.

3. Solutions and Community Needs (3 questions)

To identify the most critical interventions and support mechanisms required by communities and the sector to transition towards safer and more sustainable mining practices.

The questionnaire results for the **Awareness of Lixiviants Used in ASGM** section are presented in Figures 42–45. They reveal a community with universal recognition of the topic but critical gaps in specific knowledge and risk perception. As illustrated in Figure 42, all respondents (100%) confirmed they had heard of the chemicals used by miners to extract gold, indicating the topic is prominent within the surveyed community. However, as shown in Figure 43, this awareness is narrowly confined to a single substance, with 100% of respondents identifying mercury and 0% selecting cyanide or non-cyanide alternatives, indicating a significant blind spot regarding other prevalent and potentially less harmful technologies.

Furthermore, there is a pronounced ambiguity regarding the perceived risks associated with these chemicals. Figures 44 and 45 reveal a stark polarization in community perceptions: for both human health and environmental impact, 50% of respondents recognized the dangers, while the remaining 50% were uncertain, and no respondents considered the chemicals to be safe. This indicates that although the presence of potential hazards is acknowledged, a substantial portion of the community lacks

definitive knowledge, underscoring a critical need for targeted risk communication and education initiatives to improve understanding of the environmental and health implications of chemical use in ASGM.

Section 1. Question 1. Have you heard about the chemicals (lixivants) miners use to extract gold?

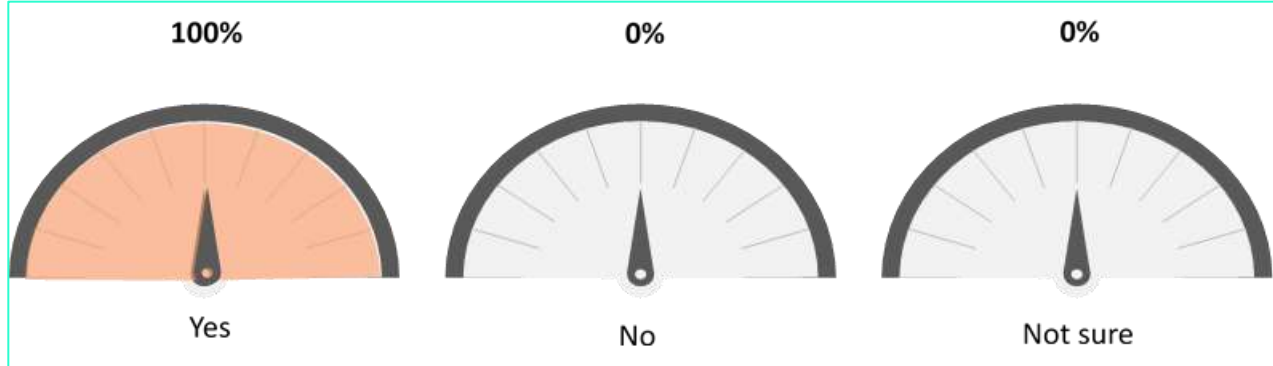


Figure 42. Survey responses to the Question 1 of Awareness of Lixivants Used in ASGM section

Section 1. Question 2. Which lixivants do you know are used in mining?
(Select all that apply)

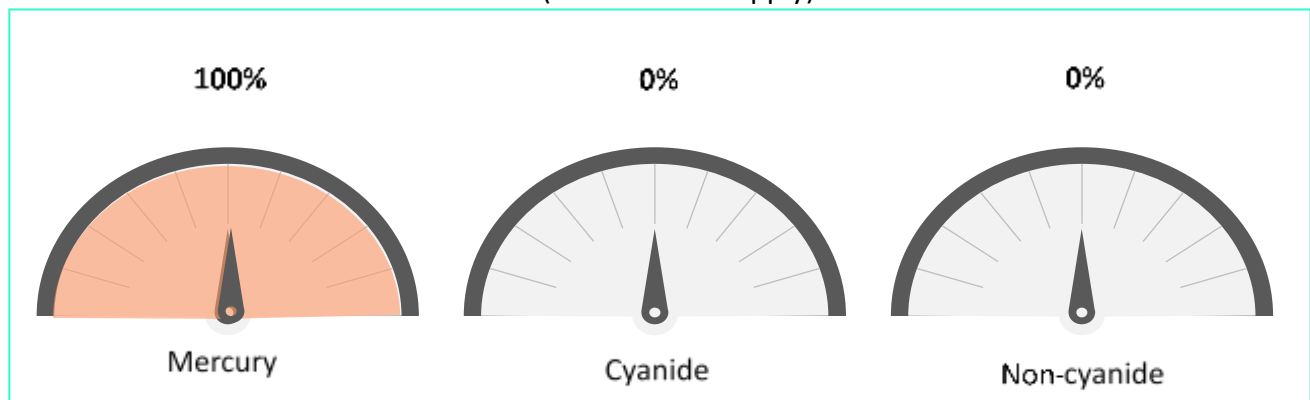


Figure 43. Survey responses to the Question 2 of Awareness of Lixivants Used in ASGM section

Section 1. Question 3. Do you think these chemicals are dangerous for health?

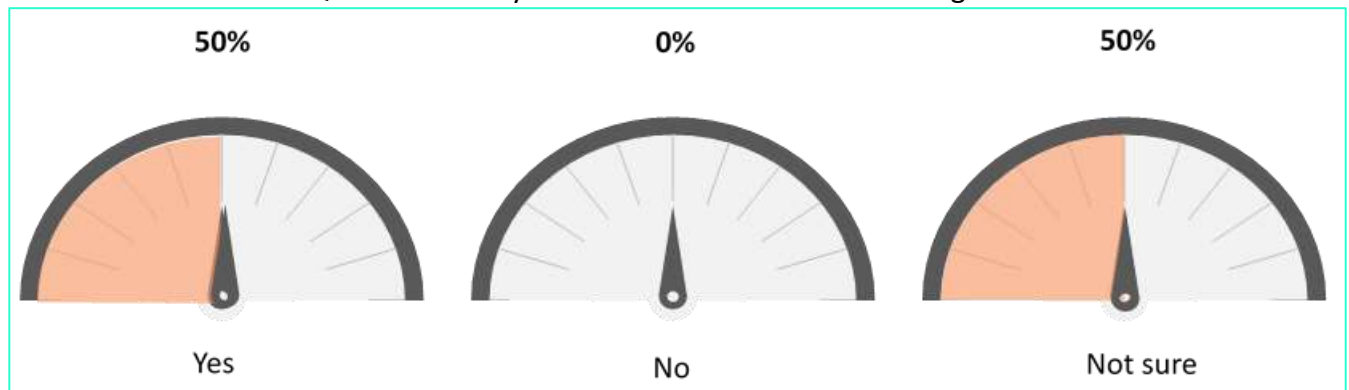


Figure 44. Survey responses to the Question 3 of Awareness of Lixivants Used in ASGM section

Section 1. Question 4. Do you think these chemicals harm the environment (rivers, soil, animals)?

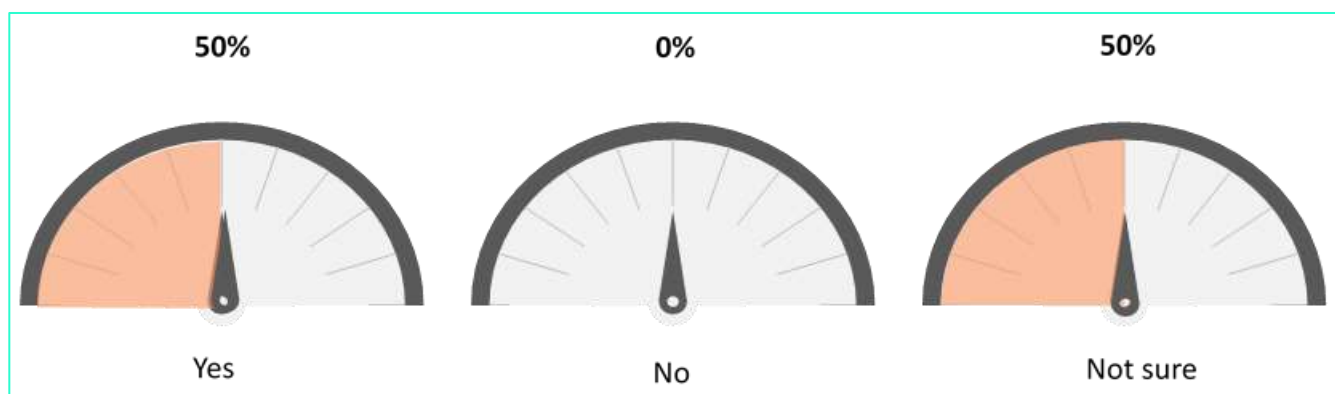


Figure 45. Survey responses to the Question 4 of Awareness of Lixiviants Used in ASGM section

The questionnaire results for **Perceptions on Regulation and Technology**, presented in Figures 46–48, reveal a complex and divided stakeholder landscape. As shown in Figure 46, responses regarding government control of chemical use were evenly split, with 50% in favour and 50% opposed. This polarization highlights a fundamental tension between the perceived need for regulatory oversight and safety on one hand, and concerns about government intervention, practicality, or potential economic impacts on the other. These findings underscore the socio-political challenges inherent in implementing chemical management policies within the ASGM sector and suggest that any regulatory approach will need to carefully balance enforcement, feasibility, and stakeholder acceptance.

Section 2. Question 1. Should the government control the use of these chemicals in mining?

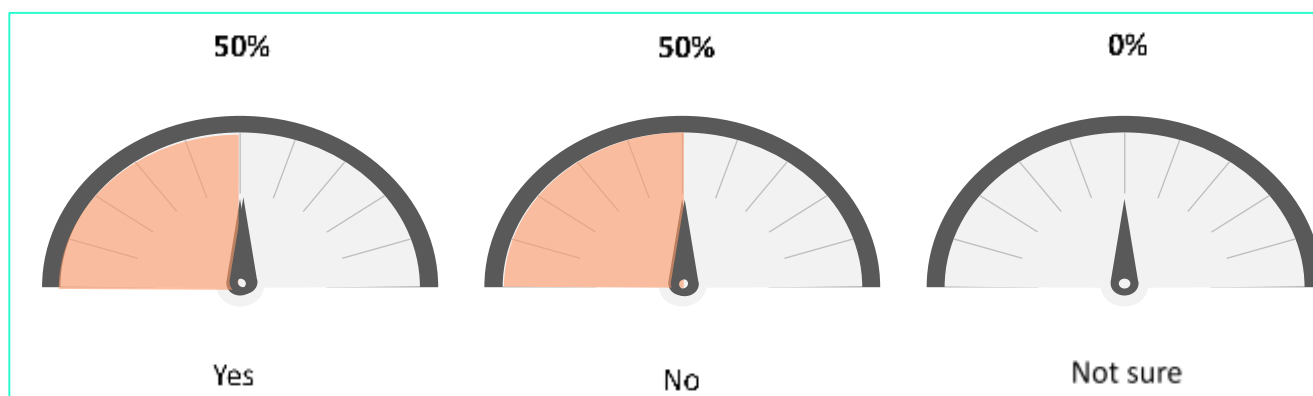


Figure 46. Survey responses to the Question 1 of Perceptions on Regulation and Technology section

Survey responses regarding the necessity of replacing mercury with other technologies, were evenly divided, with **50% of respondents answering 'Yes'** and **50% answering 'No'**. No respondents selected 'Not sure' (Figure 47).

Section 2. Question 2. Is it necessary to replace mercury with other technologies (like cyanide)?

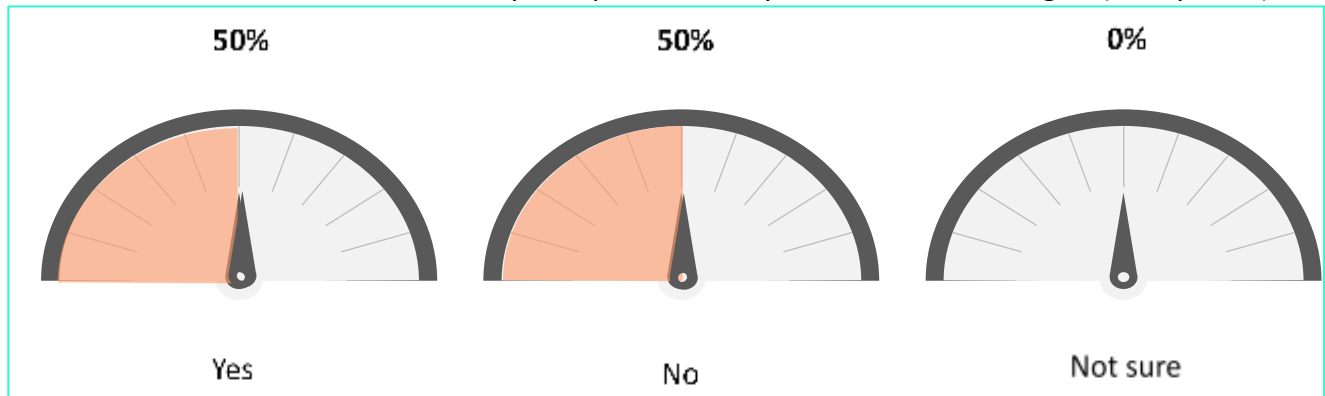


Figure 47. Survey responses to the Question 2 of Perceptions on Regulation and Technology section

For the question, which asked respondents to rank the biggest problems caused by ASGM, the results indicate a clear hierarchy of perceived severity (Figure 48). **Social conflicts and health problems were perceived as the most severe issues**, with 50% of respondents ranking water pollution as severe (rank 2) and 50% ranking the lack of fish as severe (rank 2) problems. In stark contrast, soil pollution was consistently perceived as the least severe problem, with 100% of respondents assigning it the lowest rank of 6.

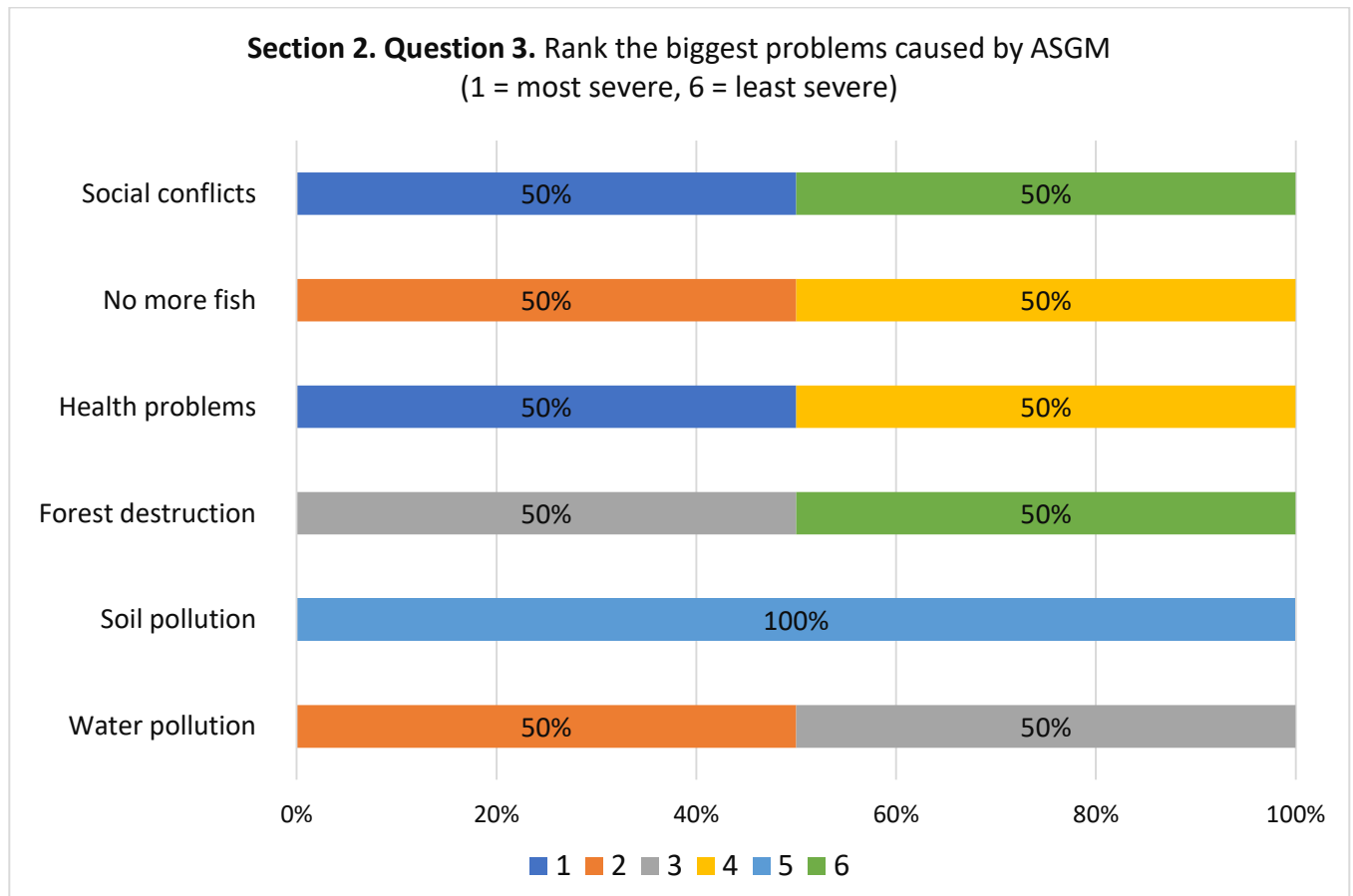


Figure 48. Survey responses to the Question 3 of Perceptions on Regulation and Technology section

Based on the survey findings, it can be concluded that the surveyed **stakeholders perceive social and direct health impacts as the most critical problems caused by ASGM**, followed closely by immediate livelihood and water quality concerns. The unambiguous consensus that soil pollution is the least severe issue indicates a prioritization of immediate human welfare and aquatic resources over broader, longer-term terrestrial environmental degradation. This hierarchy suggests that regulatory and intervention strategies may encounter greater public compliance and support if they explicitly address these top-tier concerns, particularly social stability, human health, and the protection of water-based food sources. The questionnaire results for the **Solutions and Community Needs** are presented in Figures 49–51. Survey responses to question regarding solutions to reduce harm from mining chemicals, show a distribution across several proposed measures (Figure 49).

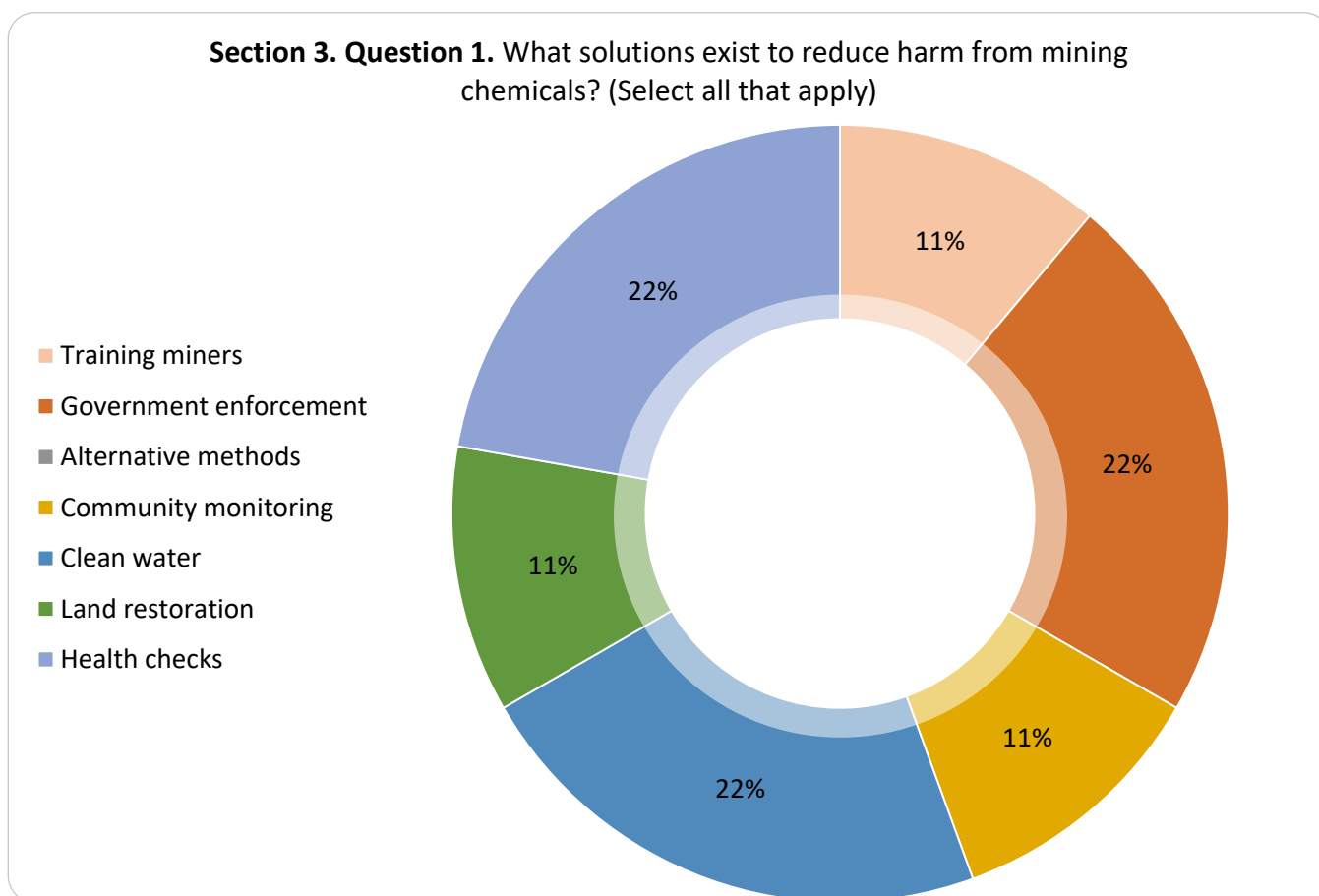


Figure 49. Survey responses to the Question 1 of Solutions and Community Needs section

Government enforcement and the provision of clean water were identified as the most frequently selected solutions, each chosen by 22% of respondents. Training miners, the use of alternative methods, community monitoring, land restoration, and health checks were all selected with equal frequency, each by 11% of respondents. This indicates that respondents perceive a combination of regulatory authority and basic public health infrastructure as the most critical solutions, while other technical, social, and restorative measures are currently considered secondary in importance.

Survey responses to question regarding community support for a ban on mercury in mining, revealed a stark division of opinion, with 50% of respondents in favour and 50% opposed; no respondents reported being unsure (Figure 50).

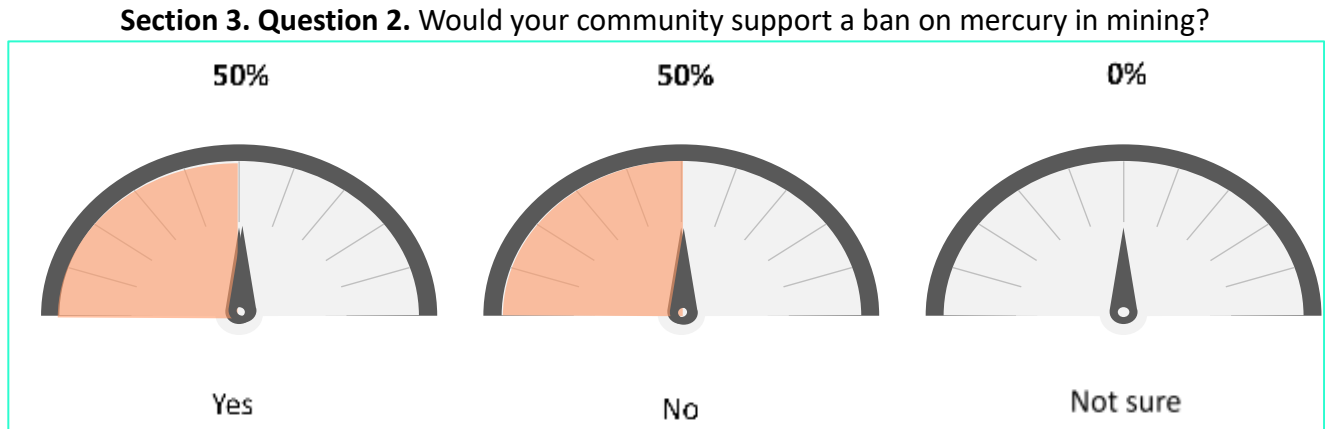


Figure 50. Survey responses to the Question 2 of Solutions and Community Needs section

For question, which asked respondents to rank the help their community needs to address mining pollution, the results demonstrate a clear primary priority (Figure 51). **"Community Control" was unambiguously ranked as the most critical need**, with 100% of respondents assigning it the highest priority (Rank 1). All other forms of assistance, including compensation, better tools, healthcare, clean water, alternative jobs, laws and enforcement, and education, were perceived as secondary, with their rankings evenly split between the remaining levels of priority. This indicates that while a mercury ban is a polarizing issue, there is a unanimous consensus that local agency and self-determination are the most fundamental requirements for addressing mining pollution.

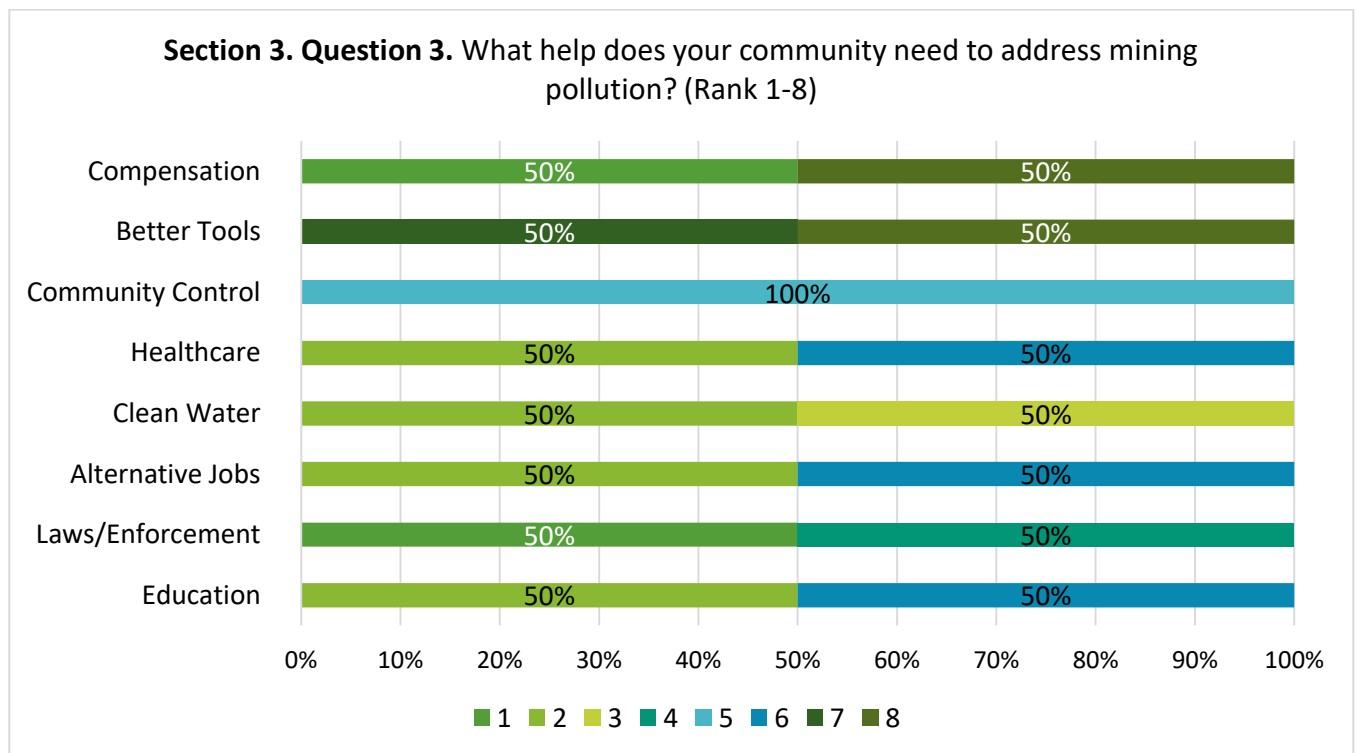


Figure 51. Survey responses to the Question 3 of Solutions and Community Needs section

6.3.2 Significance and Application of Results

The results of this questionnaire provide critical insights into the knowledge gaps, perceptions, and priorities of indigenous communities and traditional leaders regarding the use of lixiviants in artisanal and small-scale gold mining. The findings reveal that while awareness of chemical use is universal, it is limited primarily to mercury, indicating a substantial knowledge deficit concerning alternative lixiviants such as cyanide or non-cyanide reagents. Moreover, the divided opinions on the risks associated with these substances – particularly regarding human health and environmental impacts – highlight the urgent need for targeted education, risk communication, and participatory awareness programs to improve chemical literacy within these communities. The split perspectives on government regulation and the adoption of alternative technologies further underscore the socio-political complexities of transitioning to safer mining practices. These divisions suggest that effective policy interventions must balance community autonomy, economic realities, and regulatory oversight to gain local acceptance. The prioritization of social and health impacts over soil degradation reflects a community perspective focused on immediate human welfare and livelihood concerns. This insight is crucial for designing community-centred interventions that align with local values and perceptions. Additionally, the preference for government enforcement and access to clean water as primary solutions demonstrates a demand for both institutional support and basic public health measures. **The unanimous identification of “Community Control” as the foremost need underscores the importance of empowering local governance and participatory decision-making in environmental management.** Collectively, these results emphasize that **sustainable chemical management in ASGM requires a multifaceted approach – combining regulatory frameworks, health and environmental education, infrastructure support, and the strengthening of community-led governance structures** – to foster safer, more inclusive, and socially accepted pathways for mercury reduction and sustainable mining transformation.

7. REGULATORY AND INSTITUTIONAL FRAMEWORK: NATIONAL AND INTERNATIONAL STANDARDS REVIEW

This chapter presents the results of a foundational assessment of the legal, institutional, environmental, and technical implications of introducing alternative chemical agents in artisanal and small-scale gold mining (ASGM). The findings provide a basis for developing evidence-based guidelines for the safe transport, storage, use, and disposal of these substances.

7.1 Legal and Institutional Framework Assessment

7.1.1 Policy

The assessment is being carried out during a change of government, meaning that no reference or connection can be made to applicable policy documents. The only document that transcends government and is still in effect is the Multi-Annual Development Plan of Suriname (MOPS) 2022-2026. The MOPS 2022–2026 identifies the preservation of ecosystem functions as essential for achieving sustainable socio-economic development. Among the highlighted environmental challenges are climate change, pollution, waste management, deforestation, and the use of hazardous substances such as mercury. In the context of the gold sector, the MOPS emphasizes that artisanal gold mining, alongside deforestation, contributes to environmental degradation through excavation, poor waste management, and the use of toxic chemicals. The plan stresses the importance of modernizing small-scale gold mining methods to eliminate the use of mercury and mitigate the risk of mercury contamination, which poses serious health and ecological threats.

7.1.2 National Legislation

Suriname's national legal framework governing the management of hazardous chemicals in the gold mining sector is composed of a combination of environmental, occupational, and mining laws. However, this framework remains *fragmented* and lacks *comprehensive provisions* to regulate the *entire life cycle of mercury* and *alternative reagents*, such as *Jinchan* and *Sandioss*.

Mining Act (S.B. 1986 no. 28, as lastly amended by S.B. 2017 no. 41)

The Mining Act establishes the general rules for the exploration and extraction of minerals in Suriname. It affirms that all minerals are the property of the State and that mining activities may only be conducted under lawfully granted mining rights, which include rights for exploration, exploitation, small-scale mining, and the exploitation of building materials.

Small-scale mining is specifically addressed in Articles 36 through 40 of the Act. The law defines small-scale mining as the reconnaissance, exploration, and exploitation of mineral deposits that can be economically extracted using simple means and techniques. This category of mining is restricted to the minerals listed in Article 5(d), which excludes bauxite, hydrocarbons, and building materials. In practice, these provisions primarily concern gold mining.

The Act specifies that small-scale mining rights may only be granted to natural persons who are residents of Suriname, and each person may hold only one contiguous area of up to 200 hectares. Small-scale mining may only be conducted in designated areas, which are published in the Official Gazette, and land

subject to other mining rights is ineligible. A small-scale mining right is issued for a maximum of two years, with the possibility of renewal for an additional two years. Holders of such rights are authorized to explore, survey, and exploit minerals within their designated area, to the exclusion of others. They are also allowed to construct necessary buildings and facilities, use timber and building materials from designated land, and cultivate nuts, tree fruits, or vegetables for their own consumption and that of their staff. Additionally, the Act allows the holder to request technical and administrative assistance from the Minister of Mining, which should be provided free of charge whenever possible.

The Act imposes several administrative obligations on holders of small-scale mining rights. They must maintain weekly reports on the amount of soil moved and the quantity of minerals extracted. Furthermore, quarterly reports must be submitted to the Minister, providing details on invested capital, operational costs, the workforce (including names, dates of birth, and nationalities), and quantities of soil and minerals extracted. Holders are also required to pay all applicable levies and royalties.

Notably, the provisions concerning small-scale mining are heavily oriented toward the granting of rights and the reporting of production and labour, while environmental and occupational health aspects receive minimal attention. The Act contains no specific rules regarding the use of chemicals, such as mercury or cyanide, no explicit requirements for site rehabilitation, and no clearly defined standards for occupational safety or the protection of miners' health. Consequently, the regulation of small-scale mining under this law is largely administrative and economic in nature, with limited environmental and health safeguards.

It is evident that environmental and labour legislation will need to be updated to ensure adequate protection in this sector. At the time of this analysis, the permit conditions applicable to small-scale mining rights holders were not accessible, and therefore their content could not be assessed.

The ***Environmental Framework Act (EFA), S.B. 2020 no. 97, as lastly amended by S.B. 2024 no. 56***, establishes the overarching legal framework for environmental protection in Suriname. The Act mandates the creation of systems for Environmental Impact Assessment (EIA), environmental quality standards, pollution control measures, and environmental permitting. At present, the EFA serves as the most appropriate legislative instrument for regulating the use of chemicals.

Although the permitting systems under the EFA are not yet fully operational, the Act – also referred to as the EFA – imposes a general duty of care under Article 9 on all persons within the territory of Suriname. This duty requires anyone who knows or reasonably suspects that their actions or omissions may have adverse environmental effects to refrain from such actions to the extent reasonably necessary. Furthermore, anyone who becomes aware of actions or omissions that have caused, or may cause, adverse environmental effects are obligated to notify the National Environmental Authority (NMA). The law also requires that all reasonable measures be taken to prevent adverse environmental impacts, or, where prevention is not possible, to minimize or remediate them.

The ***Environmental Impact Assessment State Order, S.B. 2025 no. 23***, was recently approved and has officially entered into force. With the enactment of this State Order (*Staatsbesluit*), all applications for mining concessions must now undergo screening by the NMA. Under this State Decree, metal mining operations covering areas exceeding 10,000 hectares are classified as Category A, while operations on sites smaller than 10,000 hectares are classified as Category B. Consequently, applications submitted to the Geological Mining Department (GMD) for small-scale mining concessions are now also subject to a prior screening process.

Beyond the EIA procedure for mining, the EFA provides the legal basis for the regulation of chemicals in general, including chemicals used in the mining sector. The Act distinguishes between contaminants and hazardous substances. The product Jinchan qualifies as a hazardous substance within the meaning of the

EFA. Pursuant to Article 35, the NMA is empowered to determine, by Order (*beschikking*), which substances are considered hazardous to the environment, to specify which hazardous substances are prohibited, and to establish the procedures governing their import, export, safe storage, handling, transport, use, and disposal – covering their entire life cycle. The same article also provides the legal foundation for a permit system applicable to any activity or process in which hazardous substances are stored, treated, used, or processed.

The NMA may choose to issue a general order governing hazardous substances, or it may adopt specific orders targeting one or more particular substances. The EFA additionally authorizes the NMA to require any individual or legal entity that owns or manages a site, building, vehicle, or vessel where contaminants, waste, or hazardous substances are stored, used, or transported to prepare an Emergency Response Plan. This plan must outline the measures to be taken in the event of leaks, accidental releases, or escapes of such substances, as well as the actions required to rehabilitate the environment afterward. The plan is subject to the approval of the NMA, and any incidents must be reported immediately. Should the responsible party fail or refuse to implement the necessary countermeasures, the NMA is empowered to take such measures itself at the expense of that party.

In summary, the EFA establishes a comprehensive legal foundation for the management and control of hazardous substances, including chemicals used in the mining sector. However, its full implementation remains in progress, and detailed chemical management provisions tailored to the mining industry are not yet in place.

The ***Goods traffic Act (SB 2003 no. 58) and the State Order Negative List (S.B. 1999 no. 34, as amended last by S.B. 2006 no. 20)*** forms the legal framework for regulating the import and export of goods in Suriname. In principle, free movement of goods applies, but the law provides for the possibility of restricting or prohibiting the import and export of certain goods, if this is deemed necessary to protect, among other things, public health, public order, safety, the environment or even to be compliant with international treaties.

The State Order Negative List, issued under the Goods Traffic Act, determines which goods may not be imported or exported. It effectively acts as a filter on Suriname's international trade. The State Order uses a Negative List, a list of goods that are prohibited, require a permit, or are subject to special treatment. All goods not on this list may, in principle, be imported or exported freely. However, once a good is included on the Negative List, importers or exporters must take additional obligations into account.

On the current list, chemicals listed on the FAO Negative List are prohibited from import, and mercury imports require a permit. Other chemicals, such as Jinchan, Sandioss, and sodium isocyanate, which are used exclusively in mining, are not on the list, and imports are therefore free.

Another shortcoming in the customs legislation and enforcement mechanism for chemical declarations is the lack or limited standards for labelling and packaging. When chemicals are imported freely under customs legislation that lacks clear standards for labelling and packaging, it creates a high-risk situation for health, safety, the environment, and enforcement. Without proper labels, workers, transporters, and emergency responders cannot easily identify hazardous substances, which increases the likelihood of accidents, spills, and harmful exposure.

In essence, the absence of strong labelling and packaging requirements for chemical imports undermines safety, environmental protection, and the effectiveness of enforcement mechanisms, while creating opportunities for illegal trade and exposing the country to international compliance risks.

The Business and Professions Act (S.B. 2017 no. 40) and Ministerial Order on General conditions for

businesses and professions requiring a permit (S.B. 2019 no. 35). Under the Business and Professions Act, the practice of businesses and professions in Suriname is intended to be regulated in a modern and efficient manner. The Act provides that engaging in a business or profession is, in principle, free, unless there are compelling reasons to impose restrictions, such as risks to public health, safety, the environment, or public order.

Pursuant to this Act, the Ministerial Order establishes general licensing requirements for those businesses and professions that require a license. This Ministerial Order categorizes various types of businesses and professions. In practice, Jinchan is sold in Suriname and would therefore fall under Category A – Retailer. This category includes different types of retail activities, among which are retailers involved in the sale of agricultural chemicals. For this group, explicit requirements have been set by the National Institute for Environment and Development in Suriname (NIMOS, now NMA) and the Bureau of Public Health (BOG).

The NMA guidelines concern the proper design of chemical storage facilities, the handling of chemical waste, as well as reporting, monitoring, and control measures. The BOG requirements specifically address the sale and handling of agricultural chemicals. While these requirements for agricultural chemicals could arguably also be relevant to other types of chemicals, the law does not currently regulate them in the same way.

At present, there is no specific category for “Retailer for the Sale of Chemicals in General.” As a result, the sale of Jinchan could logically be regulated under such a category; however, since it does not exist, Jinchan sales currently fall under a general retail license. This license is very limited in scope and does not include any environmental or public health requirements.

Safety Act 1947 G.B. 1947 No. 142, amended by S.B. 2023 No. 121 aims to provide a comprehensive legal foundation for workplace safety in Suriname. Its goals are to reduce occupational injuries and diseases, ensure hygienic and safe working conditions, and hold both employers and workers accountable for safety compliance. Recent amendments enhance its enforcement effectiveness by introducing more robust penalties for repeated or continuing violations. The act contains nine safety regulations (safety requirements) that employers must observe to limit occupational accidents and risks. These instruments do not provide sector-specific requirements for the safe storage, transport, use, and disposal of chemicals in mining. Mercury, for example, is not explicitly listed as a controlled substance for mining applications.

7.1.3 Institutional Framework

Following the change in government, several ministries in Suriname have undergone structural adjustments, including modifications to their mandates. The Presidential Decree S.B. 2025 no. 94 outlines which ministries remain unchanged and which are restructured. In accordance with the State Order on the Task Description of Departments (S.B. 1991 no. 58), as last amended by S.B. 2020 no. 191, the following ministries are anticipated to have responsibilities in managing chemicals used in the mining sector. This responsibility covers the entire life cycle of chemicals, including importation, transport, storage, usage, and final disposal.

The ministries involved are:

1. **Ministry of Oil, Gas and Environment** – responsible for overall environmental policy;
2. **Ministry of Natural Resources** – responsible for regulation of the mining industry;
3. **Ministry of Public Works and Spatial Planning** – responsible for waste collection and processing in Paramaribo;

4. **Ministry of Wellbeing, Public Health and Labour** – responsible for public health, wellbeing, and occupational health and safety;
5. **Ministry of Economic Affairs (EA)**– responsible for the issuance of operating licenses and import/export permits;
6. **Ministry of Regional Development (RO)** – responsible for waste collection in districts outside Paramaribo;
7. **Ministry of Defence** – responsible for disaster prevention and response;
8. **Ministry of Justice and Police (JP)** – responsible for law enforcement

Overview of Roles Across the Chemical Life Cycle

Customs Department – Ministry of Finance and Planning

The Customs Department is the first government body to encounter chemicals upon import. It is responsible for verifying legal importation, ensuring the presence of necessary permits, collecting tariffs and indirect taxes, and maintaining a physical presence at ports during clearance procedures.

Division of Import, Export and Foreign Currency (IUD) – Ministry of Economic Affairs

The IUD issues licenses for the import and export of goods. The Ministry of EA also issues Operating Licenses (*bedrijfsvergunningen*) under the Business and Professions Act, through its Department of Operating Licenses (*Afdeling Bedrijfsvergunningen*).

Ministry of Wellbeing, Public Health and Labour

This newly established ministry is a merger of two existing ministries, namely Public Health and Labour. The responsibility will more or less correspond to the 2 ministries, namely health and labour. It is expected that the Ministry will amongst others be responsible for monitoring compliance with labour laws. The Labour Inspection Department enforces regulations on occupational safety and health, and provides guidance to both employers and employees. It is also expected that the Ministry will be responsible for public healthcare, as well as providing guidance for the destruction of pharmaceuticals and clinical or industrial waste. The Environmental Inspection of the Bureau of Public Health (BOG) inspects water, soil, and air pollution and is involved in multiple stages of the chemical cycle: import, production, storage, use, and disposal.

Suriname Standards Bureau (SSB)

The SSB is responsible for developing standards and technical regulations to support economic activities while protecting public health and the environment. Its work is carried out under the standards legislation.

Ministry of Oil, Gas and Environment

This Ministry is responsible for coordinating environmental policy, maintaining national and international environmental cooperation, preparing environmental legislation, promoting environmentally friendly technologies, and stimulating environmental education, in consultation with the Ministry responsible for education.

The **National Environmental Authority (NMA)** serves as the primary governmental body responsible for the enforcement of the Environmental Framework Act (EFA). Its mandate encompasses the control of pollution, the regulation of waste and hazardous waste, and the management of hazardous substances. The NMA also provides technical advice on the storage and handling of chemicals to other competent authorities. This includes guidance to the Ministry of Economic Affairs in connection with the issuance of enterprise establishment permits, as well as to the Customs Department with regard to the importation of chemicals

Ministry of Natural Resources (NH) – Geology and Mining Department (GMD)

The GMD regulates the mining sector, issues mining concessions, and monitors mining activities.

However, its capacity to enforce environmental and chemical safety standards is limited, and it currently lacks specific protocols for overseeing chemical use in artisanal and small-scale gold mining (ASGM).

Ministry of Defence and NCCR

The Ministry of Defence is responsible for disaster prevention and response, based on the National Army Law. The **National Coordination Centre for Disaster Management (NCCR)** monitors and assesses potential disasters and crises, and coordinates response structures in collaboration with multiple ministries and organizations, including in cases of chemical incidents.

Ministry of Justice and Police (JP)

The Ministry has overall responsibility for enforcement, including the application of criminal law and the Penal Code, which prohibits acts such as water pollution.

The **Fire Brigade**, which operates under the Law on the Fire Brigade, is responsible for supervising the storage of explosive and highly flammable substances.

This institutional framework illustrates that chemical management in the mining sector in Suriname involves a broad range of ministries and agencies, each covering specific segments of the chemical life cycle. However, the distribution of responsibilities is fragmented, and capacity gaps remain, particularly regarding chemical oversight in artisanal and small-scale gold mining.

7.2 International Obligations and Standards

7.2.1 Multilateral Environmental Agreements (MEAs)

The **Minamata Convention** on Mercury (status in Suriname: ratified (as of June 2024)) provides a comprehensive legal framework for the safe transport, storage, use, and disposal of mercury. Key provisions include consent-based trade controls (Article 3), requirements for environmentally sound interim storage (Article 10), and mandatory safe disposal of mercury waste in accordance with international standards (Article 11). Article 7 specifically addresses artisanal and small-scale gold mining (ASGM), urging countries to reduce or eliminate mercury use through National Action Plans that promote alternative technologies and protect public health. By incorporating these Convention obligations into national regulatory design, particularly in conjunction with mining licenses and environmental permits, Suriname can strengthen its chemical management regime.

The **Basel Convention** (status in Suriname: party since 1992) provides a strong framework that can be integrated into national guidelines for managing hazardous substances in the mining sector. Article 4 obliges Parties to ensure the environmentally sound management of hazardous wastes throughout their life cycle, which Suriname can apply by mandating safe storage, disposal of tailings, and operational standards for reagents like mercury and sodium isocyanate. Article 4.2(d) and Article 6 reinforce the need for prior informed consent and proper authorization for transboundary movement of hazardous materials, supporting regulatory requirements for importers and exporters to register shipments and obtain official approvals. Article 4.7 encourages waste minimization, allowing Suriname to promote cleaner production methods and require operators to submit waste reduction plans. Article 7 provides a basis for enforcing contingency and liability measures, while Article 10 supports transparency through public access to permits, safety data sheets, and awareness efforts. Lastly, Annexes I, III, and IV offer technical criteria for identifying hazardous waste and setting national disposal standards for mining-related chemicals. While Suriname lacks a dedicated Basel implementation policy, the NMA applies an export procedure for hazardous waste in line with Convention requirements.

ILO Conventions provide internationally recognized principles that can support efforts to regulate the

management of hazardous chemicals used in gold mining operations. Some of these conventions include:

Chemicals Convention, 1990 (No. 170) (status: not ratified by Suriname) obligates employers to systematically assess chemical risks, classify and label hazardous substances, provide chemical safety data sheets, maintain records, and ensure worker protection through operational controls and hygiene measures.

Safety and Health in Mines Convention, 1995 (No. 176) (status: not ratified by Suriname) requires that mining employers take all necessary measures to eliminate or minimize chemical hazards, implement protective equipment policies, and provide first aid and emergency procedures backed by inspection services and enforcement mechanisms.

Labour Inspection Convention, 1947 (No. 81) (status: ratified since 1976) mandates a robust labour inspection system, empowering inspectors to enforce occupational and chemical safety standards in the mining sector and remedy unsafe workplace conditions.

Non-ratification of ILO Convention 170 (Chemicals) and Convention 176 (Mine Safety) indicates gaps in Suriname's formal frameworks for chemical safety and mining-specific occupational health. Given the dominance of gold mining in Suriname, these conventions are especially relevant for protecting workers and the environment.

Recommendations: (i) ratifying C. 176 could enhance safety in artisanal and small-scale gold mining (ASGM); (ii) ratifying C. 170 would strengthen chemical management, complementing the Minamata Convention's focus on mercury.

7.2.2 International Mining Standards

To inform the development of safe, evidence-based guidelines for chemical use in Suriname's ASGM sector, this section reviews key international standards focused on hazardous chemical management across four critical domains: transport, storage, use, and disposal.

The **International Cyanide Management Code** (Cyanide Code) is a voluntary industry standard that promotes the safe manufacture, transport, use, and disposal of cyanide in gold and silver mining. Developed with support from UNEP, it is administered by the International Cyanide Management Institute (ICMI) and serves as the most widely recognized benchmark for managing hazardous chemicals in mining operations.

The Code establishes nine core principles supported by detailed performance standards. These include:

- **Safe transport** using certified carriers with emergency response plans.
- **Secure storage** with secondary containment systems and spill prevention measures.
- **Responsible use** through proper handling protocols, training, and worker protection.
- **Environmentally sound disposal** of cyanide-containing tailings, including detoxification and water quality monitoring.

Companies seeking certification must undergo independent third-party audits every three years, with findings made publicly available. While the Code targets large-scale mining, its technical standards offer a strong foundation for developing national guidelines tailored to ASGM contexts, particularly in regulating alternative reagents like sodium isocyanate.

The **Initiative for Responsible Mining Assurance (IRMA) Standards – Mercury & Cyanide** provides a comprehensive and independently audited standard for environmental and social responsibility in industrial-scale mining. Its chapters on cyanide (Chapter 4.7) and mercury (Chapter 4.8) establish detailed requirements for the safe transport, storage, use, and disposal of these high-risk chemicals.

Cyanide Management (Chapter 4.7)

IRMA requires operations that use cyanide to:

- **Transport** cyanide only via certified suppliers and carriers with documented emergency response capabilities.
- **Store** cyanide in secure, covered areas with secondary containment that meets or exceeds 110% of the largest vessel volume.
- **Use** cyanide with safeguards including leak detection, interlock systems on pipelines, and operator training.
- **Dispose** of cyanide-containing tailings only after detoxification and in compliance with strict discharge standards to prevent environmental harm.

Unlike the Cyanide Code, IRMA strengthens requirements for design specifications and includes community health impact considerations.

Mercury Management (Chapter 4.8)

IRMA prohibits the use of mercury for gold processing unless strictly controlled and aligned with Minamata Convention obligations. It requires:

- **Secure storage** in sealed, corrosion-resistant containers,
- **Controlled handling** with ventilation and spill prevention,
- **Safe disposal** through registered hazardous waste facilities.

The IRMA standards go beyond voluntary guidance by providing auditable, enforceable requirements that align with international environmental and labour treaties. For Suriname they can be used as a benchmark for regulating alternative reagents in ASGM, ensuring chemical handling aligns with best practices in worker safety, environmental protection, and emergency preparedness.

The **Consolidated Mining Standard Initiative (CMSI)** is a global multi-stakeholder effort launched in 2023 to develop a unified, performance-based standard for responsible mining. Led by civil society groups, industry experts, and Indigenous organizations, the CMSI aims to harmonize existing environmental and human rights standards into one comprehensive, enforceable framework for the mining sector. Although still in draft form (as of 2024), the CMSI Standard for Responsible Mining includes emerging provisions related to the transport, storage, use, and disposal of hazardous chemicals, including mercury and cyanide. Although still in draft form, CMSI offers forward-looking guidance for Suriname by supporting the phase-out of mercury, providing a framework to regulate alternatives like sodium isocyanate, and emphasizing transparent chemical management and safe disposal practices.

Although **Jinchan** and **Sandioss** lack formal global standards like those established for cyanide, they offer a strong foundation for regulatory development based on a growing body of scientific research, safety documentation, and patented production processes. Both reagents are classified as non-hazardous under the Globally Harmonized System (GHS), with material safety data sheets (MSDS) outlining hazard classifications, safe handling procedures, and spill containment protocols. In addition, both products are manufactured under patented methods and ISO-certified quality systems, ensuring consistency, traceability, and quality control³⁶. Together, these attributes closely align with recognized chemical management practices and provide a practical basis for Suriname to develop evidence-based regulations for the safe transport, storage, use, and disposal of alternative leaching agents in gold mining.

³⁶ Amankwah, R. K., et al. (2016). A Comparative Study of Sodium Cyanide and Jinchan™ Gold Leaching Reagents: A Case Study at Goldfields Ghana Limited. ResearchGate. Retrieved from <https://www.researchgate.net/publication/311440298>
 Malaysian Journal of Chemistry. (2025). Comparative Study on Cyanide-Free Reagents in Gold Extraction: A Case on Sandioss. Retrieved from <https://ikm.org.my/publications/malaysian-journal-of-chemistry>

7.3 Preliminary Issues and Opportunities Identified

The assessment of Suriname's legal and institutional framework for the management of chemicals in the gold mining sector has revealed a series of preliminary issues and opportunities that warrant attention. These findings highlight both the risks currently posed by gaps in regulation and enforcement and the potential to align national practices with international standards and best practices (Figure 52).



Figure 52. SWOT Analysis of Suriname's legal and institutional framework for the management of chemicals in the gold mining sector

One of the primary issues is the fragmentation of the legal and institutional framework. Multiple laws and regulations apply to different aspects of chemical management – ranging from the Mining Act, the Environmental Framework Act, the Goods Traffic Act with its Negative List, the Business and Professions Act, and the Safety Act – yet none of these instruments provides a comprehensive, life-cycle regulatory framework for hazardous substances used in artisanal and small-scale gold mining.

Oversight is distributed across numerous ministries and agencies, including the NMA, the Ministry of Natural Resources, the Ministry of Economic Affairs, and the Ministry of Wellbeing, Public Health and Labour. While each of these bodies has a role in managing importation, storage, handling, and disposal of chemicals, coordination is weak, responsibilities overlap, and capacity gaps persist, particularly in relation to monitoring and enforcement in the interior where ASGM activities are concentrated.

The current legal regime lacks detailed provisions for the transport, storage, use, and disposal of mercury and alternative reagents such as Jinchan, Sandioss, or sodium isocyanate. Mercury imports require a permit under the Negative List, but other chemicals commonly used in gold processing are freely imported without standardized labelling, packaging, or safety requirements. This creates significant risks for occupational health, public safety, and environmental protection. In the event of spills or accidents during transport or storage, first responders may lack the necessary information to act safely and effectively. Furthermore, the absence of clear disposal regulations raises the risk of uncontrolled releases of chemical waste into soil and waterways, potentially causing long-term ecological damage and

undermining Suriname's compliance with international environmental agreements.

Another critical issue is the limited integration of environmental and occupational health considerations into the mining regulatory framework. The Mining Act primarily focuses on granting rights and collecting production data, with minimal reference to chemical use, site rehabilitation, or worker protection. While the Safety Act sets general obligations for workplace safety, it does not provide sector-specific guidance on handling hazardous substances in mining operations. This leaves a regulatory gap where chemicals are widely used but largely unregulated in practice, particularly in artisanal and small-scale operations. The enforcement capacity of the relevant authorities remains a challenge. The NMA, while legally mandated to manage hazardous substances under the EFA, is still in the process of operationalizing its permitting and inspection systems. The Geology and Mining Department has a limited presence in the field and lacks specific protocols for monitoring chemical use in ASGM. Customs and border control focus on the legality of imports but have limited technical capacity to inspect, track, or verify the safe handling of chemical shipments. As a result, there is currently no continuous monitoring mechanism to ensure that chemicals are safely managed across their entire life cycle.

Despite these challenges, several opportunities arise from the current assessment. Suriname can leverage its existing legal foundations to create an integrated chemical management framework. The Environmental Framework Act provides a strong basis for regulating hazardous substances, including the potential to establish a comprehensive permit system covering importation, storage, handling, transport, use, and disposal. Recent adoption of the Environmental Impact Assessment State Order (S.B. 2025 no. 23) also opens the door for systematic screening of mining projects, including small-scale operations, thereby allowing environmental and chemical risks to be addressed early in the approval process.

In addition, Suriname has the opportunity to align its national practices with international standards and commitments, including the Minamata Convention on Mercury, the Basel Convention, and occupational safety conventions of the ILO. Adoption of elements from international mining standards, such as the International Cyanide Management Code and IRMA standards for mercury and cyanide, would allow the country to modernize its regulatory approach, even for alternative reagents like Jinchuan and Sandioss, which currently lack dedicated global standards. These frameworks provide practical guidance on safe transport, secure storage, operational use, emergency preparedness, and environmentally sound disposal, all of which can be adapted to Suriname's ASGM context.

Finally, there is a clear opportunity to strengthen inter-institutional coordination. Developing a formalized mechanism for collaboration between the NMA, GMD, Customs, the Ministry of Economic Affairs, the Ministry of Wellbeing, Public Health and Labour, and local authorities would allow for coherent oversight of chemical imports, on-site management, and waste disposal. This approach could be supported by capacity-building initiatives, the creation of standard operating procedures, and the introduction of mandatory reporting and emergency response planning by operators.

In conclusion, the preliminary assessment indicates that while Suriname faces significant regulatory and institutional gaps in managing hazardous chemicals in the gold mining sector, it also possesses the legal, institutional, and international foundations necessary to close these gaps. By seizing these opportunities, the country can reduce environmental and health risks, improve compliance with international obligations, and support the transition to safer and more sustainable mining practices.

7.4 Recommendations

Based on the comprehensive analysis of Suriname's national legislation, institutional framework, and international obligations, several practical and prioritized recommendations can be made to strengthen the safe management of hazardous chemicals, including mercury and alternative reagents such as Jinchan and Sandioss, within the artisanal and small-scale gold mining sector. These recommendations aim to address gaps in the current legal and enforcement framework and to align Suriname's practices with internationally recognized standards.

Independent scientific research in Suriname remains key to monitor environmental, chemical, biochemical and health parameters at the genetic level, collect data and thus allow for evidence-based policy making, management and enforcement. Forensic research needs to be implemented in order to reconstruct calamities, expose responsibility, optimize accountability, discourage misuse and to prevent disasters. This will allow for the first recommendation, which is to **develop and implement a comprehensive chemical management framework** that regulates the entire life cycle of hazardous substances used in gold mining. This framework should encompass importation, transport, storage, handling, operational use, and final disposal of chemicals. Existing legislation, particularly the Environmental Framework Act, provides a suitable legal foundation for such a framework. The development of implementing regulations under Article 35 of the EFA should be prioritized, including the issuance of general or substance-specific orders that identify hazardous substances, define prohibited or restricted substances, and establish clear permit procedures. Moreover, there is a clear necessity to conduct comprehensive research and analysis on the chemical composition, toxicity, and environmental impact of alternative gold ore dressing agents in Suriname. Such studies would provide a scientific basis for evaluating potential health and ecological risks, inform regulatory decisions, and guide the safe use or substitution of ore dressing agents in artisanal and small-scale gold mining (ASGM) operations.

The second recommendation is to **strengthen the regulation of chemical imports through the State Order Negative List and customs procedures**. Chemicals such as Jinchan and Sandioss, which are currently imported freely, should be added to the Negative List under a category requiring import permits. In parallel, clear **standards for labelling, packaging, and documentation** must be adopted, in alignment with the Globally Harmonized System (GHS). This would enhance traceability, improve emergency response capacity, and support compliance with the Minamata and Basel Conventions.

The third recommendation is to **adopt and enforce clear rules for the safe transport and storage of chemicals**, drawing from international benchmarks such as the International Cyanide Management Code and the Initiative for Responsible Mining Assurance standards. Transportation requirements should include the use of certified carriers, mandatory emergency response plans, and spill containment measures. Storage requirements should include secure, ventilated, and contained facilities, secondary spill containment, and segregation of incompatible substances. The National Environmental Authority, in collaboration with the Ministry of Economic Affairs and Customs, should establish and oversee these requirements.

A fourth recommendation focuses on **operational use, worker safety, and environmental protection in ASGM sites**. Mandatory operational guidelines should be introduced for the use of mercury and alternative reagents, including the provision of personal protective equipment, safe handling protocols, and onsite emergency procedures. These requirements should be incorporated into the Business and Professions Act licensing regime, with special categories for "Retailer for the Sale of Chemicals" and "Chemical User in Mining Operations." Training programs for miners and traders should be developed

to ensure practical understanding and compliance.

The fifth recommendation is to **introduce clear and enforceable disposal and waste management requirements** for chemical residues and contaminated tailings. Guidelines should require that all chemical waste be treated, neutralized, or disposed of in accordance with environmentally sound practices, drawing on Basel Convention standards. Operators should be required to prepare and submit an **Emergency Response and Environmental Management Plan** to the NMA, covering spill prevention, containment, and post-incident remediation.

Institutional strengthening is the sixth recommendation. Improved coordination among the NMA, the GMD, Customs, the Ministry of Wellbeing, Public Health and Labour, and local authorities is essential for effective chemical oversight. A formal inter-agency coordination mechanism or task force should be established to oversee chemical life-cycle management, facilitate information sharing, and coordinate inspections. Capacity-building initiatives should include training for customs officers, environmental inspectors, and mining regulators to enable effective field monitoring and incident response.

Finally, it is recommended to integrate international standards and best practices into national guidelines and enforcement mechanisms. Suriname should actively implement relevant provisions from the Minamata Convention, Basel Convention, and ILO chemical safety conventions. Additionally, voluntary international mining standards, such as the Cyanide Code, IRMA, and the emerging CMSI standard, should be adapted to the ASGM context. These frameworks provide ready-to-use operational protocols for chemical safety, environmental protection, and community health safeguards.

In conclusion, implementing these recommendations will enable Suriname to move from a fragmented, largely administrative system to a **modern, integrated, and enforceable chemical management regime**. This approach will significantly reduce environmental and health risks, enhance compliance with international obligations, and support the sustainable development of the gold mining sector.

8. ANALYSIS OF TECHNOLOGIES SUITABLE FOR SURINAME'S ARTISANAL AND SMALL-SCALE GOLD MINING

8.1 Assessing Suitability of Mercury- and Cyanide-Free Gold Processing Technologies

For Suriname's artisanal and small-scale gold mining sector, identifying suitable alternatives to Jinchuan and other cyanide- or mercury-based lixiviants requires a careful balance between technical efficiency, cost-effectiveness, operational simplicity, and environmental safety within the country's tropical and low-infrastructure conditions. Evaluating the appropriateness of these technologies is particularly challenging due to the diverse geological settings and variable mining practices across ASGM sites.

Based on a synthesis of literature reviews, expert opinions, and direct field experience, nine technologies were selected for evaluation as potential alternatives within the artisanal and small-scale gold mining sector. A brief description of each technology is provided in Table 37.

Table 37. **Technology descriptions and selection justifications** *(developed by the authors)*

Technology	Description	Justification
1	2	3
Gold Kacha³⁷ 	The "Gold Kacha" is a centrifugal concentrator that employs a polyurethane-lined rotating cone to separate gold from pre-milled ore. The process utilizes water as the separation medium; as the cone spins, process water washes lighter gangue material away to the middle of the bowl and it discharged as overflow (tailing) from the bowl, while the heavier gold concentrate is trapped in the cone's riffles. The collected concentrate is then discharged into a hopper for further upgrading, with This process can achieve an estimated recovery rate of 70-75%.	This technology is suitable for recovering gold from free-milling and alluvial ore deposits. It is a portable, mercury-free system capable of producing gold concentrate directly on site. Key advantages include its operational simplicity, low maintenance requirements, and usability without specialized metallurgical knowledge. These characteristics make it particularly suitable for deployment in remote areas and account for its widespread adoption in ASGM sectors across tropical regions.
Gold Konka 	This technology functions as a modular sluice-based concentrator. Its design features multiple sluices set in a trays pattern and lined with high-capture-efficiency vortex mats. Concentrate is fed manually and transported by water gravity through the series of sluices. The system operates on a batch process, where after the operating process, the concentrate is recovered by washing down the mats into a collection container for smelting process. Estimated recovery rate is 80-90%.	Designed for the ASGM sector, this technology offers a high-recovery, mercury-free alternative that is both affordable and highly accessible. It is portable, requires no fixed infrastructure, and is simple to operate and maintain, making it ideal for individual miners in remote locations. Additional benefits include the ability to reprocess tailings, thereby increasing overall gold yield.

³⁷ The name "Kacha" is most likely borrowed from languages in West Africa, particularly in Ghana, where the device is widely used. In the Twi language, one of Ghana's most common native languages, the word "kacha" means "to catch," "to grab," or "to seize." Therefore, the name "Gold Kacha" literally translates to "Gold Catcher" or "Gold Grabber."

Continuation of the Table 37		
1	2	3
iCON Gold Recovery³⁸  	This technology operates as a batch-process centrifugal concentrator. Its core component is a riffled rotating bowl into which an ore-and-water slurry is introduced. The centrifugal force generated by the bowl's rotation separates particles by density, trapping heavy gold concentrate within the riffles while lighter gangue material is washed by process water away to the middle of the bowl and it discharged as overflow from the bowl. The accumulated concentrate is subsequently flushed out for further processing. Estimated recovery rate is 40-70%.	The technology achieves substantially higher gold recovery rates compared to the conventional mercury amalgamation method. Its capability to efficiently reprocess existing tailings ponds presents an immediate economic opportunity, enabling the recovery of gold from previously discarded waste without the expense of new excavation. As a compact and portable unit with low energy requirements, it can be easily deployed in remote or off-grid locations. Its simple batch-processing design requires no continuous feed or complex infrastructure. The system's mechanical simplicity ensures that it can be operated and maintained with minimal training and without the need for advanced metallurgical expertise.
Shaking table (Gemini Shaking Table)³⁹  	This technology separates gold through a precise gravity concentration process. The system features a fibreglass deck on a steel frame, which is shaken longitudinally at a variable speed while being irrigated with a controlled flow of water. When the feed material from the hopper achieves the table deck it flows through the shaking, vibrating surface. The denser gold particles settle into the deck's grooves and flows to the concentrate hopper and the middling product hopper, while lighter gangue is washed away and discharged in the tailing hopper and the middling product hopper. The middling product requires reprocessing to maximize overall recovery. The estimated recovery rate is 99%.	This technology has the ability to produce a very clean, high-grade concentrate directly from milled ore. It is particularly valuable as a final cleaning stage following primary concentration (e.g., using a Gold Kacha or sluice), as it reduces the need for mercury to extract gold from lower-grade concentrates. Its high efficiency and capacity to upgrade middlings make it ideal for increasing overall recovery in formalized mining settings.

³⁸ The name "iCON" is a modern, branded name that likely carries a dual meaning. Primarily, it is a straightforward abbreviation for "International Concentrators," the company that manufactures it. Secondly, the name leverages the common word "icon," suggesting that the product is a standout, benchmark, or "iconic" solution within the field of gravity gold recovery.

³⁹ The Gemini Table was developed as an improved version of the traditional Wilfley shaking table, a widely used gravity separation device for gold and other heavy minerals. The name "Gemini" (Latin for *twins*) likely refers to the table's dual-motion or twin-deck design concept used in some early models, which enhanced gold recovery by improving the separation of fine particles.

Continuation of the Table 37		
1	2	3
Blue Bowl Concentrator 	The Blue Bowl Concentrator is a simple, water-based gravity separation device, typically made of plastic. It consists of a bowl with a water inlet at its base and a central column. When feed material is added and water is pumped in, a vortex is created. This fluidizes the ore, suspending and washing away lighter particles over the rim of the central column, while denser gold and heavy minerals settle and are retained at the bottom of the bowl for collection. Estimated recovery rate is 85-95%.	It is highly effective in recovering fine and ultra-fine gold – typically lost through rudimentary methods – allowing miners to capture more value from their ore. Its affordability, simplicity, and suitability for individual batch operation make it ideal for artisanal miners. The device requires minimal training, low maintenance, and no metallurgical expertise, facilitating quick adoption across decentralized mining sites. Its local feasibility is high, as both the equipment and necessary inputs (water and limited electricity) are readily available, and its portability enables use in remote mining areas.
Knudsen Bowl Concentrator 	This technology operates as a batch centrifugal concentrator. Its key component is a rotating bowl with an internal rubber riffle lining. During operation, feed slurry and water are delivered through a central pipe. The resulting centrifugal force separates particles by density, pinning dense gold in the riffles and expelling light tailings over the edge. The cycle concludes by stopping the unit to hydraulically wash out the secured concentrate (Grayson, 2007). Estimated recovery rate is 80-90%.	Based on its operational profile, the Knudsen Bowl is a highly suitable technology for the Surinamese ASGM sector, particularly for medium-scale operations or cooperative mining groups. Its key advantage lies in its high recovery rates for fine gold, that is often lost using rudimentary methods. While the technology requires a power source and has higher upfront costs than simpler tools like the Blue Bowl, its efficiency and ability to process larger batch volumes justify the investment for miners seeking to increase yield and formalize their operations.
Direct Smelting (Borax method) 	This technology is a pyrometallurgical process for directly extracting gold from concentrates. The key reagent is borax (sodium tetraborate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$)), used as a flux. The concentrate-borax mixture is heated in a crucible beyond the melting point of the gangue minerals. The borax flux dissolves metal oxides and silicates, allowing the molten gold to coalesce and sink due to its high density. The resulting slag, which solidifies on top of the gold bead, is physically separated by breaking it with a hammer, yielding a semi-pure gold ore (Davies, 2014). Estimated recovery rate is 98%.	The process can be carried out with minimal and portable equipment – a crucible, a gas torch or charcoal, and a hammer – making it suitable for remote locations without access to grid power. Its relatively low technical barrier is another key advantage; the basic smelting technique can be learned quickly without formal metallurgical training, enabling rapid adoption. The primary reagent, borax, is inexpensive and widely available. This method effectively replaces the dangerous and inefficient final processing step traditionally performed with mercury, providing a safer, more efficient, and more profitable alternative for individual miners and cooperatives.

Continuation of the Table 37		
1	2	3
Knelson Concentrator⁴⁰ 	It is a centrifugal gravity separation device featuring a vertically oriented, ribbed cone that rotates at high speed. Feed slurry is introduced into the cone, where centrifugal force pins heavy mineral particles into the grooves between the ribs. The key to its high efficiency is the continuous injection of pressurized fluidization water through the base of the grooves, which flushes out lighter gangue materials while allowing dense gold particles to be retained. This process creates a highly efficient concentrating action, producing a rich concentrate and separate tailings streams (Grayson, 2007). Estimated recovery rate is 32-70%.	The concentrator achieves very high recovery rates through its centrifugal force and fluidized bed system, which is specifically designed to capture fine gold particles often lost by traditional sluices or manual panning. Its continuous concentration process allows it to handle larger volumes of ore compared to batch systems, such as the Blue Bowl, making it well suited for upgrading operations with higher throughput. This technology is particularly appropriate for established mining cooperatives and small-scale companies.
Cleangold Sluice 	This is an innovative gravity concentrator that replaces traditional fixed riffles with polymeric magnetic sheets housed in a standard sluice box. As ore slurry passes over the sheets, magnetic materials – either naturally present in the ore or added as a supplement – are attracted to the surface, forming temporary, corduroy-like structures that trap dense gold particles while lighter gangue is washed away. The key advantage of this design is the rapid and clean concentration release: the magnetic sheet can simply be scraped, releasing the trapped gold and simplifying the final upgrading process (Grayson, 2007). Estimated recovery rate is 84-98%.	This technology can be easily built and maintained using local materials. It is a low-cost innovation capable of recovering up to 90% of very fine gold particles, down to approximately 30 µm. Its main advantage is the rapid and clean concentration release: by simply scraping the magnetic sheet, miners can complete the clean-up process in minutes without disassembling the sluice or scrubbing traditional riffle mats, saving significant time and labour. The system is particularly effective for capturing fine gold, a common characteristic of Suriname's alluvial deposits that is often lost using rudimentary methods. It is a fully mercury-free technology that requires no chemicals, directly addressing a major source of environmental degradation. While the need for magnetic material represents a minor logistical consideration, its low cost, durability, and compatibility with both motorized and manual water pumps make it an affordable and practical upgrade, immediately enhancing recovery efficiency and productivity for individual miners and small crews.

⁴⁰ The "Knelson Concentrator" is an eponym, named after its inventor, Byron Knelson, who developed the technology in the late 1970s.

Figure 53 summarizes the principal factors influencing the suitability of gold recovery technologies for Suriname's artisanal and small-scale gold mining sector.

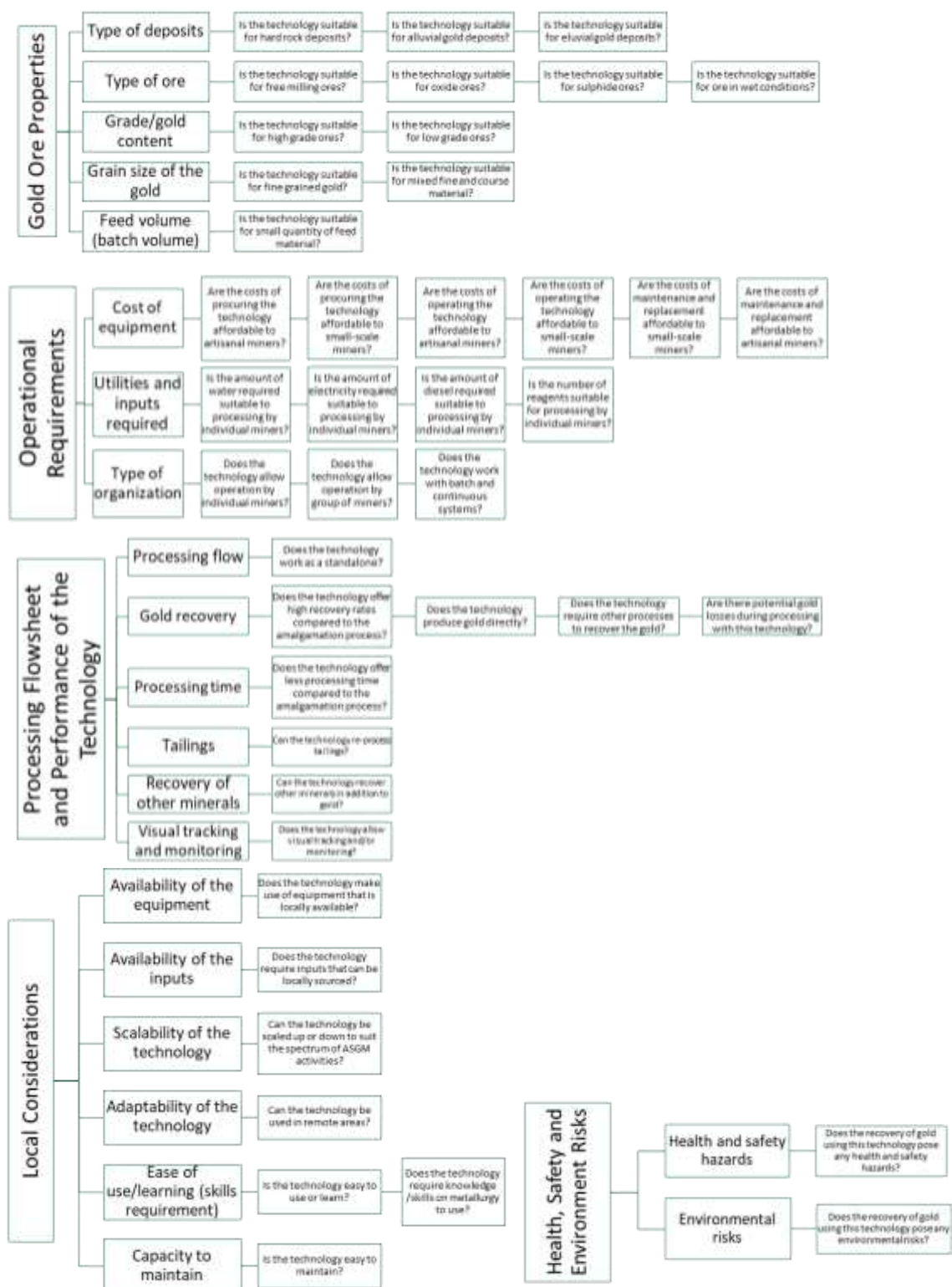


Figure 53. Key factors for assessing the suitability of mercury- and cyanide-free gold processing technologies for Suriname's ASGM (developed by the authors using data from the PlanetGOLD official website: <https://www.planetgold.org>)

These include gold deposits and ore characteristics, operational requirements, process performance, type of process unit, local technical capacity, and health, safety, and environmental considerations. Collectively, these criteria form a structured framework for evaluating and comparing potential technologies under Surinamese ASGM conditions.

When focusing primarily on the type of processing unit, the summarized equipment and tools can be divided into the following categories:

- **Centrifugal concentration units:** Gold Kacha, iCON Gold Recovery, Knudsen Bowl, Knelson Concentrator;
- **Gravity concentration units:** Gold Konka, Cleangold Sluice, mineral jig separators;
- **Gravity separation units:** Shaking table, Blue Bowl Concentrator;
- **Smelting unit:** Borax direct smelting method.

When focusing primarily on ore characteristics, and type of ore processing operation, the equipment and tools summarized in Table 37 are suitable technologies for Suriname's ASGM sector. These systems are well suited to the **predominantly free-milling alluvial and eluvial ores** typical of the region, enabling efficient recovery of both **coarse and fine gold** without relying on toxic chemicals. Figure 54 shows the particle size ranges over which the equipment and tools can perform effectively.

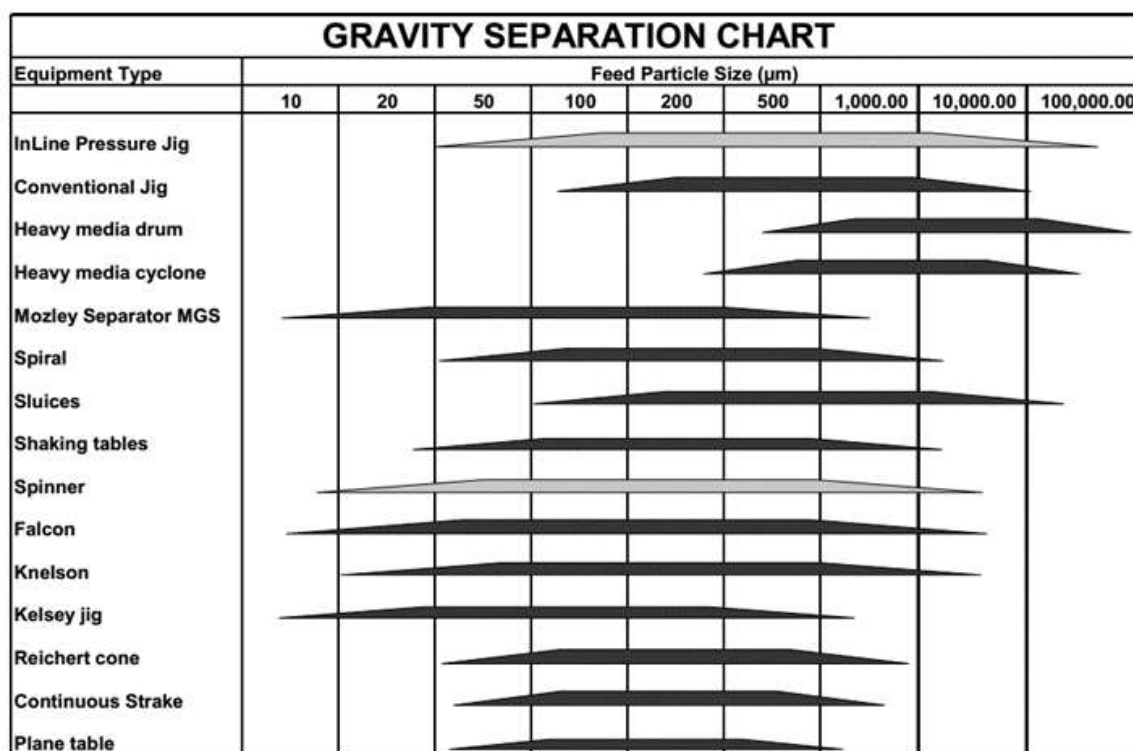


Figure 54. Gravity separation chart (Mwanga, 2010)

Considering **operational requirements** (including local technical expertise and maintenance needs), the remote and low-infrastructure conditions of mining sites, process performance, and health, safety, and environmental risks, the equipment and tools summarized in Table 37 are considered suitable technologies for Suriname's ASGM sector. However, the selection and implementation of a production circuit from the equipment and tools listed in Table 35 will require specialized training to support miners

in the proper operation and maintenance of certain equipment.

Considering **operational requirements** – such as power supply, portability, maintenance demands, and ease of use – the **Blue Bowl Concentrator** and **Cleangold Sluice** were identified as the most appropriate technologies for Suriname’s ASGM context. Both systems are **lightweight, compact, and user-friendly**, requiring **minimal energy and water**, which makes them particularly suitable for **remote, low-infrastructure mining sites** where access to electricity and mechanical support is limited. Together, these technologies represent **practical, low-cost, and environmentally responsible solutions** that can be readily integrated into existing artisanal operations.

From a **process performance perspective**, the **Gemini Shaking Table** and **Cleangold Sluice** demonstrated the highest potential for application in Suriname’s ASGM sector. Both technologies are capable of achieving **high gold recovery efficiencies**, particularly for fine and ultra-fine particles that are typically lost through conventional methods. Among these, the **Cleangold Sluice** stands out due to its **shorter processing time, low maintenance requirements, and efficiency comparable to or even exceeding that of traditional mercury amalgamation**. Its innovative magnetic recovery system enables rapid and clean separation of gold without the need for complex setup or chemical reagents. This makes it a **viable mercury- and cyanide-free alternative**, offering both environmental and occupational health benefits. In terms of **local technical considerations** – including the **availability of spare parts, local expertise, and maintenance feasibility** – the **Blue Bowl Concentrator** and **Cleangold Sluice** were assessed as the most **practical and acceptable options** for Surinamese artisanal miners. Both technologies rely on **simple mechanical principles and readily available materials**, allowing for easy assembly, repair, and operation without dependence on specialized technicians or imported components. The **Blue Bowl Concentrator** can be maintained with minimal tools and training, while the **Cleangold Sluice** is designed for durability and straightforward cleaning, making it well suited for the rugged and remote conditions of ASGM sites. The ability of local operators to quickly learn and maintain these systems enhances their **adoption potential and long-term sustainability** within the local mining community.

Finally, when evaluating **health, safety, and environmental risks**, most of the examined technologies were found to present **minimal hazards**, particularly when compared to mercury-based processing methods. However, both the **Knudsen Bowl** and **Direct Smelting (Borax Method)** may introduce **localized safety concerns**, primarily due to the **high temperatures and potential exposure to fumes** generated during smelting operations. These risks can be effectively mitigated through the **consistent use of personal protective equipment** and by ensuring **adequate ventilation or open-air setups** during processing. Importantly, these requirements are **manageable at the artisanal scale** and do not outweigh the significant environmental and health benefits achieved by eliminating mercury and cyanide from gold recovery.

The assessment indicates that the **Cleangold Sluice, Blue Bowl Concentrator, and Direct Smelting (Borax Method)** offer the most effective combination of **technical suitability, operational practicality, safety, and environmental performance** for advancing **mercury-free gold recovery** in Suriname’s ASGM sector. Together, these technologies address the key challenges faced by local miners – limited infrastructure, low capital investment capacity, and a need for simple, reliable processing systems – while ensuring high gold recovery efficiency and minimal ecological impact. The **Cleangold Sluice** provides rapid, low-maintenance concentration with excellent fine gold recovery; the **Blue Bowl** offers an easy-to-use and portable option ideal for field conditions; and the **Borax Method** delivers a safe, chemical-free smelting alternative for final gold purification.

8.2 Replacing Jinchan in Suriname's Artisanal Gold Mining: Practical Guidance

In Suriname's artisanal and small-scale gold mining (ASGM) sector, **Jinchan** is commonly used as a **chemical lixiviant** for **tailing conversion**, a process designed to leach residual gold from previously processed tailings. Although Jinchan is marketed as a “**non-cyanide**” reagent, it nevertheless relies on **chemical dissolution mechanisms** and generates **residues that require careful management**. Independent studies have raised concerns about the **uncertainty surrounding its active chemistry**, as several analyses indicate the presence of **cyanate or cyanuric-type compounds**, which can exhibit **cyanide-like behavior under certain environmental or process conditions** (Guo et al., 2022). These substances are **not inert or environmentally benign salts**; rather, they are **chemically related to cyanide systems** and therefore warrant **comprehensive toxicological and environmental fate assessments** before being promoted as safe alternatives for mercury or cyanide-based processing.

Cleaner **gravity-based and smelting alternatives** – notably the **Cleangold Sluice**, **Blue Bowl Concentrator**, and **Borax Smelting Method** – can replace Jinchan under many field conditions, especially where gold is **free-milling** (liberated particles).

These alternatives can **fully replace Jinchan** when gold occurs as free or partially liberated grains, typically in:

- **Alluvial and eluvial tailings** rich in fine or ultra-fine gold;
- **Reprocessed sluice concentrates** or residues from mercury amalgamation.

Under such conditions:

- **Cleangold Sluice** captures gold as fine as 5 µm using magnetic separation (Cleangold, 2022).
- **Blue Bowl Concentrator** recovers free gold by water vortex flow with minimal energy and water needs (Veiga and Gunson, 2020).
- **Borax Method** refines the gravity concentrate safely without mercury, reaching >95% purity (Appel and Na-Oon, 2014).

These systems work effectively without chemicals, making them suitable for **remote ASGM camps** with limited infrastructure.

Limitations: Jinchan or other lixiviants may still be required when:

- The ore or tailings contain **refractory gold** (encapsulated in sulphides or silicates);
- Gold is **chemically bound** or too fine for gravity recovery;
- There is evidence of **preg-robbing carbonaceous material** that inhibits physical concentration.

In such cases, a **combined approach** – gravity concentration followed by controlled chemical leaching of residues – may be justified after laboratory verification.

The recommended field workflow for Jinchan-free gold recovery in Suriname's ASGM is presented in Table 38. This workflow outlines a step-by-step approach, from initial tailings assessment to final concentrate smelting, designed to optimize gold recovery while minimizing the use of chemical lixiviants. It provides guidance for evaluating ore liberation, conducting gravity concentration trials, comparing alternative recovery methods, and making informed decisions on the most efficient, safe, and environmentally responsible processing route.

Table 38. **Recommended field workflow** (developed by the authors)

Step	Purpose	Recommended Tools / Notes
1. Tailing's sampling and panning	Assess gold liberation, size distribution, and physical characteristics	Pan, magnifier, simple microscope; record particle size and visible gold content
2. Initial gravity trial	Evaluate coarse gold recovery efficiency	Cleangold Sluice, Blue Bowl, Shaking Table (Gemini Table); run small representative samples
3. Fine gold concentration	Recover fine and ultra-fine gold	Portable Knelson Concentrator, Cleangold Sluice; note recovery rates for different particle sizes
4. Concentrate smelting	Final purification	Borax Method (gas torch or charcoal furnace); ensure proper ventilation and PPE
5. Optional comparison test	Assess incremental benefit of chemical leaching	Jinchan or other safe lixiviant in controlled lab/pilot test; assay gold content before and after leaching
6. Recovery evaluation	Quantify total gold recovered	Weigh concentrates, record smelted gold yield; compare with original tailings weight
7. Adoption decision	Select optimal, field-adapted recovery route	Consider efficiency, safety, cost, labour, and environmental impact; decide if Jinchan-free workflow is sufficient

While preliminary evidence suggests that **gravity-based concentration combined with Borax smelting** can replace Jinchan for many free-milling tailings in Suriname, several **knowledge gaps remain** that warrant additional investigation:

- 1. Ore and tailings variability:** Suriname's ASGM operations work with a wide range of alluvial and eluvial deposits. The liberation characteristics, particle size distribution, and gold associations can differ substantially across sites, affecting the efficiency of gravity-based recovery. Detailed **site-specific studies** are needed to determine where Jinchan-free technologies can reliably replace chemical leaching.
- 2. Fine and ultra-fine gold recovery:** Some tailings can contain extremely fine or colloidal gold that may not be fully captured by existing gravity devices under field conditions. Research is required to **optimize equipment configurations** (e.g., flow rate, sluice riffle design, centrifugal concentrator settings) to maximize recovery without chemicals.
- 3. Economic and operational feasibility:** While Jinchan-free methods reduce chemical risks, it is important to evaluate **costs, labour requirements, throughput, and maintenance needs** for miners. Pilot studies across different ASGM communities can identify potential barriers and practical adaptations.
- 4. Health and environmental monitoring:** Switching from chemical lixivants to gravity and Borax methods is expected to reduce occupational and environmental risks. However, **systematic monitoring of air quality, dust, and residual contaminants** is recommended to quantify the safety benefits and ensure compliance with environmental standards.

By addressing these gaps, additional research will **support evidence-based recommendations**, enhance **technology adoption**, and ensure that Suriname's ASGM sector moves toward **sustainable, safe, and economically viable gold recovery practices**.

Practical recommendations for replacing Jinchan use in Suriname's ASGM include the following:

- 1. Training and capacity building:** Provide comprehensive training for local miners on the operation of the equipment and tools summarized in Table 35. Training should include proper handling of

concentrates, maintenance of equipment, safety practices, and environmental protection measures, ensuring miners can operate these systems effectively and sustainably.

2. Pilot trials and validation: Conduct pilot-scale trials on representative tailings and ores to evaluate recovery efficiency, equipment performance, and operational feasibility under field conditions. These trials will provide site-specific data and help refine procedures before large-scale adoption.

3. Cooperative equipment ownership: Encourage cooperative or community-based ownership of gravity concentrators and smelting equipment to reduce individual costs, improve access to high-performing technologies, and foster collective responsibility for maintenance and sustainable operation.

4. Demonstration and outreach sites: Establish demonstration sites in key ASGM districts, such as Brokopondo and Sipaliwini, to showcase mercury- and Jinchan-free gold recovery workflows. These sites can serve as learning hubs where miners, local authorities, and technical advisors observe best practices, test equipment, and exchange knowledge.

5. Continuous monitoring and feedback: Implement a system for ongoing monitoring of gold recovery rates, operational challenges, and environmental impact at trial and demonstration sites. Regular feedback will inform adaptive management, helping miners optimize procedures, reduce losses, and improve safety.

6. Integration with local practices: Work closely with mining communities to adapt workflows to local conditions, including variations in ore type, water availability, and labour capacity. Emphasize incremental adoption, starting with partial replacement of Jinchan leaching and gradually moving toward fully chemical-free processes.

7. Policy and support framework: Encourage collaboration with local authorities, technical agencies, and NGOs to support technology adoption through training programs, funding, regulatory guidance, and dissemination of best-practice guidelines.

9. SURINAME NATIONAL CODE FOR THE MANAGEMENT OF ALTERNATIVE LIXIVIANTS IN GOLD MINING

Preamble

Recognizing the need to promote responsible and sustainable mineral development while safeguarding human health, freshwater resources, and biodiversity; Acknowledging the specific environmental and social risks associated with the use of synthetic alternative lixiviants – including, but not limited to, Jinchan – particularly in the sensitive ecological and community contexts of Suriname; and Affirming the heightened vulnerability of the artisanal and small-scale gold mining (ASGM) sector to the improper handling and mismanagement of such chemicals; this Code establishes a definitive regulatory framework for their use and application.

Chapter 1: General Provisions

1.1 Definitions

<i>Alternative Lixiviant</i>	Any chemical used to dissolve and extract gold from ore, excluding mercury. Includes cyanide, thiourea, thiosulfate, glycine-based reagents, and proprietary formulations such as Jinchan.
<i>ASGM (Artisanal and Small-Scale Gold Mining)</i>	Gold mining carried out by individuals, small groups, or cooperatives with low mechanization, low capital investment, and informal operations.
<i>Chemical Lixiviant</i>	A chemical substance applied in hydrometallurgy to dissolve metals from ore for recovery.
<i>Containment</i>	Engineered systems or structures designed to prevent lixiviant, process solution, or tailings from entering the environment (e.g., liners, leak detection, secondary containment).
<i>Detoxification/Neutralization</i>	Processes that transform or treat hazardous chemicals to render them safe for the environment before disposal.
<i>Environmental Monitoring</i>	Systematic measurement and analysis of soil, water, sediment, biota, and air to detect, prevent, or respond to chemical contamination.
<i>Large-Scale Mining (LSM)</i>	Mining operations conducted by registered corporate entities capable of fully implementing the Code, including safe chemical and environmental management.
<i>Laboratory-Scale Research</i>	Controlled experiments with lixiviants conducted under strict safety protocols in labs or pilot settings.
<i>Mercury-Free Gold Recovery Technologies</i>	Methods to extract gold without mercury or hazardous lixiviants, including gravity concentration, shaking tables, sluices, centrifuges, and borax-assisted smelting.

<i>Operator</i>	Any individual, company, cooperative, or organization engaged in gold mining, including chemical handling and management.
<i>Tailings</i>	Residual material left after gold extraction, including rock, water, and residual chemicals.
<i>Jinchan</i>	A synthetic lixiviant marketed as a cyanide alternative; prohibited in ASGM due to environmental and health risks.
<i>Risk Assessment</i>	Evaluation of potential adverse effects on human health and the environment from chemicals or mining activities, including mitigation planning.
<i>Safety Data Sheet (SDS)</i>	A document describing a chemical's composition, hazards, handling, storage, and emergency measures.
<i>Verification/Audit</i>	Formal assessment by competent or independent auditors to ensure operator compliance with the Code, including chemical, environmental, and safety standards.
<i>Zero Discharge/Zero Release</i>	Principle ensuring no intentional release of lixiviants, process solutions, or chemical residues into the environment through containment, recycling, or treatment.

1.2 Scope

This Code establishes the principles, requirements, and prohibitions for the use of Jinchan and similar cyanide-free lixiviants in artisanal and small-scale gold mining operations in Suriname. Its purpose is to ensure the safety of miners, communities, and the environment while guiding research and responsible practices.

1.3 Applicability

This Code applies to all forms of artisanal and small-scale gold mining operations conducted within the territory of the Republic of Suriname, including but not limited to:

- Alluvial, eluvial, and secondary deposits;
- Ore processing, tailings reprocessing, and any experimental or pilot-scale use of chemical lixiviants;
- The storage, transport, handling, and disposal of Jinchan or related lixiviant products.

Compliance with this Code is mandatory for all large-scale mining operations.

For the ASGM sector, the provisions set forth in Chapter 4 are strictly prohibitive, particularly regarding the use of Jinchan and similar chemical lixiviants in ore or tailings processing.

1.4 Objective

The objectives of this Code are to:

- Prevent chemical-related accidents, human exposure, and environmental contamination arising from the use, handling, or disposal of Jinchan and similar lixiviants;
- Promote the adoption of non-chemical and mercury-free gold recovery technologies within Suriname's artisanal and small-scale gold mining sector;
- Provide technical and safety guidance for the limited, laboratory-scale use of Jinchan under strictly controlled and supervised research conditions.

Chapter 2: General Principles for Lixiviant Use (Applicable to LSM Only)

2.1 Risk Assessment

Prior to the introduction or use of any alternative lixiviant, a comprehensive site-specific environmental and human health risk assessment shall be conducted, reviewed, and approved by the competent national authority. This assessment must evaluate potential impacts on soil, water, air, biota, and human health throughout the lixiviant's life cycle – from transport and storage to use and waste management.

2.2 Chemical Registration and Disclosure

All lixiviants intended for industrial or pilot use must be registered with the relevant regulatory body. Full disclosure of the chemical composition, accompanied by Safety Data Sheets (SDS) and ecotoxicological profiles, is mandatory.

Where proprietary formulations are claimed, sufficient toxicological and environmental information must still be provided to allow regulatory evaluation of safety and risk.

2.3 Worker Safety

Operators shall ensure that all personnel involved in the handling, preparation, or application of lixiviants are adequately protected through:

Mandatory training on chemical hazards, handling, and emergency procedures;

Continuous availability and proper use of certified personal protective equipment (PPE);

Established and practiced emergency response and first-aid protocols for chemical spills or exposure incidents.

2.4 Community Communication

Companies must develop and maintain a transparent community communication plan for all areas potentially affected by lixiviant-related activities.

This plan shall include mechanisms for public notification, consultation, grievance redress, and disclosure of monitoring results, ensuring communities are informed and engaged in matters affecting their environment and health.

2.5 Environmental Monitoring

Operators must establish and maintain a comprehensive environmental monitoring program to ensure early detection and prevention of lixiviant-related contamination.

The program shall include:

- Baseline environmental studies prior to lixiviant use, covering water, soil, sediment, and biota;
- Routine sampling and analysis of surface and groundwater quality, particularly for cyanide analogues, thiourea, thiosulfate, and other degradation products;
- Leak detection systems and containment inspections at storage, mixing, and processing areas;
- Periodic reporting of monitoring data to regulatory agencies and public disclosure of summarized findings;
- Immediate corrective and remedial actions in the event of any detected contamination or abnormal chemical release.

Chapter 3: Operational Requirements for Lixiviant Management (Applicable to LSM Only)

3.1 Transportation

Lixiviants shall be transported in full compliance with international standards governing the transport of hazardous materials, including the UN Recommendations on the Transport of Dangerous Goods and IMO/ICAO regulations, as applicable.

Operators must ensure that:

- Transport contractors are licensed and trained in handling hazardous substances;
- Containers and tankers are clearly labelled, compatible with the chemical being transported, and in sound condition;
- Emergency response plans and spill containment materials are available along transport routes;
- The competent national authority is notified of all shipments, and transport records are maintained for audit purposes.

3.2 Storage and Handling

Lixiviants shall be stored in secure, purpose-built facilities designed to prevent leaks, spills, or releases into soil or water.

Storage and handling systems must include:

- Impermeable secondary containment capable of holding at least 110% of the largest tank's volume;
- Automated and controlled dosing systems to minimize human exposure and prevent overuse;
- Segregated chemical storage to avoid incompatible material interactions;
- Clearly displayed hazard signage, restricted access, and 24-hour surveillance;
- Routine inspection, maintenance, and integrity testing of tanks, pipelines, and valves.

3.3 Containment

All process areas – including leach vats, heap leach pads, solution ponds, and tailings impoundments – must be designed and constructed to achieve zero intentional discharge to the environment.

These facilities shall include:

- Engineered synthetic liners (HDPE or equivalent) with proven chemical resistance to the lixiviant;
- Leak detection and collection systems beneath all lined areas;
- Diversion channels to manage stormwater and prevent contact with process solutions;
- Regular inspection and integrity verification of containment systems, with immediate corrective action for any detected leak or failure.

3.4 Decommissioning and Closure

Operators must prepare and maintain a fully funded decommissioning and closure plan approved by the regulatory authority prior to the commencement of lixiviant use.

The plan shall include:

- Procedures for detoxification or neutralization of all process solutions and residual chemicals;
- Secure long-term containment and stabilization of tailings and contaminated materials;
- Progressive reclamation measures during operations where feasible;
- Post-closure environmental monitoring of groundwater, surface water, and soil;
- Financial assurance mechanisms (such as bonds or trust funds) to guarantee implementation of closure and long-term monitoring activities.

Chapter 4: Prohibitions for the Artisanal and Small-Scale Gold Mining Sector

4.1 General Prohibition

The use, handling, storage, transport, trade, or disposal of Jinchan or any alternative chemical lixiviant for gold extraction is strictly prohibited in all forms of artisanal and small-scale gold mining (ASGM) activities within the Republic of Suriname.

This prohibition applies to:

- Ore processing and amalgamation replacement;
- Tailings reprocessing and chemical enhancement;
- Experimental or pilot-scale lixiviant use at mining camps or informal sites.

4.2 Rationale for Prohibition

The prohibition is based on the unacceptable environmental and human health risks posed by chemical lixiviants when used under uncontrolled ASGM conditions.

Such substances:

- Present high potential for water contamination and ecosystem toxicity due to improper containment and waste disposal;
- Pose severe occupational and public health hazards through ingestion pathway;
- Are incompatible with low-technology ASGM environments, which lack the infrastructure and expertise for safe chemical management;
- Risk creating irreversible contamination of river systems, soils, and biodiversity, especially in sensitive tropical ecosystems.

4.3 Specific Prohibitions

The following practices are expressly forbidden in ASGM operations:

- Use of Jinchan or any other cyanide-analogue lixiviant;
- Chemical treatment of tailings from mercury amalgamation or gravity concentration;
- Open-pit, sluice-based and heap chemical leaching;
- Use in rivers, creeks, tailings ponds, or uncontained pits;
- Importation, sale, or distribution of Jinchan or similar lixiviants for ASGM purposes;
- Construction or operation of chemical leaching facilities, including vats, tanks, or ponds, at ASGM sites;
- Storage, disposal, or discharge of lixiviant residues, containers, or waste into natural water bodies or open land.

4.4 Enforcement and Penalties

National authorities shall enforce this prohibition through:

- Inspection and monitoring of mining sites, processing facilities, and supply chains;
- Immediate confiscation of any prohibited chemical substances found in ASGM areas;
- Administrative and criminal penalties for individuals or entities involved in the import, sale, or use of prohibited lixiviants;
- Mandatory remediation orders for contaminated sites, to be implemented under government supervision.

Chapter 5: Safe Alternatives and Best Practices for ASGM

5.1 Promotion of Non-Chemical Gold Recovery Technologies

The Government of Suriname, through the National Environmental Authority (NMA) and Ministry of Natural Resources and in collaboration with national and international partners, shall actively promote and support the implementation of mercury-free and chemical-free mineral processing technologies, including but not limited to:

- Gravity-based recovery systems, such as the Gold Kacha, Blue Bowl Concentrator, Cleangold Magnetic Sluice, and Gemini Shaking Table, proven effective for fine and ultra-fine gold recovery;
- Enhanced gravity concentration circuits, optimized for local alluvial and eluvial deposit characteristics;
- Mercury-free smelting and borax-assisted methods, which improve gold purity while eliminating toxic emissions.

5.2 Capacity Building and Community Training

The Government and its partners shall establish continuous capacity-building programs for miners, cooperatives, and community groups focused on:

- Cleaner production techniques and safe handling of materials;
- Improved ore beneficiation and recovery efficiency through proper equipment use and maintenance;
- Environmental management practices, including proper tailings handling and site rehabilitation;
- Occupational safety and health awareness to minimize exposure to physical and environmental hazards.

Training shall be delivered in collaboration with local technical institutions, NGOs, and extension services, ensuring accessibility for remote and small-scale mining communities.

5.3 Incentives and Support Mechanisms

To accelerate the transition to cleaner technologies, the Government shall implement economic and institutional incentives, including:

- Access to microcredit or financial support schemes for the purchase of mercury-free processing equipment;
- Tax incentives or import duty exemptions for certified environmentally sound technologies;
- Recognition and certification programs for compliant and environmentally responsible mining cooperatives;
- Facilitation of public – private partnerships for local equipment manufacturing and maintenance.

5.4 Research and Innovation

The National Environmental Authority and Ministry of Natural Resources, in collaboration with Anton de Kom University of Suriname, shall encourage and support applied research into locally adapted, low-cost, and sustainable gold recovery technologies.

Research priorities include:

- Optimization of gravity recovery systems for Suriname's specific ore and sediment types;
- Development of small-scale recycling systems for tailings reprocessing without chemical inputs;
- Assessment of energy-efficient and water-conserving techniques applicable to remote ASGM regions.

5.5 Integration with National Development Goals

The promotion of safe ASGM practices shall be integrated into national strategies for:

- Sustainable livelihoods, poverty reduction, and rural development;
- Implementation of the Minamata Convention on Mercury;
- Protection of water resources and biodiversity;
- Advancement of gender equality and community participation in resource governance.

Chapter 6: Institutional Responsibilities and Oversight

6.1 Competent Authorities

The implementation and enforcement of this Code shall fall under the jurisdiction of the National Environmental Authority and Ministry of Natural Resources, in collaboration with other relevant governmental entities. These institutions are responsible for:

- Establishing and updating the national regulatory framework governing the use and prohibition of lixivants;
- Issuing permits and authorizations for large-scale mining operations that comply with this Code;
- Conducting site inspections, audits, and verification of compliance;
- Coordinating with regional and local authorities to ensure effective enforcement and public awareness.

6.2 Monitoring and Reporting

All large-scale mining operators utilizing lixivants shall:

- Submit periodic environmental monitoring reports detailing chemical usage, waste management, and containment integrity;
- Report immediately any spills, leaks, or unplanned discharges to the competent authority and affected communities;
- Maintain transparent documentation of all chemical inventories, transport records, and monitoring data for at least ten (10) years;
- Allow third-party audits or independent verification of compliance when required by the authority.

Authorities shall consolidate submitted data into an annual national report evaluating industry performance, environmental trends, and the effectiveness of regulatory enforcement.

6.3 Coordination and Inter-Agency Collaboration

The National Environmental Authority, the Ministry of Natural Resources and the Ministry of Wellbeing, Public Health and Labour shall jointly develop protocols for:

- Information exchange on chemical safety, environmental monitoring, and occupational health;
- Emergency preparedness and response coordination in the event of chemical incidents;
- Training programs for inspectors, enforcement officers, and technical staff on safe lixiviant management;
- Collaboration with customs and border control agencies to prevent illegal importation or distribution of prohibited lixivants.

6.4 Stakeholder Engagement and Transparency

The competent authorities shall ensure that:

- Public access to information regarding lixiviant use, monitoring results, and enforcement actions is maintained;
- Consultation mechanisms with communities, civil society organizations, and the private sector are established;
- Feedback from stakeholders is systematically integrated into policy updates and capacity-building initiatives.

This participatory approach aims to build trust, promote responsible mining practices, and strengthen environmental governance.

6.5 International Cooperation

The Government of Suriname shall actively engage with international organizations and regional partners to:

- Exchange best practices in chemical management and mercury-free mining;
- Participate in research and pilot projects on sustainable gold recovery methods;
- Seek technical and financial assistance for capacity building, monitoring, and remediation of contaminated sites.

Chapter 7: Verification, Compliance, Penalties for Non-Compliance and Continuous Improvement

7.1 Compliance Verification

All large-scale mining operations utilizing lixiviants shall be subject to regular verification audits to ensure full compliance with the provisions of this Code. Verification shall include:

- Initial certification audits prior to the commencement of lixiviant use;
- Periodic re-certification audits every three (3) years conducted by independent, qualified auditors;
- Interim surveillance reviews or inspections when required by the competent authority;
- Verification of compliance with environmental monitoring, worker safety, and community communication requirements.

Audit findings shall be documented in formal reports submitted to the Nationale Milieu Autoriteit and Ministry of Natural Resources, and summaries shall be made publicly available.

7.2 Non-Compliance and Corrective Action

7.2.1 Sanctions for ASGM Operators

Violations of this Code in the ASGM sector shall result in:

- Immediate confiscation of any prohibited chemicals, equipment, or contaminated materials;
- Fines proportionate to the quantity of chemicals found and the severity of the violation;
- Suspension or revocation of mining permits or cooperative registration;
- Mandatory remediation of contaminated sites under government supervision;
- Criminal prosecution in cases of repeated, negligent, or intentional violations that endanger human health or the environment.

7.2.2 Sanctions for LSM Operators

Violations of the Code by LSM operators shall result in graduated sanctions based on severity and recurrence:

1. Minor violations (e.g., incomplete reporting, minor procedural lapses):
 - Written warning;
 - Mandatory corrective actions within a specified timeframe.
2. Major violations (e.g., accidental release of lixivants, failure of containment):
 - Fines proportional to environmental and operational impact;
 - Temporary suspension of lixiviant-related operations;
 - Requirement to implement remediation measures.
3. Severe or repeated violations (e.g., intentional misuse, failure to implement corrective actions, environmental contamination):
 - Revocation of chemical use permits;
 - Civil and criminal liability under national environmental law;
 - Mandatory long-term remediation and monitoring funded by the operator.

7.2.3 Compliance Incentives

Operators and communities that demonstrate full compliance and actively adopt safe, mercury-free technologies may receive:

- Recognition through certification programs;
- Priority access to training, technical assistance, and microcredit programs;
- Inclusion in government-supported sustainable mining initiatives.

7.3 Independent Auditing and Public Disclosure

Independent auditors must be:

- Technically qualified and institutionally independent from the operator;
- Accredited by a recognized environmental auditing body;
- Bound by transparency and impartiality standards.

Audit results and environmental performance data shall be disclosed publicly through annual sustainability reports managed by NMA, promoting transparency and accountability in the mining sector.

7.4 Continuous Improvement

Operators and authorities shall pursue continuous improvement in lixiviant management through:

- Periodic review and updating of operational procedures and safety standards;
- Adoption of emerging best available technologies (BAT) and cleaner production methods;
- Capacity-building programs for technical staff, inspectors, and local communities;
- Collaboration with Anton de Kom University of Suriname to evaluate new, environmentally benign lixivants or gold recovery methods.

This approach ensures that regulatory and operational practices evolve in step with scientific progress and international sustainability objectives.

7.5 Code Review and Revision

The National Environmental Authority in coordination with the Ministry of Natural Resources and relevant stakeholders, shall review and update this Code every five (5) years, or earlier if:

- Significant new scientific data on lixiviant risks or alternatives become available;
- Major incidents, spills, or environmental findings necessitate stronger controls;
- International regulations or conventions affecting lixiviant management are revised.

Revisions shall be conducted transparently, with stakeholder consultation, and published in the Official media of the Republic of Suriname.

Summary: This Code recognizes Jinchan as a potentially hazardous chemical in informal ASGM contexts. Its use in Suriname's ASGM is prohibited, especially for tailings. Gravity-based and mercury-free methods are the safest and most effective alternatives. Controlled laboratory research may proceed only under strict safety protocols (Figure 55).

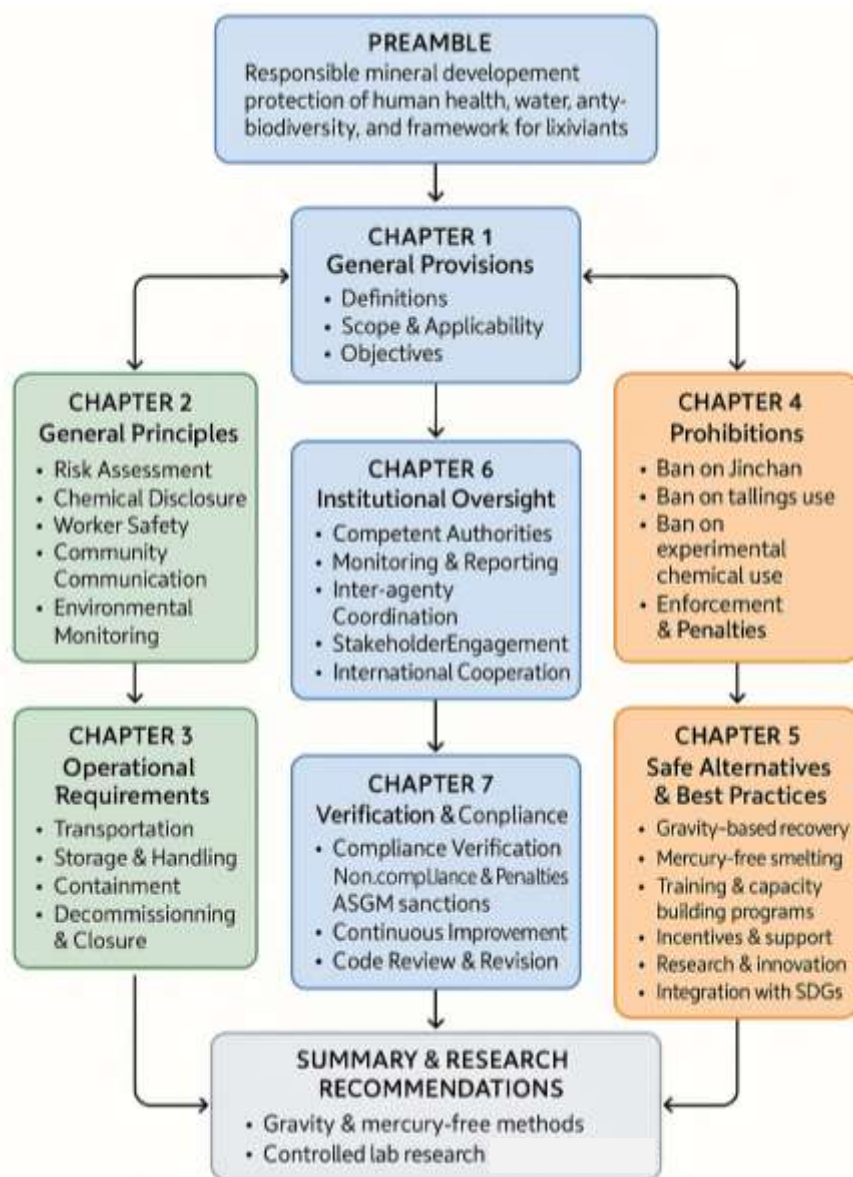


Figure 55. Suriname National Code for the management of alternative lixiviants in gold mining summary diagram (developed by the authors)

CONCLUSIONS AND RECOMMENDATIONS

1. Jinchan lixiviant is not eco-friendly and can produce, e. g. free cyanide (CN^-) under acidic (pH sensitive) or oxidizing conditions, posing environmental and health risks, (particularly at Bohmila this has been proven).
2. Mercury in water samples is below WHO and EPA limits because volatile mercury evaporates and the remainder settles in sediments; thus, sediment analysis is essential to detect contamination. Mercury cycle produces Methyl-mercury, that bio-accumulates and enters the fish cycle causing the most harm to biodiversity and human health in areas beyond mining sites.
3. Cyanide in natural waterways showed to be mostly below reference limits, with occasional exceedances (e. g., Ero Bergi W1), indicating localized contamination linked to site-specific discharges. Although a less expected outcome, it can be explained by phenomena such as significant Dilution Factor in open water, UV exposure breakdown, and a relatively short half-life.
4. Heavy metals in natural waters are below safety limits, but barren solutions, especially at Bohmila, show elevated Cu and Pb, requiring strict handling and monitoring.
5. Gold mining methods directly affect soil mercury contamination; amalgamation increases mercury levels, while heap leaching has lower impact.
6. Most metals show low geo-accumulation, but Co, Ni, Cu, As, and particularly Hg in Kwangoe indicate localized contamination requiring further investigation.
7. Elevated soil concentrations of Cu, Zn, Ni, and Co in ASGM areas result from natural geology, uncontrolled mining practices, waste dumping, and enhanced mobilization, exceeding global and local background levels.
8. The Nemerov Comprehensive Index (Pi) effectively identifies spatial variations and localized contamination; Bohmila shows moderate pollution, Ero Bergi has localized significant contamination, and Kwangoe shows severe mercury contamination.
9. The non-carcinogenic risk from soil exposure is low, but combined exposure from contaminated water, mercury vapor, lixiviants, and bioaccumulation increases cumulative health risk.
10. Carcinogenic risk from soil is relatively low, with arsenic ingestion as the main concern, emphasizing the need for continuous monitoring with cumulative risk assessments.
11. Water pollution in ASGM areas of Suriname poses clear non-carcinogenic health risks primarily through river water ingestion, and cyanides (91%) as the dominant contributor affecting the nervous, cardiovascular, respiratory, thyroid, liver, and kidney systems.
12. Most artisanal miners lack awareness of safe chemical handling, environmental impacts, and legal obligations, increasing misuse and contamination risk; targeted education and stronger enforcement are needed.
13. The representatives of the Suriname Geological Mining Service highlights major structural and institutional weaknesses in chemical governance within the ASGM sector, emphasizing the urgent need for stricter regulation and coordinated reform.
14. Regulatory enforcement gaps in ASGM areas allow unsupervised use of chemical lixiviants like Jinchan; limited capacity, infrastructure, and public awareness exacerbate environmental and health risks.
15. For free-milling ASGM tailings in Suriname, technologies such as the Cleangold Sluice, Blue Bowl, and Borax Method offer effective, low-cost, and environmentally sustainable alternatives to Jinchan leaching.
16. Considering current ASGM conditions and potential community exposure, a temporary ban on Jinchan and similar lixiviants is recommended until proper research, controls, and monitoring systems are established.

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Appendixes

Appendix A.1 – Bohmila Site Description

1. Site Identification

Site Name:	Bohmila
Resort/District:	Sarakreek / Brokopondo
Coordinates:	54° 55' 10" W; 4° 44' 54" N
Date of Survey:	July 15, 2025

2. General Site Characteristics

Topography:	Hilly, island
Land Cover:	The forested and cleared (former mining) areas, including the tailings pond, consist of bare soil and water
Hydrology:	An island located in the eastern part of Afobaka Lake
Climate Conditions:	Temperature – 27°C Long rainy season
Accessibility:	The site is accessible by both boat and road

3. History and Type of ASGM Activities

Activity Type:	Hydraulic mining using a sluice box, and chemical extraction of gold from tailings through heap leaching with Jinchan lixiviant
Duration of Activity:	The leaching operation has been ongoing for about 6 months, whereas the hammer mill – sluice box operation has been in use for over 10 years
Mining Methods:	Hydraulic mining, a method that uses high-pressure water jets to dislodge rock or move sediment, is employed at the site. Heap leaching is used as the gold recovery method, with Jinchan lixiviant applied for chemical extraction from the tailings

Appendix A.2 – Bohmila Site Photo Description

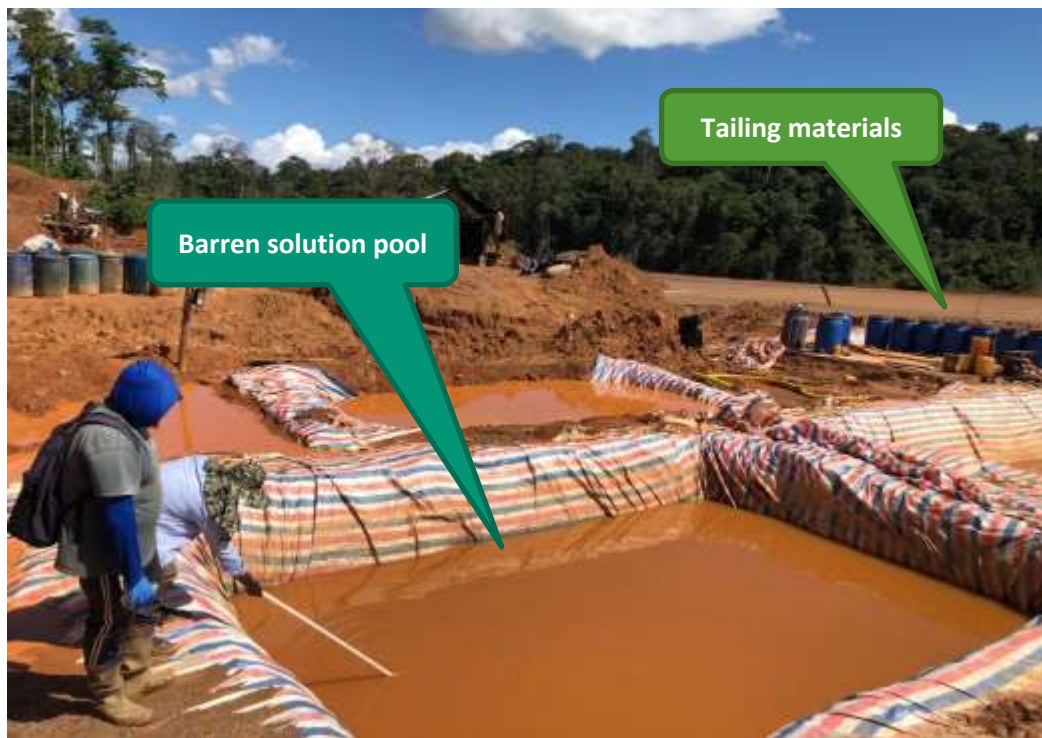


Figure 1. Collection of barren solution after Jinchan application



Figure 2. Sluice box and prepared tailing material for leaching

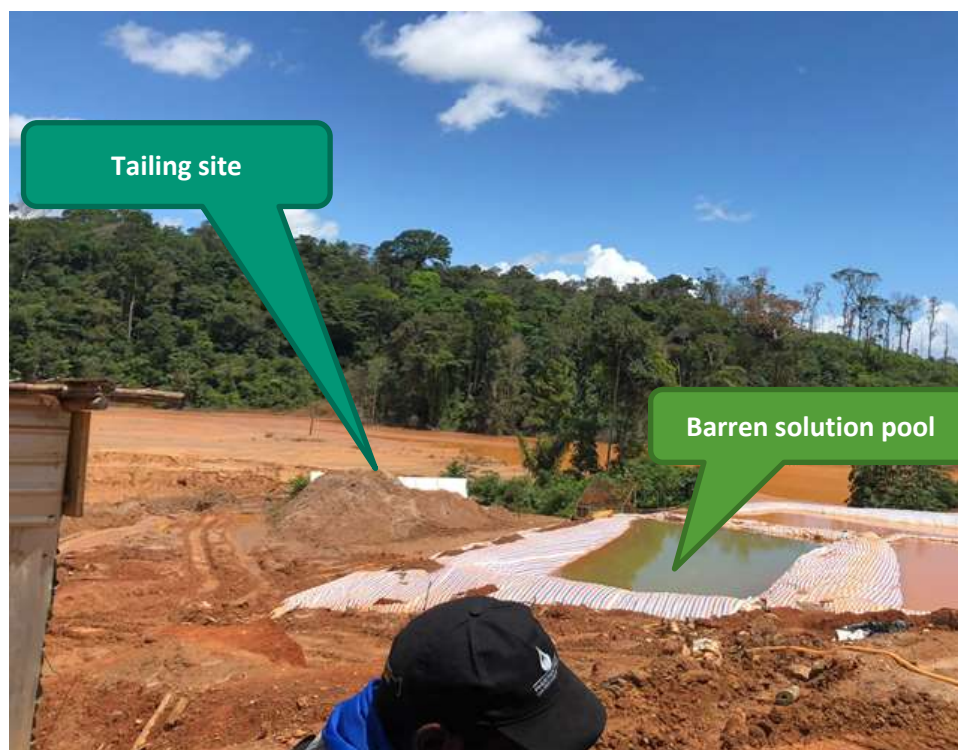


Figure 3. Tailing from the hammer mill – sluice box and the solution pool



Figure 4. Part of the water sampling process during the Bohmila site visit



Figure 5. **Prepared tailing material and raw tailings before leaching**



Figure 6. **Heap leaching setup at Bohmila site**

Appendix A.3 – Ero Bergi Site Description

1. Site Identification

Site Name:	Ero Bergi
Resort/District:	Sarakreek / Brokopondo
Coordinates:	54° 58' 18" W; 4° 49' 00" N
Date of Survey:	July 16, 2025

2. General Site Characteristics

Topography:	Hilly, island
Land Cover:	The forested and cleared (former mining) areas, including the tailings pond, consist of bare soil and water
Hydrology:	An island located in the eastern part of Afobaka Lake
Climate Conditions:	Temperature – 28°C Long rainy season
Accessibility:	The site is accessible by boat

3. History and Type of ASGM Activities

Activity Type:	Mining, processing (hammer mill – sluice box operation and chemical extraction)
Duration of Activity:	The leaching operations have been ongoing intermittently over an extended period, with phases of inactivity followed by resumption. The hammer mill – sluice box operation has been active for more than 10 years.
Mining Methods:	Open-pit mining is used to extract gold-bearing material. The extracted ore is processed using a hammer mill and sluice box system. Amalgamation is carried out on the sluice box concentrate to recover gold by separating it from the remaining materials using mercury. Heap leaching is used as the gold recovery method, with Jinchuan lixiviant applied for chemical extraction from the tailings
Processing Zones:	The mining area and hammer mill – sluice box operation is located approximately 150 meters from the heap leaching site. The heap leaching setup is situated close to a lake, with a varying distance of approximately 5 to 50 meters from the shoreline.

Appendix A.4 – Ero Bergi Site Photo Description



Figure 1. **Hammer mill – sluice box setup**
(This type of setup is the most commonly used processing circuit in the ASGM sector in Suriname)



Figure 2. **Pregnant and barren solution pools at Ero Bergi site**



Figure 3. **Material already mixed with cement and caustic soda for the leaching process**



Figure 4. **Boat landing area at Ero Bergi, with field investigation team approaching the site**



Figure 5. **Collecting of heap material**

Appendix A.5 – Kwangoe Site Description

1. Site Identification

Site Name:	Kwangoe
Resort/District:	Sarakreek / Brokopondo
Coordinates:	55° 04' 48" W; 4° 59' 11" N
Date of Survey:	July 16, 2025

2. General Site Characteristics

Topography:	Hilly, island
Land Cover:	The forested and cleared (former mining) areas, including the tailings pond, consist of bare soil and water
Hydrology:	An island located in the northern part of Afobaka Lake
Climate Conditions:	Temperature – 28°C Long rainy season
Accessibility:	The site is accessible by boat

3. History and Type of ASGM Activities

Activity Type:	Mining, processing (hammer mill – sluice box operation and chemical extraction)
Duration of Activity:	The leaching operation are applying for more than 6 years. The hammer mill – sluice box operation has been active for more than 10 years.
Mining Methods:	Open-pit mining is used to extract gold-bearing material. The extracted ore is processed using a hammer mill and sluice box system. Amalgamation is carried out on the sluice box concentrate to recover gold by separating it from the remaining materials using mercury. Heap leaching is used as the gold recovery method, with Jinchuan lixiviant applied for chemical extraction from the tailings
Processing Zones:	The mining site and the hammer mill–sluice box operation is located approximately 100 meters from the heap leaching area. The heap leaching setup is situated near the lake, with the distance ranging from 5 to 50 meters.

Appendix A.6 – Kwangoe Site Photo Description



Figure 1. Oil storage facilities are located on one of the Kwangoe islands



Figure 2. Collecting water samples at Kwangoe area



Figure 3. A tank leaching setup on one of the islands in the Kwangoe area



Figure 4. A heap leaching setup on one of the islands in the Kwangoe area



Figure 5. A barren solution pool on one of the islands in the Kwangoe area



Figure 6. A barren solution pool on one of the islands in the Kwangoe area

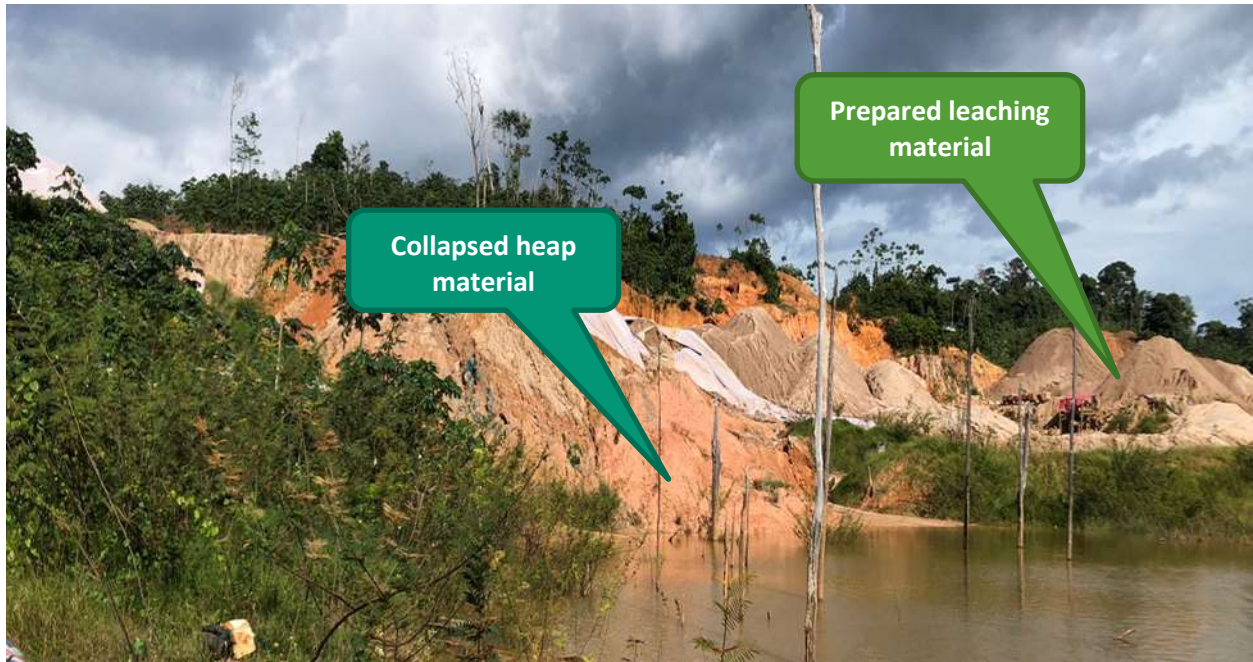


Figure 7. Leaching material prepared and collapsed heap material observed at the Kwangoe area

Appendix B.1 – Samples Location

Sample code	Medium	X coordinate, m	Y coordinate, m
<i>Bohmila Site</i>			
BMA W1	Water	730721.134034	525135.338993
BMA W2	Water	730701.951704	525225.165214
BMA W3	Water	730739.125737	525191.430772
BMA S1	Soil	730795.283661	525213.325087
BMA S2	Soil	730771.471114	525141.887444
BMA S3	Soil	730746.666377	525175.621886
BMA B1	Barren solution	730828.025914	525190.835458
<i>Ero Bergi Site</i>			
EB W1	Water	724918.404503	532774.288969
EB W2	Water	724895.121123	532923.514267
EB W3	Water	724934.279535	533106.6063
EB S1	Soil	724854.904376	533066.389553
EB S2	Soil	724810.454287	532834.614089
EB S3	Soil	724703.662506	532815.473761
EB B1	Barren solution	724603.020539	532776.405639
<i>Kwangoe Site</i>			
KWA W1	Water	712231.442956	551430.893387
KWA W2	Water	712809.180124	552135.732732
KWA W3	Water	712427.873593	551673.542997
KWA S1	Soil	712149.34874	551592.680386
KWA S2	Soil	712163.136572	551480.551513
KWA S3	Soil	712878.012698	552153.069007

Appendix C.1 – Questionnaire for Indigenous Communities and Traditional Leaders on ASGM Practices

Objective: To understand the awareness, concerns, and perspectives of Indigenous communities and traditional leaders regarding the use of lixiviants (such as mercury and cyanide) in Artisanal and Small-Scale Gold Mining (ASGM) and explore potential solutions.

Instructions:

The interviewer will read each question aloud.

The respondent can answer by pointing to pictograms (☑=Yes, ✕=No, ⚠=Not sure) or by selecting from multiple-choice options.

For ranking questions, the respondent can order options by importance (1 = most important, 4 = least important).

Section 1: Awareness of Lixiviants Used in ASGM

1. Have you heard about the chemicals (lixiviants) miners use to extract gold?



Yes



No



Not sure

2. Which lixiviants do you know are used in mining? (Select all that apply)



Mercury



Cyanide



Non-cyanide



Other (describe: _____)



Don't know

3. Do you think these chemicals are dangerous for health?



Yes



No



Not sure

4. Do you think these chemicals harm the environment (rivers, soil, animals)?



Yes



No



Not sure

Section 2: Perceptions on Regulation and Technology

5. Should the government control the use of these chemicals in mining?



Yes



No



Not sure

6. Is it necessary to replace mercury with other technologies (like cyanide)?

☒ Yes

☐ No

☐ Not sure

7. Rank the biggest problems caused by ASGM (1 = most severe, 6 = least severe)

 = Water pollution

 = Soil pollution

 = Forest destruction

 = Health problems

 ☒ = No more fish

 ☐  = Social conflicts

Section 3: Solutions and Community Needs

8. What solutions exist to reduce harm from mining chemicals? (Select all that apply)

☒ = Training miners

☐ = Government enforcement

☐ = Alternative methods

☐ = Community monitoring

☐ = Clean water

☐ = Land restoration

☐ = Health checks

9. Would your community support a ban on mercury in mining?

☒ Yes

☐ No

☐ Not sure

10. What help does your community need to address mining pollution? (Rank 1-8)

☐ = Education

☐ = Laws/Enforcement

☐ = Alternative Jobs

☐ = Clean Water

☐ = Healthcare

☐ = Community Control

☐ = Better Tools

☐ = Compensation

Appendix C.2 – Questionnaire for Suriname Gold Miners Association (VGS) and Miners involved in ASGM Practices

Objective: To assess miners' perspectives on lixiviant use (mercury, cyanide, and alternatives), challenges in technology adoption, and potential policy interventions to improve ASGM practices in Suriname.

Section 1: Current Practices & Chemical Use

1. Which lixiviants does your operation currently use for gold extraction? (Select all that apply)
 - Mercury (Hg) – Amalgamation
 - Cyanide (NaCN/KCN) – Heap leaching/vat leaching
 - Borax – Mercury-free gravity concentration
 - Nitric Acid (HNO₃) – Gold purification
 - Thiourea/Thiosulfate – Alternative lixiviants
 - Other (specify): _____

2. What are the MAIN REASONS for using mercury in your operations? (Rank by importance, 1 = most important)
 - Low cost & easy availability
 - Fast & simple process (no complex equipment)
 - Works well with fine gold particles
 - Lack of access to alternatives
 - Tradition / miners are familiar with it

3. What are the MAIN DISADVANTAGES of using mercury? (Select all that apply)
 - Health risks (neurological damage, poisoning)
 - Environmental pollution (rivers, fish contamination)
 - Low gold recovery efficiency (losses in tailings)
 - Government restrictions / crackdowns
 - Negative international perception (affects gold sales)

Section 2: Cyanide & Non-Cyanide Alternatives

4. Has your operation ever used CYANIDE for gold extraction?
 - Yes, currently using
 - Yes, but stopped due to challenges
 - No, but interested
 - No, not suitable for our ore type

5. If using cyanide, what are the MAIN ADVANTAGES? (Select all that apply)
 - Higher gold recovery rates (90%+)
 - Works with low-grade ores
 - Can be managed safely with proper controls
 - More accepted by international buyers

6. What are the MAIN CHALLENGES of using cyanide? (Select all that apply)
- High toxicity (risk of poisoning workers/communities)
 - Requires strict waste management (tailings ponds, detox)
 - Expensive setup (needs infrastructure, permits)
 - Requires technical expertise (pH control, monitoring)
7. Are you aware of NON-CYANIDE alternatives (e.g., thiourea, thiosulfate, borax)?
- Yes, we have tried them
 - Yes, but not suitable for our ore
 - No, need more information
 - No, too expensive/complicated

Section 3: Barriers to Technology Change

8. What are the BIGGEST OBSTACLES to switching from mercury to cleaner methods? (Rank 1-5)
- High cost of new equipment
 - Lack of training/technical knowledge
 - Resistance from miners (tradition, distrust of new methods)
 - No financial incentives (gold prices don't reward clean methods)
 - Government policies not supportive (no subsidies, strict bans without alternatives)
9. What kind of SUPPORT would help your operation transition? (Select all that apply)
- Government subsidies for mercury-free technology
 - Training programs on cyanide/borax methods
 - Access to cheap, reliable equipment (retorts, leaching kits)
 - Better gold pricing for mercury-free gold
 - Legal protection for miners who adopt cleaner practices

Section 4: Policy & Future Outlook

10. Should Suriname implement a FULL BAN on mercury in ASGM?
- Yes, but only if alternatives are provided
 - No, miners should have a choice
 - Only in certain regions (e.g., near rivers)
 - Not sure / need more discussion
11. How should the government regulate cyanide use?
- Strict permits + mandatory safety training
 - Only allow cyanide in controlled processing plants
 - No restrictions – miners should self-regulate
 - Ban it completely (too dangerous)
12. What is the FUTURE of ASGM in Suriname? (Select one)
- Mercury will remain dominant (no realistic alternatives)
 - Gradual shift to cyanide if regulations allow
 - Borax/gravity methods will replace mercury
 - Industrial mining will take over, leaving no space for ASGM

Appendix C.3 – Questionnaire for Suriname Geological Mining Service (GMD) on ASGM Practices

Objective: To assess the regulatory framework, enforcement challenges, and policy gaps related to the use of cyanide and non-cyanide lixiviants in ASGM, and to identify opportunities for improved governance of gold extraction chemicals.

Section 1: Current Regulatory Framework

1. How does Suriname currently regulate the use of the following lixiviants in ASGM? (Check all that apply)

Lixiviant	Full Ban	Restricted Use (Permits)	No Regulation	Partial Ban (e.g., near rivers)
Mercury				
Cyanide				
Non-Cyanide				
Borax				
Thiourea/Thiosulfate				

2. What are the key legal instruments governing lixiviant use in Suriname? (Select all that apply)

- Mining Decree (Mijnbouwdecreet)
- Environmental Management Act
- Chemical Substances Control Regulations
- International Agreements (Minamata Convention, etc.)
- Other (specify): _____

3. Does GMD conduct environmental impact assessments (EIAs) for ASGM operations using cyanide or mercury?

- Yes, for all operations
 - Only for medium/large-scale mines
 - No, but it should be mandatory
 - No, and it's not necessary
-

Section 2: Enforcement & Compliance Challenges

4. What are the biggest challenges in ENFORCING lixiviant regulations? (Rank 1-5)

- Lack of monitoring capacity (staff, equipment, labs)
- Corruption/illegal smuggling of chemicals
- Miners' resistance to regulation (informal sector)
- Weak penalties for violations
- Conflicting policies between agencies

5. How does GMD verify compliance with cyanide/mercury regulations? (Select all that apply)

- Field inspections
- Satellite monitoring
- Community reporting systems
- Random chemical testing of tailings
- No systematic monitoring

6. Are there "hotspots" where illegal lixiviant use is most severe?

- Yes (specify regions: _____)
- No, usage is evenly distributed
- No data available

Section 3: Gaps in Legislation & Policy

7. What are the biggest GAPS in Suriname's regulation of mining chemicals? (Select all that apply)

- No clear distinction between ASGM and industrial mining rules
- Lack of alternatives promotion (e.g., no subsidies for mercury-free tech)
- Weak controls on chemical imports/sales
- No rehabilitation requirements for contaminated sites
- Inconsistent enforcement across regions

8. Should Suriname adopt STRICTER rules on cyanide (e.g., mandatory detox, closed-loop systems)?

- Yes, immediately
- Yes, but phased implementation
- No, current rules are sufficient
- No, it would push miners further underground

9. Does GMD have a strategy to phase out mercury in line with the Minamata Convention?

- Yes, with clear timelines
- In development
- No, but it's being discussed
- No, and no plans exist

Section 4: International Collaboration & Capacity Building

10. What international support would help improve lixiviant regulation? (Select all that apply)

- Funding for monitoring equipment/labs
- Training for inspectors on chemical management
- Technology transfer (cyanide detox, mercury-free methods)
- Regional cooperation (e.g., with Guyana/French Guiana)

11. Should Suriname establish a CENTRALIZED DATABASE for lixiviant use in ASGM?

- Yes, with real-time tracking
- Yes, but only for permitted operations
- No, too difficult to implement
- No, privacy/security concerns

Section 5: Future Recommendations

12. What are the TOP 3 reforms needed for safer lixiviant use? (Rank 1-3)

- Stronger penalties for illegal chemical use
- Incentives for mercury-free technology adoption
- Better coordination between GMD, environmental agencies, and police
- Public awareness campaigns on chemical risks
- Formalization of ASGM sector (licensing, zoning)

13. What policy changes would most improve chemical management in Suriname's ASGM sector? (Select all that apply)

- Regulatory & enforcement improvements
- Economic incentives & alternatives
- Capacity building & education
- Environmental & health safeguards
- Formalization & governance
- International cooperation
- Research & innovation

Date: 12 December 2025

SAFE draft FINAL REPORT

Research and Analysis of the Composition and Environmental Impact of Ore Dressing Agent Comprising Sodium Isocyanate for ASGM in Suriname and Developing Sustainable Environmental Regulations

OVERALL EXECUTIVE SUMMARY (pp. 9–12)

Critical Findings

1. Lack of compliance with TOR requirements

- No explicit evidence that the study covered the three mandatory districts (Brokopondo, Sipaliwini, Marowijne), as required in TOR §2 and §3.2.
- The report focuses solely on Sarakreek sites in Brokopondo.

Answer:

See detailed answer in the Table of answers for Page 26–45.

2. Unsubstantiated claims of “strict Quality Assurance/Quality Control”

- No indication of which international laboratory standards (ISO/ASTM) were applied.

Answer:

All analyses were conducted in an accredited laboratory operating in accordance with ISO/IEC 17025. Analytical procedures followed internationally recognized ISO and/or ASTM standard methods appropriate to the analytes and matrices. Quality assurance and quality control were ensured through the routine use of certified reference materials (OREAS 550 and OREAS 603C), secondary standards, blanks, and duplicates. For more detailed information, see Table 10 of the report in 2.5 “Laboratory Testing and Analytical Methodology” and 2.7.2 “QA/QC in Laboratory Testing”.

3. Incomplete chemical characterization

- The report claims cyanide formation through thiourea degradation but provides no analytical evidence.

Answer:

The potential formation of cyanide through thiourea degradation is a well-established and extensively studied phenomenon in the chemical sciences. Numerous peer-reviewed studies have documented the decomposition pathways of thiourea under oxidative and acidic conditions, including reactions that can lead to cyanide formation. The report therefore relies on this substantial body of existing scientific literature rather than presenting new site-specific analytical measurements.

Critical Questions to the Consultant

- Which analytical methods were applied to detect hidden toxic components (CN precursors, heavy metals)?

Answer:

For more detailed information, see Table 10 of the report in 2.5 “Laboratory Testing and Analytical Methodology”.

- How many times was sampling conducted?

Answer:

For more detailed information, see answer in the Table of answers for Page 26–45.

- Is the comparison between the GDA versus mercury conduct, as required by the TOR?

Answer:

For more detailed information, see answer in the Table of answers for Page 14.

Table of Answers

Page	Subject	Comments
Introduction	Wat is de reden dat alleen thiourea-systemen worden behandeld, terwijl ToR verwijst naar sodium isocyanate?	Geen expliciete verwijzing naar chemische risico's van sodium isocyanate zoals gevraagd Answer: Sodium isocyanate is a single chemical compound that acts as an active ingredient, whereas Jinchan is a proprietary gold ore lixiviant composed of sodium isocyanate and additional conditioning agents, formulated to enable efficient, safer, and field-applicable gold extraction. In a nutshell: Sodium isocyanate is like flour. Jinchan is like bread. Flour alone cannot be eaten, but bread is ready to use.
14	Figure. 2. Project objectives – detailed overview: Fieldwork and Sample Collection	- The description of environmental conditions is missing here, such as temperature, time, prevalent vegetation, and other relevant factors. Answer: Detailed descriptions of the ASGM sites' locations and accessibility, topography, land cover, hydrology, climate conditions, as well as information on the history and types of ASGM activities, are presented in Appendices A1, A3, and A5. - Given that this document also includes an investigation into the product Jin Chan itself, the table lacks a detailed overview of it. For instance, it does not indicate whether the Safety Data Sheet (SDS) of Jinchan has been examined.

		Answer: The Safety Data Sheet (SDS) for Jinchan was reviewed and assessed during the desktop research phase. This information informed the environmental, health, and safety assessment presented in the report. Table 6, presenting a comparative evaluation of the Jinchan and mercury SDS, has been included in paragraph 1.3 of the report.
19	Table 3. Overview of environmental and health impact of some lixivants utilized in ASGM (developed by the authors)	Could the authors clarify whether Table 3 was compiled through a literature-based desktop review, or whether the environmental and health impacts of the listed lixivants were experimentally verified before drawing conclusions? Answer: The authors clarify that Table 3 was compiled based on a literature-based desktop review. The environmental and health impacts of the listed lixivants were not experimentally verified as part of this study. All information presented in the table is supported by published literature, with references cited within the table content and included in the report's reference list.
25	To minimize environmental and health risks associated with gold leaching in Suriname, the following measures should be implemented: • Strict regulation: Authorities should enforce mandatory disclosure of chemical compositions and require independent toxicity testing before approving any leaching reagents. • Mercury removal mandate: All tailings must be treated to eliminate mercury before leaching to prevent dangerous chemical interactions. • Independent monitoring: Government agencies and NGOs should conduct thorough environmental impact assessments to verify manufacturer claims and	- Could the authors clarify whether mandatory training and capacity-building programs for miners and operators in the safe handling of chemicals have been considered, as this aspect appears to be missing from the current measures? Answer: This requirement is not mentioned in the ToR "Result and Output" and "Deliverables" sections. However, it is addressed in paragraph 5.2 "Capacity Building and Community Training," of Chapter 9 of the report. - Are there established guidelines for waste and water management, specifically regarding the storage, neutralization, and treatment of effluents and residues, as these procedures are not addressed in the recommendations? Answer: This requirement is not mentioned in the ToR "Result and Output" and "Deliverables" sections. However, it is addressed in paragraph 2.5 "Environmental Monitoring," of Chapter 9 of the report. - Have contingency plans and liability frameworks been incorporated to ensure preparedness and accountability in the event of accidents or chemical spills, since such provisions are not mentioned?

	ensure compliance with safety standards. Promotion of safer alternatives: The adoption of proven non-cyanide lixiviants, such as thiosulfate and glycine, should be encouraged, provided their safety and efficacy are transparently documented.	Answer: Contingency plans and liability frameworks are incorporated for large-scale mining operations through requirements for emergency response, spill containment, decommissioning and closure plans, and financial assurance mechanisms (Chapters 2 and 3 of Suriname National Code for the Management of Alternative Lixiviants in Gold Mining). For the ASGM sector, the use of Jinchan or similar chemical lixiviants should be strictly prohibited (Chapter 4 of Suriname National Code); therefore, chemical spill contingency and liability frameworks are not applicable, as regulatory enforcement ensures environmental and human health protection by preventing such activities.
26	RESEARCH METHODOLOGY AND FIELD PREPARATION	In the methodology, a description of the investigation into the GDA product (Jinchan) itself is missing. It is not clearly indicated whether this raw material was examined to identify its components and to verify whether they correspond with those listed in the Safety Data Sheet (SDS) Answer: The investigation of the GDA product, Jinchan, included a detailed chemical analysis of a representative sample (Sample ID 252155, JC1), which was combined with the five-point samples. The measured concentrations of elements such as Al, As, B, Ba, Be, Ca, Cd, Cl, Co, Cr, Cu, Fe, F, Hg, K, Mg, Mn, NO₂, NO₃, SO₄, PO₄, and CN (total and free) were compared with reference materials (SS2, OREAS 550, OREAS 603C) and with the components listed in the Safety Data Sheet. All relevant information is presented in paragraph 3.3, “Chemical Composition of Jinchan Lixiviant.”
26-45	1. Why were Snesi Kondre and Roma East not included in the research?	Answer: According to the ToR, the three sampling locations should have been Sarakreek, Snesi Kondre, and Roma East, situated in the Brokopondo, Sipaliwini, and Marowijne districts. However, a preliminary spatial assessment using GIS and Remote Sensing techniques revealed inconsistencies between the ToR and the actual geographic locations of the proposed sites. The analysis showed that Snesi Kondre is indeed located in the Sipaliwini district, but both Roma East and Sarakreek fall within Brokopondo. This does not correspond with the district distribution specified in the ToR. Furthermore, the ToR simultaneously requests an evaluation of the environmental impacts of gold-ore lixiviants (including cyanide and mercury) on water and soil, and highlights specific concern regarding cyanide, which is volatile and

		undergoes transformation in the environment. To properly address these objectives, the SAFE research team selected active ASGM sites where lixiviant use, water contamination risk, and potential exposure pathways are all present. Given that ASGM activities directly influence nearby water bodies, remote sensing-based analysis was applied to identify areas with the highest likelihood of contamination. Sentinel-2A MSI imagery was processed to compute and visualize the Normalized Difference Turbidity Index (NDTI). NDTI highlights zones of elevated water turbidity, which often correlate with increased suspended sediment concentrations. Since mercury strongly binds to fine sediments and clay particles, highly turbid waters are more likely to accumulate mercury-laden material. Based on the preliminary findings and the identification of areas with the highest turbidity levels, Bohmila, Ero Bergie, and Kwangoe were selected as the most suitable and scientifically justified sampling locations. These sites best align with both the environmental objectives of the ToR and the observed spatial patterns of potential contamination.
	2. Has prior baseline sampling been conducted as required by the TOR?	Answer: Yes, prior baseline sampling has been conducted as required by the ToR. Environmental and chemical analyses were performed on representative samples, including water, soil, and the GDA product Jinchan, to establish reference concentrations of key elements and compounds. These baseline data provide the necessary context for assessing potential impacts and ensuring compliance with safety and environmental standards. The sampling strategies were guided by the principles outlined in BS 10175:2011+A2:2017, with specific adaptations for the environmental and logistical context of Suriname.
	4. It has been noted that on July 15 and 16, 2025, samples were taken from Bohmila, Ergo Bergi, and Kwangoe. How many times were samples collected? Is frequency not a determining factor in establishing the validity of a scientific conclusion?	Answer: Samples were collected on two consecutive days, July 15 and 16, 2025, from the three locations: Bohmila, Ergo Bergi, and Kwangoe. While this represents a single sampling campaign over two days, it provides an initial dataset for analysis (not for monitoring). It is acknowledged that sampling frequency is an important factor in establishing the robustness and statistical validity of scientific conclusions; however, the collected data were sufficient to meet the objectives of the current assessment, particularly for preliminary characterization and baseline evaluation. Additional sampling campaigns

		could be conducted in future studies to strengthen temporal representativeness and confirm trends.
46	4. LABORATORY ANALYSIS RESULTS	In Section 3.2 Site Selection Criteria and Rationale, it is stated that both active and abandoned ASGM sites were included to evaluate the environmental legacy effects of past operations and the ongoing impact of current practices. However, in Chapter 4, this comparison (if abandoned sites show lower/higher concentrations) is not addressed and appears to be missing from the results. Could this comparison be clearly presented in the form of a table? Answer: The comparison is presented in Section 3.4, "Relationship Between Mining Practices and Environmental Contamination at ASGM Sites," which has been added to Chapter 3 of the report.
37	"In accordance with the TOR, laboratory and field test results are required. Kindly confirm whether these have been completed and indicate which laboratory provided the service.	Answer: Laboratory and field test results have been completed in accordance with the ToR. Laboratory analyses, including chemical characterization of the GDA product Jinchan and associated environmental samples, were performed to determine elemental composition and relevant parameters. These analyses were conducted by FILAB SURINAME N.V., a certified laboratory with expertise in chemical and heavy metal testing. Field sampling campaigns were carried out at the specified ASGM sites to collect representative soil, water, and ore samples for laboratory evaluation.
52	Although free cyanide levels are low, the total cyanide burden remains substantial, warranting classification of Jinchan as a cyanide-bearing reagent? Could we conclude this from the sampling?	Answer: Yes. Laboratory analysis confirms a high total cyanide concentration (9333 mg kg^{-1}, ~0.93%) despite low free cyanide levels (6.5 mg kg^{-1}). This demonstrates that cyanide is predominantly present in complexed forms. Classification as a cyanide-bearing reagent is therefore justified based on total cyanide content and potential cyanide release under changing environmental conditions, and is fully supported by the sampling results.
54-60	RISK ASSESSMENT Could you clarify why acute toxicity modelling for potential spill scenarios has not been included in the risk assessment?	Answer: Acute toxicity modelling for potential spill scenarios was not included because it represents a fundamentally different assessment approach from the risk assessment defined in the Terms of Reference (ToR). The risk assessment conducted under this study focuses on hazard identification, chemical characterization, and exposure potential under normal and regulated handling

		conditions, rather than on worst-case accidental release or emergency scenario modelling. Acute toxicity modelling is typically applied to hypothetical spill events, requiring detailed assumptions on spill volumes, release pathways, dispersion dynamics, environmental fate, and receptor exposure over short timeframes. Such modelling falls within the scope of emergency preparedness and contingency planning, which was not requested under the ToR. Therefore, the absence of acute toxicity modelling does not represent an omission but reflects a clear methodological distinction between baseline risk assessment and incident-specific impact modelling.
61-69	STAKEHOLDER MAPPING	
	Mapping of importers/suppliers has not been carried out.	Answer: Mapping of importers and suppliers of Jinchan in Suriname has not been carried out as part of this study because it falls outside the scope defined in the ToR. The assignment focused on the chemical characterization, environmental risk considerations, and regulatory implications of Jinchan use, rather than on market surveillance, trade chain analysis, or enforcement mapping. Identifying importers and suppliers would require access to customs records, commercial trade data, licensing information, and enforcement databases, which are typically managed by regulatory and customs authorities and were not available within the framework of this assessment. As such, the absence of importer/supplier mapping does not affect the scientific conclusions of the study but highlights an area that could be addressed through a separate regulatory or compliance-focused investigation.
	No mapping of enforcement gaps?	Answer: A detailed, site-by-site mapping of enforcement gaps was not conducted as a standalone exercise; however, the assessment includes a systematic qualitative analysis of enforcement and institutional weaknesses within Suriname's legal and regulatory framework for chemical management in the gold mining sector. As presented in the SWOT analysis (Figure 52), the study identifies key enforcement gaps, including fragmented legal mandates, overlapping institutional responsibilities, limited field presence of regulatory authorities, insufficient coordination among agencies, and constrained technical and inspection capacity – particularly in ASGM areas in the interior.

		The analysis further highlights the absence of life-cycle controls for hazardous chemicals, limited monitoring of transport and use, and the lack of continuous oversight mechanisms as critical enforcement challenges. While these gaps were not mapped geographically or operationally at the site level, they were explicitly identified at the systemic and institutional level , consistent with the scope of the ToR.
70-102	STAKEHOLDER INTERVIEWS	
	“The interviews were carried out among small-scale gold miners; however, how many of them are actually using Jinchan Have the actual end-users been interviewed?”	Answer: As was mentioned in First National Action Plan on Artisanal and Small-Scale Gold Mining in Suriname (2023) in recent years, Chinese mining teams operating in Suriname’s artisanal and small-scale gold mining sector have increasingly adopted heap leaching methods, employing so-called “cyanide-free” and “environmentally friendly” lixiviants to extract residual gold from tailings generated by previous mining activities. During the survey, two miners from Nowkie, four miners from Bohmila, and two miners from Ero Bergie were interviewed. Based on their responses to the interview questions (see Section 6.1, “Analysis of Survey Responses from Artisanal and Small-Scale Gold Miners”), none of the respondents had ever heard of lixiviants, despite having used them for heap leaching of gold ore tailings.
116-124	TECHNOLOGY ANALYSIS 1. Please clarify why pilot heap leach tests were not undertaken.” 2. Please explain why toxicity assessments of each leach residue were not performed.”	Answer: It is not necessary to test the gold recovery efficiency of Jinchan and Sandioss, as there is a wealth of evidence and numerous scientific studies that confirm, with a high degree of confidence, the effectiveness of these lixiviants. Under Surinamese conditions, if they were not efficient, they simply would not be used in ASGM. In other words, the effectiveness of these gold recovery agents does not require further confirmation. Pilot heap leach tests were not undertaken because the study was designed as a desk-based and laboratory-based assessment, in line with the ToR, and did not include experimental field trials or pilot-scale processing activities. Conducting heap leach tests would require site preparation, large volumes of ore, prolonged operational control, environmental permitting, and occupational safety oversight. Such activities fall outside the scope of the assignment. Toxicity assessments of individual leach residues were not performed because no pilot or operational leaching experiments were conducted under this study. Without

		the generation of actual leach residues, residue-specific toxicity testing (e.g., leachability or ecotoxicity assays) was not applicable. Instead, the assessment focused on chemical characterization of the Jinchan reagent, review of its SDS, and evaluation of potential risks based on known chemical properties and regulatory considerations. Residue toxicity testing could be addressed in future controlled pilot studies if such activities are authorized and included within an expanded project scope.
125-134	NATIONAL CODE	
127	The use, handling, storage, transport, trade, or disposal of Jinchan or any alternative chemical lixiviant for gold extraction is strictly prohibited in all forms of artisanal and small-scale gold mining (ASGM). “Considering the significant environmental and occupational risks associated with Jinchan, please provide a comprehensive list of all identified risks and the necessary conditions. This will allow the NMA for a balanced assessment to determine whether its use should be prohibited or permitted.	Answer: (this information was inserted into the report) A review of available technical documentation, Safety Data Sheets (SDS), published case studies, and field observations indicates that the use of Jinchan is associated with several health, environmental, and operational risks. These risks, as well as the necessary conditions for their management, are summarized below to support a balanced regulatory assessment by the NMA. 1. Health Risks • Potential chronic health effects associated with repeated or long-term exposure. • Elevated health risks from water-related exposure, particularly through ingestion and dermal contact. • Potential adverse effects on the central nervous, cardiovascular, respiratory, and thyroid systems, which may result in acute and/or chronic health outcomes. 2. Environmental risks • Contamination of surface water and groundwater resulting from leakage, spills, or improper disposal of leach solutions and residues. • Toxic effects on aquatic organisms in the event of uncontrolled discharge. • Persistence of toxic compounds in tailings if residues are not adequately detoxified or neutralized. 3. Process and waste management risks • Generation of hazardous leach residues requiring controlled handling, treatment, and storage. • Risk of secondary pollution during tailings transport, heap dismantling, or residue reprocessing. • Limited data on long-term behaviour of residues under tropical climatic conditions. 4. Operational and institutional risks • Misuse or overuse due to inadequate understanding of chemical properties and process controls. • Absence of standardized operating procedures and emergency response plans.

		- Weak monitoring, inspection, and enforcement capacity in remote ASGM areas. Necessary Conditions for Risk Management If the use of Jinchan is to be considered for conditional authorization rather than prohibition, the following minimum conditions would be required: - Mandatory training and certification of miners and operators in chemical handling, process control, waste management, and emergency response. - Implementation of closed or well-contained leaching systems to prevent environmental releases. - Mandatory neutralization, detoxification, and controlled disposal or storage of all leach residues and effluents. - Development and enforcement of standard operating procedures, monitoring protocols, and incident reporting requirements. - Regular oversight by competent authorities, including periodic site inspections and environmental monitoring. In the absence of these conditions, the use of Jinchan presents significant and potentially unacceptable environmental and health risks in the ASGM context. The NMA may therefore consider either prohibition or strictly controlled, conditional use, based on the feasibility of enforcing the above requirements within Suriname's institutional and operational context.
Answers to remarks from Mr Iwan Samoender		
1. De ToR vereist een analyse om de technische prestaties en effectiviteit van Jinchan/Sodium Isocyanate te evalueren. Vraag die niet is beantwoord: Wat is het goudwinningsrendement (de gold recovery rate) van Jinchan in vergelijking met cyanide en kwik onder Surinaamse omstandigheden? Het rapport bevat gedetailleerde chemische analyses over wat er misgaat (cyanide-vorming, toxiciteit), maar bevat geen data over de economische voordelen of de technische efficiëntie (hoeveel goud de mijnwerkers met Jinchan uit het erts halen).		The shortcoming in meeting the ToR requirement on the evaluation of technical performance in gold extraction does not reflect an oversight or negligence by the researchers, but rather a practical and methodological constraint inherent to the project context. The ToR requirement implies the availability of site-specific, experimentally derived performance indicators (e.g., gold recovery rates, reagent efficiency, residue characteristics) under Surinamese ASGM conditions. However, such an evaluation would require controlled field trials or pilot-scale heap or vat leaching tests, access to representative ore and tailings, regulatory approvals, and sufficient time to observe full leaching cycles and validate results. These prerequisites could not be met within the four-month project duration, nor within the logistical constraints associated with experimental chemical use in active ASGM sites. Furthermore, Jinchan and mercury are primarily used within ASGM settings – often for tailings reprocessing under highly variable and informal operational conditions – whereas cyanide leaching is designed for large-scale

	industrial mining with standardized process control. This fundamental mismatch in scale and application context makes direct technical performance comparisons impractical without purpose-built experimental design. In light of these constraints, the researchers adopted a precautionary and scientifically responsible approach by not presenting speculative recovery figures. Instead, they addressed the ToR requirement qualitatively, using established chemical principles, peer-reviewed case studies, and documented operational experience to assess expected performance trends and limitations. This approach ensured analytical integrity and avoided overinterpretation of incomplete or non-verifiable data, while clearly identifying technical performance evaluation as a priority for future, longer-term, and experimentally focused studies.
2. Hoewel de ToR de term niet expliciet gebruikt, is de evaluatie van de "potential for adoption" onlosmakelijk verbonden met de economische haalbaarheid, kosten-baten analyse. Wat is de kosten-batenverhouding (cost-effectiveness) van Jinchan in vergelijking met alternatieve middelen, inclusief de verhoogde kosten door de vereiste milieubeheersmaatregelen (die de NMA zou moeten opleggen)? Het rapport adviseert het gebruik van niet-toxische alternatieven (Cleangold Sluice, Borax) op basis van lage milieu-impact en lage operationele kosten . Maar het biedt geen concrete economische vergelijking (bijv. prijs per ton erts verwerkt) tussen Jinchan en de aanbevolen mechanische/niet-toxische alternatieven.	The comment regarding cost-effectiveness and economic feasibility is acknowledged. While the ToR does not explicitly require a formal cost-benefit analysis, the assessment of “potential for adoption” was approached qualitatively, taking into account the economic realities of ASGM operations in Suriname and the availability of verifiable data within the project timeframe. A quantitative cost-effectiveness comparison (e.g., cost per tonne of ore processed) between Jinchan and alternative methods was not undertaken because reliable, site-specific cost data were not available. Jinchan pricing, dosage rates, gold recovery efficiencies, waste management requirements, and compliance costs vary widely across ASGM settings and are not transparently documented. In addition, the environmental management measures that would be required under NMA oversight (e.g., secure storage, effluent treatment, residue handling, monitoring, and training) have not yet been defined in regulatory or operational detail, making it impossible to credibly estimate their associated costs within this study. By contrast, the recommended alternatives (e.g., Cleangold Sluice, borax) are mechanical or low-toxicity methods with well-documented operational characteristics, minimal regulatory compliance costs, and demonstrated applicability in ASGM contexts similar to Suriname. Their promotion in the report is therefore based on a precautionary and pragmatic assessment: low capital and operating costs, ease of implementation, and the absence of significant downstream environmental or health liabilities. Accordingly, the report avoids presenting speculative economic figures and instead highlights relative cost drivers and risk-adjusted feasibility. A detailed,

	quantitative cost–benefit analysis of Jinchan versus alternative technologies is identified as a necessary next step and would require longer-term field data, defined regulatory requirements, and pilot-scale implementation under controlled conditions.
3. Mining process accepted within the limits of gold mining site directly impact on the level of soil contamination with mercury. Sites employing amalgamation (especially alongside other chemical methods) tend to show higher mercury contamination, whereas sites relying solely on heap leaching generally have lower impacts on soil mercury. Wordt er niet alleen tailings gebruikt?	In practice, heap leaching does not involve the use of tailings only. Heap leaching can be applied also to crushed ore that has not yet undergone chemical gold extraction. In other words, tailings are the residual material after processing, but they are not the standard input material for heap leaching operations. In the context of the report, the statement refers to the dominant processing method used at an investigated site, not exclusively to the material type (ore versus tailings). Sites where amalgamation is practiced – whether as a primary method or in combination with tailings reprocessing – introduce mercury directly into the processing circuit and the surrounding environment. This results in higher soil mercury contamination due to spills, volatilization, and improper residue handling. By contrast, sites that rely solely on heap leaching (using cyanide or cyanide-forming reagents) do not introduce mercury into the process, regardless of whether fresh ore or previously processed material is used. Consequently, these sites generally show lower mercury levels in surrounding soils. Any mercury detected at such sites is typically attributable to legacy contamination from earlier amalgamation activities rather than from heap leaching itself. However, when tailings are reprocessed by heap leaching, it is important to recognize that the original ore from which these tailings were generated was often previously treated with mercury. As a result, residual mercury is commonly present in the tailings. During subsequent heap leaching, cyanide can react with this residual mercury, leading to the formation of highly toxic mercury–cyanide complexes and, under certain conditions, organomercury compounds. Consequently, although heap leaching itself does not introduce mercury, the reprocessing of mercury-contaminated tailings can mobilize and transform existing mercury into more toxic and environmentally mobile forms.
4. If the gold present in Suriname’s ASGM tailings is primarily free-milling, technologies such as the Cleangold Sluice, Blue Bowl, and Borax Method can serve as effective replacements for Jinchan leaching. These systems combine high gold recovery with low operational costs and minimal environmental impact, offering practical and	This statement should be understood not as a formal finding explicitly required by the ToR, but as a reasoned conclusion and recommendation derived from the research results and supporting evidence. While the ToR does not require the identification or validation of alternative gold recovery technologies, the research findings – particularly the characterization of

sustainable alternatives that support Suriname's transition toward responsible, mercury- and cyanide-free gold production. Is this a finding of this research?	ASGM practices, tailings composition, and environmental risks – indicate that a substantial portion of gold in Suriname's ASGM tailings is likely to be free-milling. On this basis, and taking into account documented experience from Guyana, where geological settings, mining methods, and ASGM operating conditions are comparable, technologies such as the Cleangold Sluice, Blue Bowl, and the Borax Method are considered technically feasible and appropriate. These conclusions are further supported by recommendations and implementation experience from the planetGOLD programme, which promotes gravity-based and mercury-free gold recovery methods in similar ASGM contexts. The proposed alternatives are therefore not speculative but are grounded in regional operational experience, established best practices, and international guidance. Accordingly, the inclusion of these technologies in the report represents a contextualized, evidence-informed recommendation aimed at supporting Suriname's transition toward responsible, mercury- and cyanide-free gold production, rather than a ToR-mandated performance evaluation of specific technologies.
5. Is Jinchan is cyanide based or non-cyanide based?	Based on the chemical analysis, Jinchan is a cyanide-bearing lixiviant, even though it is not a conventional free-cyanide solution. The total cyanide content is high ($\approx 0.93\%$), but almost all cyanide is present in complexed or organocyanide forms, with very low free cyanide (6.5 mg kg^{-1}). Its formulation – strongly alkaline, highly saline, and containing chloride and nitrate species – stabilizes the cyanide in these complexes, reducing acute toxicity compared to standard cyanide solutions. However, Jinchan still poses significant environmental and safety risks, because under acidic or oxidative conditions, the complexed cyanide can decompose, releasing toxic free cyanide. Therefore, despite its reduced immediate toxicity, Jinchan must be managed as a cyanide-bearing reagent, following proper cyanide management and handling procedures. In short: Jinchan is non-free-cyanide but still a cyanide-containing lixiviant.

Date: 13 August 2025

Interim Report Research and Analysis of the Composition and Environmental Impact of Ore Dressing Agent Comprising Sodium Isocyanate for ASGM in Suriname and Developing Sustainable Environmental Regulations

Page	Subject	Comments
General comment	Negative impact Jin Chan on human health	Does Jin Chan have a negative impact on human health? Answer: Yes. Jinchuan is a complex compound and thiourea-based lixiviant. While it's promoted as an environmentally friendlier substitute for cyanide with lower toxicity, Jinchuan can still cause eye, skin, and respiratory harm. Safe handling and protective precautions remain essential. It can form toxic sulphides and cyanamide in acidic conditions. LD₅₀ (dose of a substance that kills 50% of a test population): 125–640 mg/kg (moderately toxic)
General comment	Cumulative impacts	What are the cumulative impacts of the combined heavy metals? Answer: When multiple heavy metals are present together (e.g., As, Cd, Pb, Ni, Cu, Co, Zn), their toxic effects often add up or even amplify each other. <i>Example 1:</i> Lead (Pb) and cadmium (Cd) both damage the kidney; exposure to both at moderate levels can result in stronger renal impairment than predicted from each metal alone. <i>Example 2:</i> Some combinations (like arsenic + cadmium) show synergistic carcinogenicity, raising cancer risk beyond simple addition.
General comment	Water and soil samples numbering	The collected water and soil samples lack numbering: there is no precise indication of the exact location where each sample was collected. Could you provide this information as well? Answer: List of samples with the coordinates added in Appendixes (Appendix 6.7). Additional marks put on Figures 3-5.
General comment	JinChan	<u>NOTE: The below answers to comments and questions are based on preliminary findings of the SAFE Interim Report, only. Conclusions may</u>

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		<u>change over time as further investigation may lead to additional insights.</u> Is Jinchan a hazardous substance for Suriname, and should its use be banned? Answer: Given current ASGM conditions (remote sites, weak tailings control, exposure of downstream communities), the public-health-protective path is a moratorium or ban for ASGM until further investigation, robust controls and transparency are proven.
General comment	Results and Summary	The data shows varying contaminant levels in water and sediment samples, with some readings above guideline thresholds. However, the conclusion suggests that contamination is within acceptable limits overall. Conclusion does not fully align with the results Answer: Corrected
General comment	Tables	It would be handy to mention the reference levels in all the tables. Answer: Corrected, reference values added
General comment Report formats		Submit reports in Words to enable review with track changes and comments. Will do. Can you also provide us a non-technical summary in Dutch? Answer: <u>The below are preliminary findings based on the SAFE Interim report.</u>
	SUMMARY IN DUTCH <u>Het gaat onderstaand om voorlopige bevindingen zoals verwoord in het SAFE interim rapport.</u> 1. Jinchan lixiviant is geen eco-vriendelijk product en kan onder bepaalde condities zuur-base en redox reacties ondergaan waardoor oa cyanide kan vrijkomen. Dit vormt een significant milieu risico vanwege de extreme giftigheidsgraad van vrijkomende stoffen zoals cyanide. 2. Kwik standaarden van de WHO en EPA bieden evaluatie opties van waarden op een	1. Jinchan lixiviant is not eco-friendly and can produce, e. g. free cyanide (CN⁻) under acidic (pH sensitive) or oxidizing conditions, posing environmental and health risks, (particularly at Bohmila this has been proven). 2. Mercury in water samples is below WHO and EPA limits because volatile mercury evaporates and the remainder settles in sediments; thus, sediment analysis is essential to detect contamination. Mercury cycle produces Methyl-mercury, that bio-accumulates and enters the fish cycle causing the most harm to biodiversity and human health in areas beyond mining sites.

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	meetmoment en op een bepaalde locatie, tegen een specifieke dreiging. Gezien de natuurkundige en chemische eigenschappen van kwik moet het effect echter gezien worden binnen een ruimere geïntegreerde context. Zaken die te vaak over het hoofd gezien worden zijn: chemische vormen met hun specifieke risico's, verdamping en atmosferische verspreiding, de kwik cyclus, de hydrologische cyclus, de vis cyclus en bio-accumulatie/bio-magnificatie van organische vormen alsook het neurotoxisch en teratogeen effect op de gezondheid. 3. Cyanide concentraties van onderzochte watermonsters was grotendeels beneden de referentie limiet. Dit is buiten de verwachting maar wel te verklaren vanwege oplossingsfactoren, UV blootstelling en natuurlijke afbraak met de tijd. Op bepaalde locaties in de natuur, die meer specifiek gekoppeld zijn aan de directe uitstoot werden echter hogere waarden gemeten die binnen de context van het acuut giftig karakter, onacceptabel zijn. 4. Over het algemeen bleken concentraties van zware metalen in open waterwegen in de vrije natuur binnen de perken. Maar in mijnwater van de concessie (barren solution), vooral op Bohmila, waren met name de koper en lood gehalten hoog.	3. Cyanide in natural waterways showed to be mostly below reference limits, with occasional exceedances (e.g., Ero Bergi W1), indicating localized contamination linked to site-specific discharges. Although a less expected outcome, it can be explained by phenomena such as significant Dilution Factor in open water, UV exposure breakdown, and a relatively short half-life. 4. Heavy metals in natural waters are below safety limits, but barren solutions, especially at Bohmila, show elevated Cu and Pb, requiring strict handling and monitoring. 5. Gold mining methods directly affect soil mercury contamination; amalgamation increases mercury levels, while heap leaching has lower impact. 6. Most metals show low geo-accumulation, but Co, Ni, Cu, As, and particularly Hg in Kwangoe indicate localized contamination requiring further investigation. 7. Elevated soil concentrations of Cu, Zn, Ni, and Co in ASGM areas result from natural geology, uncontrolled mining practices, waste dumping, and enhanced mobilization, exceeding global and local background levels. 8. The Nemerov Comprehensive Index (Pi) effectively identifies spatial variations and localized contamination; Bohmila shows moderate pollution, Ero Bergi has localized significant contamination, and Kwangoe shows severe mercury contamination. 9. The non-carcinogenic risk from soil exposure is low, but combined exposure from contaminated water, mercury vapor, lixivants, and bioaccumulation increases cumulative health risk. 10. Carcinogenic risk from soil is relatively low, with arsenic ingestion as the main concern, emphasizing the need for continuous monitoring with cumulative risk assessments. 11. Water pollution in ASGM areas of Suriname poses clear non-carcinogenic health risks primarily through river water ingestion, and cyanides (91%)

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	Strikte regels voor monitoring vereist. 5. Goudmijn activiteiten hebben direct effect op bodem verontreiniging met kwik. Amalgaam vorming blijkt meer kwik vrij te maken dan heap leaching. 6. Verhoogde concentraties aan de meeste metalen waren zichtbaar in de bodem, maar nikkel, koper, arsenicum en lood tonen vergiftiging van bepaalde bodems in vooral Kwangoe. Nader onderzoek is nodig. 7. Verhoogde concentraties aan zink, koper, nikkel en cobalt in ASGM kunnen verschillende oorzaken hebben: Ze kunnen er van nature al zijn, ongebreidelde mijnbouw kan bijdragen, maar ook vuilstorten en kunstmatige neerslag kunnen leiden tot hogere gehalten. 8. Nemerov methode toont locatie specifieke verschillen in verontreiniging. Bepaalde locaties zoals Bohmila blijkt gematigd verontreinigd te zijn terwijl Ero Bergi significante contaminatie op bepaalde locaties te vertonen en Kwangoe gekenmerkt door hoge kwik contaminatie. 9. Niet-kanker vormende risico's in bodems blijken vrij laag. Maar, gecombineerde blootstelling aan kwik en vormen van kwik vanuit zowel bodem, lucht en water verhogen bio-accumulatie en gezondheidsrisico's. 10. Kanker vormende risico's in de bodems blijkt relatief laag, met	as the dominant contributor affecting the nervous, cardiovascular, respiratory, thyroid, liver, and kidney systems. 12. Most artisanal miners lack awareness of safe chemical handling, environmental impacts, and legal obligations, increasing misuse and contamination risk; targeted education and stronger enforcement are needed. 13. Regulatory enforcement gaps in ASGM areas allow unsupervised use of chemical lixivants like Jinchan; limited capacity, infrastructure, and public awareness exacerbate environmental and health risks.

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	voornamelijk Arsenicum als voornaamste dreiging. Dit benadrukt de noodzaak voor continue monitoring en risico analyse. 11. Watervervuiling in ASGM-gebieden van Suriname brengt duidelijke niet-carcinogene gezondheidsrisico's met zich mee, voornamelijk door inname van rivierwater, waarbij cyaniden (91%) de belangrijkste bijdrage leveren en het zenuwstelsel, cardiovasculaire en ademhalingsstelsel, evenals de schildklier, lever en nieren aantasten. 12. De meeste kleinschalige mijnbouwwerkers hebben gebrek aan besef hoe verantwoordelijk met chemische stoffen om te gaan, wat de milieu invloeden zijn, de wettelijke verplichtingen. Dit draagt bij tot verkeerd gebruik, gezondheidsrisico's, verontreiniging en vergiftiging van het milieu. Het benadrukt de noodzaak tot educatie en strikte handhaving. 13. Onvoldoende wet en regelgeving leidt tot ongecontroleerd gebruik van chemische middelen zoals Jinchan, De beperkte capaciteit, infrastructuur en publiek besef vergroten de milieu en gezondheidsrisico's.	
		Based on the interim report, there has not been a specific lab test analysis to determine if the gold ore dressing agents (GDA), such as Jinchan and Sandioss, are "eco-friendly." the report's findings on the non-hazardous classification of Jinchan and Sandioss are based on the Globally Harmonized

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		System (GHS) and Material Safety Data Sheets (MSDS) for these products. However, the report also notes that critical information is often missing from these MSDS Answer: In the interim report it is mentioned that it is not necessary to test the gold recovery efficiency of Jinchan and Sandioss, as there is a wealth of evidence and numerous scientific studies that confirm, with a high degree of confidence, the effectiveness of these lixivants. Key details such as the exact chemical composition, degradation products, persistence in soil and water, and chronic toxicity data are, however, not fully disclosed. Without these, it is difficult to validate the “eco-friendly” claim. In the current research, independent laboratory analyses and environmental risk assessments were conducted to investigate the environmental consequences of Jinchan application in ASGM. However, detailed product evaluation will provide additional information in the next project phase.
		The report provides a desk research analysis of their chemical properties and environmental behavior, which is used to infer their environmental impact: • Classification: The report states that the agents are classified as non-hazardous under the Globally Harmonized System (GHS). This classification primarily relates to health and safety hazards, not necessarily long-term environmental friendliness. • Cyanide: The report notes that these agents are based on sodium isocyanate, and some may contain or release cyanide. It describes how cyanide is acutely toxic and detrimental to ecosystems and biodiversity upon immediate release. • Environmental Degradation: The report details that in Suriname's tropical climate, natural processes like high UV exposure, rainfall, dilution factors in large bodies of water and microbial

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		activity can degrade cyanide into less toxic compounds. • Heavy Metals: The report also found elevated levels of heavy metals in soil samples from mining sites, which are toxic to all living organisms.
		Explain fig 1 Answer: Figure 1 provides a detailed depiction of the site investigation process, illustrating step by step how the field investigations were conducted and which activities were carried out at the different stages.
		While the report classifies the agents as "non-hazardous" from a health and safety perspective, it does not explicitly label them as "eco-friendly" and highlights several environmental and toxicological concerns associated with their use and byproducts Answer: The report, specifically Chapter 5, does not classify lixivants as 'non-hazardous' from a health and safety perspective. This chapter analyzes international mining standards as well as the information provided on Jinchan and Sandioss.
		• Jinchan lixiviant (a non-cyanide, thiourea-based solution) is applied via drip irrigation systems. Despite being marketed as a non-cyanide alternative, international reports on chemical analysis indicate that Jinchan does contain a cyanide compound in the form of a stable ferrocyanide complex. The interim report also noted that the agents are based on "sodium isocyanate," and that cyanide can be a byproduct or component. So, unless there is a lab testing of the composition of Jinchan it cannot be concluded that it is a non-cyanide chemical. Answer: Lab testing of Jinchan will be conducted, and the results will be presented in the final report.
		Toxicity Levels: The report indicates that the gold ore dressing agents Jinchan and Sandioss are classified as non-hazardous under the Globally

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		Harmonized System (GHS). Their Material Safety Data Sheets (MSDS) provide information on hazard classifications, safe handling, and spill containment. However, the report also notes that for many products, critical MSDS information is not always fully available, which contributes to a lack of awareness and improper handling. But the report does not question the reliability of the MSDS information, neither urges the need for further investigation on the composition. Answer: Corrected, relevant information added in paragraph 5.4
15 30	Bohmila site: Heap leaching preparation Jinchan Lixiviant (non-cyanide) Table 14: Barren solution samples, particularly from Bohmila, indicate severe cyanide	Isn't this contradictory? Can you explain? Answer: Jinchan belongs to thiourea-based lixivants and does not contain cyanides. Thiourea ($\text{SC}(\text{NH}_2)_2$) is chemically unstable in acidic or oxidizing conditions commonly used in gold leaching. It can decompose to produce by-products such as cyanate (OCN^-), and under further chemical transformations, certain amounts of free cyanide (CN^-) may form.
28	The detection limits for all analytes were documented and compared to relevant regulatory thresholds.	What types of instruments were used to analyze the collected water and soil samples? What are the detection limits of the instruments used for the analyses? Answer: Laboratory testing of collected samples – including soil, water, and barren solution – was conducted in accordance with the requirements of standard methodologies, presented in Table 4 of the interim report. <i>Detection limits for water samples testing, ug/l:</i> As – 0.050; Cd – 0.010; Co – 0.050; Cu – 0.500; Ni – 0.500; Pb – 0.050; Sb – 0.010; Zn – 1.000; CN^- (mg/l) – 0.010. <i>Detection limits for soil samples testing, ppm:</i> As – 0.100; Cd – 0.010; Co – 0.050; Cu – 0.500; Ni – 0.100; Pb – 0.050; Sb – 0.050; Zn – 1.000; CN^- (mg/l) – 0.100.
31	Natural water samples show no signs of heavy metal contamination and	Where were the natural water samples collected? Could this also be indicated on the map or in the images included in the appendices?

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	remain within safe ecological and human health limits.	Answer: Corrected. See Figures 4–6 and Appendix 6.7
31	‘Cobalt.....this metal’	Is there another threshold besides EPA which can be used as standard for this instance? For example, on page 32 Canadian thresholds were used for cyanide levels in soil due to no available EPA or WHO thresholds. Answer: Corrected. See explanation for Table 15.
33	Table 18 and discussion	The discussion of table 18 is unclear. Co ranges from 0.89 to 3.05 and the background is 12.5. Why does the text suggest that it succeeds the background? The same for Ni exceeding the background level. Answer: Table 18 presents the heavy metal content (mg/kg) in soil relative to background concentrations . Values such as 0.89 and 3.05 indicate how many times the measured concentrations of Co, Ni, or other heavy metals exceed their respective background levels.
34	At Ero Bergi, cobalt again showed significant enrichment, particularly in one sample reaching 5.81× the target value.	Where exactly was this sample collected? Answer: See Figure 4 (S1).
34	“At Kwangoe, most metals were within safe limits.....”	Which safe limits? There is other instance in the text where phrases like “within acceptable limits” or “slightly elevated is used, without a reference. Seems vague Answer: The key point is that heavy metal concentrations do not exceed background levels and remain within the typical range for the region of interest.
35	Stakeholder mapping: according to the TOR : ‘Conduct interviews with miners, environmental regulators, NGOs focused on environmental issues, relevant institutions, experts, and local	In the report only miners are mentioned, is there a stakeholder mapping? Answer: Detailed information on stakeholder mapping is provided in the Inception Report. This process identified artisanal and small-scale gold miners (ASGM), the Suriname Geological Mining Service (GMD), and indigenous communities and traditional leaders as key actors. To date, only the

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	authorities or community representatives. This includes engaging with district commissioners and tribal authorities to assess the application and use of Jin Chan and Sandioss in gold mining'	survey with miners has been completed, while surveys with GMD and local authorities involved in ASGM are still ongoing. The full set of survey results will be presented in the Final Report.
36	Interestingly, 60% of miners reported using other substances in their operations. These include cement (30%), cement combined with lime (15%), and battery acid (15%).	Could you indicate the location where this is taking place? And why battery acid is being used? Answer: Location cannot be identified because survey was anonymous. Battery acid is sometimes used to pre-treat gold-bearing ore before applying a lixiviant (like cyanide or thiourea). In some mercury-free methods, miners mix battery acid with other chemicals to liberate gold from the ore.
36	Fig 7, section 1	The amount of the respondent is unknow and which area the interview take place? Answer: 8 respondents, only the miners within the limits of investigated gold mining sites.
39	Fig 10, section II, question 1	Amount of the respondent unknow and which area site Answer: 8 respondents, only the miners within the limits of investigated gold mining sites.
39	Fig 11, section II, question 2	Same question above Answer: 8 respondents, only the miners within the limits of investigated gold mining sites.
40	Fig12, section II, question 3	Expensive set up option, 28.6% refers to permit.... which permits we are referring to. Answer: Corrected. The edition changed on "However, 28.6% of participants cited high capital costs for infrastructure and permitting (licensing) as a significant barrier, particularly for small-scale operations."
42	Result from section III, question 2	While a transition gap is identified, it is important to understand who is affected by this gap and how large this group is. "Is it appropriate to generalize in this context? Answer: Survey Participants: Nowkie – 2 miners; Bohmila – 4 miners; Ero Begi – 2 miners. Considering that each investigation site had no more than 10 miners present (excluding

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		Kwangoe), surveying at least 70–90% of the miners at each site ensures that the results are representative of the site population.
45	Fig. 17, section IV, question 2	There is a contradiction there, which is reflected in the sentence. However, the overwhelming.....mandatory training.... but in the figure depict 86% with the caption “ ban it completely” Answer: Corrected, see explanations for the Figure 19 (in new edition of interim report)
49-50	Use of the acronym EFA and MRw.	These two acronyms are both used in the text explaining the Environmental Framework act. It is advisable to use the English acronym: EFA throughout the text. Answer: Corrected. Acronyms replaced.
53	‘In addition....hazardous substances’	The second part of this sentence is not correct. The NMA is <u>not</u> the national focal point for the Minamata convention in Suriname. The link with the up-to-date information concerning the national focal point can be read on this link: https://minamataconvention.org/en/parties/focal-points Answer: Corrected, see new version of the interim report.
54	On this page several conventions are mentioned	Suriname is not a party to all of the conventions mentioned on this page. Suggestion: Also include in the text if Suriname is party to the described convention or not. Answer: Corrected. See paragraph 5.2.1
Additional Questions		
General Explanation		In essence, when soil or water contains several pollutants – some exceeding reference limits while others remain below them – risk assessment provides an integrated evaluation . It determines whether the overall situation poses a threat to the environment (ecological risk) or to human health (health risk) , rather than relying solely on individual pollutant concentrations. Soil pollution drives localized ecological risk, while water pollution translates contamination into widespread health risk. Both need to be assessed together to fully understand the environmental and public health burden of ASGM activities.

1. What is the relation between ecological risk assessment and water pollution assessment results?	Answer: For water pollution, only health risk assessment was conducted. The relationship between health risk assessment and water pollution is clear: water pollution assessment identifies the presence and concentration of contaminants, while health risk assessment evaluates whether those concentrations translate into actual risks for human health. In this case, even when only a few pollutants are elevated, their contribution – especially cyanides – pushes overall HI values well above safety thresholds, signaling significant non-carcinogenic health risks for local populations.
2. What is the relation between ecological risk assessment and soil pollution assessment results?	Answer: Soil pollution assessments quantify contamination levels, while ecological risk assessments (ERA) interpret their environmental significance. The two are closely related – soil results explain the source and scale of contamination, while ERA translates these results into ecological risk categories. In current study, this relation is evident: Bohmila and Ero Bergi soils show low contamination and correspondingly low ecological risk, whereas localized mercury enrichment in Kwangoe soils directly results in very high ecological risk.
3. What is the correlation between ecological risk assessment and the concentration of heavy metals, cyanide and mercury in soil?	Answer: Ecological risk assessment is directly correlated with the concentrations of heavy metals, mercury, and cyanide in soil, since these concentrations determine the calculated risk quotients and hazard indices. For instance, localized enrichment of Co, Ni, Cu, and Zn (notably at Ero Bergi) results in elevated ecological risk, whereas low or background-level concentrations correspond to negligible ecological risk.
4. What is the correlation between ecological risk assessment and the concentration of heavy metals, cyanide and mercury in water?	Answer: For water pollution, only health risk assessment was conducted. Health risk assessment outcomes are directly correlated with pollutant concentrations in water. Cyanide, mercury, and lead concentrations drive most of the calculated risk, with ingestion as the dominant pathway. Elevated concentrations at Bohmila and Ero Bergi resulted in risk values far exceeding safe limits, confirming that even localized contamination can translate into substantial non-carcinogenic health risks for communities relying on untreated river water.