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Operational Structures, Formalisation Barriers, and Sustainable Governance of Artisanal and Small-Scale Gold Mining in Zimbabwe's Midlands Province

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Abstract

Artisanal and small-scale gold mining (ASGM) accounts for around 65% of Zimbabwe's national gold production and forms the lynchpin (yet largely ungoverned) part of the country's mineral economy. Based on results from multi-site field research conducted in six ASGM districts (Kadoma, Norton, Chegutu, Shurugwi, Kwekwe and Zvishavane) in Zimbabwe's Midlands Province, this paper seeks to describe operational characteristics, compliance status and governance bottlenecks of the sector at sub-national level. Through a qualitative, multi-site case study design utilizing semi-structured interviews with operators, claim holders, financial sponsors, regulators and community representatives, the paper attempts to profile the sector's diverse labour relations from licensed claim holders to semi-formal operators and the highly marginalized labor force. Evidence shows that limited access to finance, the complexity of the regulatory regime and bureaucratic friction hinder formalization. Informal trilateral production relationships between claim holders, artisanal miners and external financial sponsors have become the sector's dominant operational mode where formal

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structures are inaccessible. The paper looks at the significance of the sector at the macro-economic level (12% contribution to the national GPD and contribution to the livelihoods of workers in the midst of Zimbabwe's long-running economic crisis) and its liabilities (mercury pollution, fluvial sedimentation, unrehabilitated excavations). Informed by mineral economics, mine planning and environmental management principles, the paper proposes policy recommendations on segmented formalization, compliance assistance, and structural governance changes that would push the Midlands ASGM sector toward sustainable mining.

Keywords
Artisanal and small-scale gold mining; ASGM; mineral governance; formalisation; Zimbabwe; Midlands Province; mercury contamination; mine planning; sustainable mining; mine rehabilitation; mineral economics; informal mining operations

1. Introduction

Artisanal and small-scale mining (ASM) presents one of the most technically and institutionally complex sectors in global mineral resources governance. It employs an estimated 40-100 million people in more than 80 countries, spanning a wide range of minerals (gold, diamonds, coltan, tin and tungsten) and geological, technical and regulatory environments [1]. Artisanal and small-scale gold mining (ASGM) is the principal livelihood for many millions of people in sub-Saharan Africa and, for several producing countries, an important source of foreign exchange; because much of this output is produced outside official regulatory and mine management frameworks, ASGM remains a persistent challenge for mineral resource governance and for environmental and occupational health management [2].

Following Article 2 of the Minamata Convention on Mercury, ASGM is defined as gold mining conducted by individual miners or small enterprises with limited capital investment and production [3]. Zimbabwe's National Action Plan (NAP) for ASGM distinguishes formal large-scale, formal small-scale, and informal small-scale and artisanal gold producers, and describes artisanal miners as operators using approved tools and employing up to 50 people, including registered syndicates and cooperatives [4]. The term ASGM is used consistently throughout this article; the broader term ASM is retained only where the literature refers to artisanal and small-scale mining of all minerals.

Formalisation is similarly contested. In its narrowest sense, it denotes legal recognition through the acquisition of a mining title or licence. The ASGM literature, however, distinguishes this legal-administrative dimension from several others: regulatory compliance with mining, safety and environmental rules; institutional inclusion in state support, extension and representation structures; economic formalisation through access to formal finance and official gold markets; environmental compliance, including mercury reduction; and social protection for workers [5]. These dimensions do not necessarily move together. Licensing can coexist with poor working conditions and informal labour relations [6], and state-led formalisation drives can recentralise control or marginalise livelihoods rather than improve practices [7]. In this article, formalisation is therefore understood as a multidimensional, graduated process of incorporating ASGM actors into legal, regulatory, economic and social institutions, rather than a binary legal status that

automatically produces better outcomes. Because operators differ in what they can afford and in what they stand to gain, a differentiated or segmented approach to formalisation may be necessary.

In Zimbabwe, these problems are sharply focused in the central gold belt formed by the Midlands Province and adjoining parts of Mashonaland West Province. This greenstone belt terrain includes the six study districts of Kwekwe, Shurugwi and Zvishavane (Midlands) and Kadoma, Chegutu and Norton (Mashonaland West), and is among the most active ASGM regions in Zimbabwe [8]. Its stratigraphy, formed by Archaean greenstone belt development and subsequent mineralisation through lode quartz reef, palaeoplacer and alluvial accumulation in major river drainage systems, has underpinned gold recovery for centuries. In recent decades, ASGM has expanded from a largely artisanal activity into a major mode of gold production and an important rural livelihood [9].

The structure and characteristics of ASGM in the study area are complex, not easily represented by conventional mining engineering and mineral economics frameworks [10]. The sector comprises a highly diverse range of operators, from formally licensed small-scale miners using mechanized open-pit and underground stoping, to subsistence-level wage labourers without ownership of mineral rights, or equipment and working capital. The geology presents both narrow, high-grade quartz vein reefs that require selective hand-mining and broad, low-grade disseminations or alluvium that require mechanized extraction (and processing via heap leach or sluicing, respectively). Under these conditions, imposing universal standards of regulatory compliance, environmental management and occupational health is particularly challenging. This heterogeneity is analytically consequential, not merely descriptive. Operations that differ in deposit type, capitalisation, labour organisation and technology face different compliance costs, incentives to formalise and environmental risk profiles. Hence, a single licensing and compliance template is likely to be attainable for some operators, irrelevant to others, and exclusionary for the majority [5, 11].

Existing scholarship on Zimbabwean ASGM has illuminated its livelihood significance [9, 12], its political economy and patronage networks [8], the shifting and often recentralising character of formalisation policy [13], and violence associated with contested access to gold [14]. At the same time, health and safety studies have documented occupational hazards [10]. Less developed is an empirically grounded analysis that links the internal heterogeneity of ASGM operations, in deposit type, capital, labour arrangements and technical capacity, to the specific constraints that different operators face in formalising, and that uses this link to derive a differentiated governance framework. Much policy discussion continues to treat ‘the ASGM sector’ as a single regulatory object.

To address this gap, the article asks three research questions. First, what is the typical mine structure, composition of the workforce and mine management regime under which ASGM operates in the study area, and what are the variations related to mineral deposit type, geological settings and the regulatory environment? Second, what are the main technical, financial and institutional constraints associated with formalising ASGM and how is each navigated (or avoided) by mine operators in practice? Third, what mining planning, environmental management and governance measures should be employed in the study area to support sustainable resource extraction? The paper presents a detailed analysisto answer these three research questions and contextualizes them against the existing literature on ASGM governance, mineral economics and sustainable mining [15].

The central argument is that the persistent informality of ASGM in the study area cannot be explained by regulatory exclusion alone. It reflects the interaction between operational

heterogeneity, the cost and complexity of a compliance architecture designed for large-scale mining, and the economic functions performed by informal arrangements, particularly trilateral claim holder-sponsor-labour arrangements, that some actors may rationally prefer to formal alternatives. Formalisation is therefore more likely to succeed if it is segmented according to operational capacity and structured as a progressive pathway. The article contributes (i) a stratified empirical account of workforce and production arrangements across six districts; (ii) an analysis that combines legalist and structuralist explanations of noncompliance, including strategic informality and privatised governance; and (iii) an empirically derived three-tier model of segmented formalisation. The article presents the study context (Section 2), analytical framework (Section 3) and methodology (Section 4); reports findings for RQ1 (Section 5) and RQ2 (Section 6); discusses these findings and derives the governance framework that addresses RQ3 (Section 7); and concludes (Section 8).

2. Study Context: Geology, Political Economy and the Formalisation Landscape

2.1 Geological Setting and Historical Development of Gold Mining

The study area is underlain by part of the Zimbabwe Craton, an Archaean terrane that hosts numerous gold deposits. The principal gold-bearing units are Archaean greenstone belts, including the Midlands greenstone belt around Kwekwe, the Shurugwi greenstone belt and the Kadoma-Chakari area of Mashonaland West [16]. Gold mineralisation within these greenstone belts takes several forms, including orogenic lode gold deposits hosted within shear zones and quartz vein systems; intrusion-related gold mineralisation hosted in a late-stage intrusive granitoid association; and secondarily precipitated placer deposits derived from modern and palaeo-drainage systems developed upon heavily weathered regolith profiles [17].

The specific style of mineralisation dictates the mining techniques available to the artisanal operator: narrow, high-grade quartz reef systems can be selectively hand-mined or worked by small-scale underground stopping with minimal investment in capital equipment (although significant constraints to roof stability and mine gas arise). Disseminated oxide gold within saprolite profiles is readily worked open-pit, typically using light mechanisation (e.g., pneumatic drills, excavators and hand tools), followed by gravity concentration and cyanide leaching or mercury amalgamation. The alluvial and eluvial deposits that occur along the Munyati (formerly Umniati), Sebakwe and Ngezi river systems can readily be hand-panned or worked with simple sluice boxes and, sometimes, light dredging [18, 19].

Mining in the study area has a long history dating back to the pre-colonial period and the Great Zimbabwe civilisation, when gold was mined and traded within the greenstone belt topography for several centuries prior to European intrusion [20]. During the colonial period, production was developed as a system of large-scale exploitation of the province's gold resources. Big mining companies such as the Globe and Phoenix Mine near Kwekwe, the Empress Mine, and numerous operations in the Kadoma region dominated Rhodesian gold production throughout much of the twentieth century.

During the latter years of the 1990s, the collapse of Zimbabwe's formal economy fundamentally changed the structure of gold mining in the study area, culminating in the hyperinflationary crisis of 2007-2009 and continued economic contraction throughout the following decade. In the absence of major capital investment in and output from large corporate mines which closed, scaled back, or became non-operational owing to outflow of capital, input cost escalation and lack of foreign

currency, small scale/artisanal miners came to dominate gold production, moving into abandoned underground workings, establishing open pits at greenstone belt targets and working alluvial river deposits that were formerly uneconomical. By 2018, gold deliveries from small-scale producers to Fidelity Printers and Refiners (FPR; now Fidelity Gold Refinery, FGR) had overtaken deliveries from large-scale producers for the first time.

2.2 Political Economy of ASGM and Why Formalisation Matters

The study area is analytically important not only because of its geology but because of the political economy that has developed around its gold. Kwekwe District has been described as being at the heart of the post-2000 expansion of ASGM, where access to gold became intertwined with party-state networks, patronage and local political competition [8]. Formalisation policy has oscillated between district-level licensing, recentralisation of regulatory authority and periodic crackdowns on informal [7] miners, while machete gangs contesting mining sites in Shurugwi and Kwekwe have made violence a salient governance concern [14]. ASGM is also embedded in rural livelihoods, with mining often combined with farming [9]. Governance of the sector therefore operates through overlapping national institutions (the Ministry of Mines and Mining Development [MMMD], the Environmental Management Agency [EMA], Fidelity Gold Refinery, the Reserve Bank of Zimbabwe and the police), provincial mining offices, local authorities and traditional leaders, alongside informal actors who control access to sites.

ASGM's economic significance is central to why its governance matters. At national level, small-scale producers accounted for about 65% of official gold deliveries at the 2018 peak, and the sector proved comparatively resilient through a decade of economic contraction [12]; the small-scale share of official deliveries was later reported at 55.8% and 52.8% for the first seven months of 2020 and 2021, respectively. [21] estimates that ASGM contributes around 12% of GDP and circulates in policy discussions.

ASGM also supports substantial employment: Zimbabwe's NAP reports that more than 300,000 people are involved in ASGM and the sector has been characterised as both a challenge to and a potential contributor to sustainable development [22]. This economic weight gives formalisation a distinctive policy logic. For the state, formalisation promises to channel gold into official markets, increase royalty and foreign-exchange receipts, and bring hazardous practices under oversight [23]. For miners, it can offer secure tenure, access to finance and official markets, and protection from arbitrary enforcement. These objectives are not automatically compatible: revenue-oriented formalisation can prioritise gold capture over labour conditions or environmental performance, and incentives aimed at increasing deliveries may bypass the structural constraints facing the poorest operators [13]. The magnitude of ASGM's contribution therefore makes the design of formalisation (who it reaches, on what terms and with what obligations) a first-order governance question.

Table 1 summarises key economic indicators, including ASGM's contribution to national gold production, GDP, employment creation, informal gold exports, average wages, and formalisation costs. Because the national indicators derive from official statistics and the district-level indicators from participant reports, they differ in reliability. They should be read as orders of magnitude rather than precise measures.

Table 1 Estimated Economic Parameters of ASGM in Zimbabwe and the Study Districts.

Economic Indicator	Scale	Estimate/Value	Source/Basis
National gold output from ASGM	National	~65% of deliveries (2018); 52.8-55.8% (Jan-Jul 2020-2021)	FPR/RBZ data as reported [4]
ASGM contribution to GDP	National	~12% (unverified estimate)	[21]
Estimated direct employment	National	>300,000 (NAP); up to 500,000 (other estimates)	[24]
Informal gold exports (estimated)	National	30-50% of ASGM output	Participant estimates (this study); not independently verified
Average daily wage (unskilled)	Study districts	USD 3-12/day	Field interview data (this study)
Formalisation cost (single claim)	Study districts	USD 2,500-8,500	Regulatory schedule and field data (this study; Section 6.1)

2.3 Formalisation in Zimbabwe: Institutions, Legal Frameworks and Persistent Bottlenecks

Zimbabwe's ASGM governance architecture is layered. The Mines and Minerals Act [Chapter 21:05], which commenced in 1961 and has been repeatedly amended, vests mineral rights in the President and regulates prospecting, pegging and registration of claims, inspection certificates, tribute agreements and royalties; it was designed primarily around title-holding mining enterprises rather than artisanal producers. A precious metal block of claims may not exceed 500 m × 200 m (10 ha), which constitutes a block of ten claims. The Environmental Management Act [Chapter 20:27] of 2002 established EMA and, through regulations including the Environmental Impact Assessment and Ecosystems Protection Regulations (SI 7 of 2007), the Effluent and Solid Waste Disposal Regulations (SI 6 of 2007) and the Hazardous Substances, Pesticides and Other Toxic Substances Regulations (SI 12 of 2007), governs environmental assessment, discharges and the handling of hazardous substances such as mercury and cyanide. Gold marketing is centralised through Fidelity Gold Refinery (FGR, formerly Fidelity Printers and Refiners, FPR) under the oversight of the Reserve Bank of Zimbabwe, with taxation administered by the Zimbabwe Revenue Authority (ZIMRA). Internationally, Zimbabwe's obligations under the Minamata Convention on Mercury require a NAP to reduce and, where feasible, eliminate mercury use in ASGM [24].

The literature identifies recurring bottlenecks. Some are national in character: licensing costs and procedures calibrated to larger operations, sequential approvals across several agencies, limited access to finance, weak and uneven enforcement capacity, and policy volatility, including alternating crackdowns and decriminalisation measures [13, 25, 26]. Others are particularly acute in the central gold belt: the density of reef and alluvial workings, the prevalence of abandoned underground workings (Section 2.1), contested site access and associated [14], violence, and the concentration

of patronage networks around lucrative sites [8]. Table 2 summarises the principal instruments and institutions, their objectives, relevance to ASGM and documented implementation challenges.

Table 2 Legal and Institutional Framework Relevant to ASGM Formalisation in Zimbabwe.

Instrument/institution	Origin and main objective	Relevance to ASGM	Implementation and compliance challenges
Mines and Minerals Act [Chapter 21:05]	Commenced 1961, repeatedly amended; vests mineral rights in the President; regulates pegging, registration, inspection, tribute agreements and royalty	Claim registration (precious metal blocks up to ten claims/10 ha); tribute agreements; mine plans	Designed around title-holding enterprises; survey, inspection and planning requirements costly for artisanal operators; production agreements often unregistered (Sections 5.2, 6.1)
MMMD and Mining Commissioners (provincial and district offices)	Administer the Act at mining-district level	Registration, dispute adjudication, inspection and safety enforcement	Limited inspectorate capacity; enforcement reactive rather than systematic (Section 6.4)
Environmental Management Act [Chapter 20:27] (2002); EMA; SI 7, SI 6 and SI 12 of 2007	Environmental protection; EIA; pollution control; licensing of hazardous substances	EIA and environmental management plans; tailings and effluent; mercury and cyanide handling	EIA cost through registered practitioners; changing EIA requirements for small-scale operators [25]; limited monitoring capacity
Gold-marketing framework: FGR (formerly FPR) and Reserve Bank of Zimbabwe	Centralised purchase and export of gold; foreign-exchange mobilisation	Legal outlet for ASGM gold; delivery incentive schemes	Price, payment and currency-retention terms have periodically made side-selling attractive (Sections 6.5, 7.4)
Minamata Convention on Mercury; Zimbabwe ASGM NAP (2019)	Protect human health and the environment from mercury; Article 7 and Annex C require NAPs for ASGM	Mercury-reduction targets; elimination of worst practices, including whole-ore amalgamation and open burning of amalgam	Mercury widely available; alternatives require capital and technical support; limited enforcement against informal users (Section 6.6)

3. Analytical Framework

The analysis draws on four complementary bodies of theory, each selected because it illuminates a different dimension of the relationship between mining heterogeneity and formalisation. Table 3 summarises how each was operationalised.

Table 3 Operationalisation of the Analytical Framework.

Concept	Key literature	What it explains/limitation	Operationalisation in this study	RQ
Formalisation continuum	[5]	Graduated legal-economic positions/does not explain why actors occupy them	Classification of five operational strata by legal standing, capital and market access	RQ1
Legalist explanation of informality	[5, 7]	Exclusion through costly bureaucracy/underplays benefits of informality	Codes on compliance cost, procedural burden, delays and informal payments	RQ2
Structuralist explanation; strategic informality	[27, 28]	Informality as functional for powerful actors/requires evidence on actors' motives	Codes on benefits of informal arrangements for sponsors and claim holders; informal marketing	RQ2
Labour arrangements	[6, 29]	Heterogeneous workers; output-sharing and risk allocation	Codes on remuneration, shares, occupational protection, dispute resolution	RQ1, RQ2
Hybrid/ privatised governance	[30, 31]	Non-state regulatory authority, including coercion/risk of over-interpreting limited evidence	Codes on site control, enforcement of shares and coercive dispute resolution	RQ2, RQ3
Sustainable livelihoods	[32]	Livelihood strategies and vulnerability/weak on power and institutions	Sensitising lens for labour choices and affordability of compliance	RQ1, RQ3

First, formalisation is conceptualised as a continuum rather than a binary status [5]. This perspective recognises that operators may hold some permits but not others, may be legally titled yet economically dependent, or may comply with some rules while evading others. Its limitation is that it describes positions on the continuum without explaining why actors occupy them. In this study, the continuum was operationalised to classify operators by legal standing, capitalisation and market access (Table in section 5.1), providing the descriptive foundation for RQ1.

Second, explanations of why ASGM remains informal are drawn from debates on the informal economy. The legalist perspective, associated with De Soto and applied to ASGM by [5, 7], attributes informality to costly, slow and inappropriate bureaucratic requirements. Structuralist perspectives emphasise that informality can be functional for more powerful actors: [27] shows how ASGM entrepreneurs in the Philippines benefit from a flexible regime built on informal labour, while [28] documents how miners and officials in Liberia negotiate intermediate forms of legality through informal payments. Informality may therefore be strategic, chosen because it lowers transaction costs, reduces regulatory exposure, preserves operational flexibility or enables access to informal finance and labour, rather than simply imposed. Previous Zimbabwean studies have tended to foreground regulatory exclusion; this study examines both explanations, which guided codes on

compliance costs (legalist) and on the benefits of informal arrangements to sponsors and claim holders (structuralist).

Third, the organisation of work is examined through the literature on ASGM labour arrangements, which highlights heterogeneity among workers, the prevalence of output-sharing and the distribution of risk and reward among capital providers, title holders and labourers [6]. [6] found in the Philippines that formal mines may replicate the working conditions of informal ones and that workers may prefer non-standardised forms of remuneration. This literature informed codes on remuneration, risk sharing and dispute resolution within trilateral arrangements (RQ1, RQ2).

Fourth, site governance is analysed using the concept of hybrid governance, in which non-state actors, including coercive groups, perform regulatory functions such as controlling access, enforcing agreements and adjudicating disputes, often in negotiated relationships with state actors [31]. In ASGM, such arrangements have been linked to protection rackets and political competition [30]. The concept allows the analysis to distinguish state governance, community and customary governance, informal contractual governance and coercive private governance, rather than treating violence only as an absence of the state. It guided interpretation of dispute resolution and the Mashurugwi phenomenon (Section 7.3).

Finally, the sustainable livelihoods framework [32] was used as a sensitising lens to situate mining decisions within households' asset portfolios and vulnerability, particularly in interpreting why labourers accept precarious arrangements and how formalisation costs are weighed against immediate income needs. Taken together, these perspectives address a gap in previous work: continuum models describe positions, legalist accounts explain exclusion, and structuralist and governance accounts explain persistence and control, but they have rarely been combined to link operational heterogeneity to differentiated formalisation pathways.

4. Research Methodology

4.1 Research Design and Study Sites

This research used a multi-site qualitative case study design, a widely accepted methodological approach when exploring complex, context-specific resource management phenomena [33]. The six sites were Kadoma, Norton, Chegutu, Shurugwi, Kwekwe and Zvishavane, selected as they represent a range of main gold deposit types, sizes of operation and legislative and regulatory conditions, typical of gold mining in the central gold belt of the Midlands and Mashonaland West provinces. The selection also included both more easily accessible peri-urban mining sites (Norton and Chegutu) and more distant, historically established mining districts (Shurugwi and Zvishavane), allowing comparison of operating conditions in a range of geographic and infrastructural settings. Across the six districts, 25 active ASGM sites were visited and 78 participants were interviewed (Table 4).

Table 4 Summary of Field Investigation Sites and Interview Participant Distribution.

Mining District	Primary Deposit Type	Active ASGM Sites Visited	Interview Participants
Kadoma	Orogenic lode gold; alluvial	6	15
Norton	Saprolite disseminated oxide; alluvial	4	11
Chegutu	Quartz reef; saprolite oxide	3	10
Shurugwi	Orogenic lode gold; chrome/gold	4	14
Kwekwe	Multiple: reef, oxide, alluvial	5	16
Zvishavane	Reef gold; placer	3	12
TOTAL	-	25 sites	78 participants

District selection was purposive and designed to maximise variation on dimensions expected to shape formalisation: deposit type and mining method, the density and age of mining activity, proximity to regulatory offices and markets, and governance conditions, including violent contestation over sites in Shurugwi and Kwekwe [14]. Participant numbers differed between districts (10-16) because recruitment followed the density of accessible active operations rather than a quota: numbers broadly track the number of sites visited per district (Table 4), with the long-established, high-density hubs of Kwekwe and Kadoma contributing the most participants and Chegutu and Zvishavane, where accessible activity was more localised during fieldwork, contributing fewer. The sample is not statistically representative of districts or of the national ASGM workforce; district-level comparisons are interpreted qualitatively, and the findings support analytical rather than statistical generalisation to comparable greenstone-belt ASGM settings.

4.2 Participants, Eligibility Criteria and Sample Size

Participants were purposively sampled to include every actor category directly involved in, or regulating, ASGM production and formalisation. The sample comprised artisanal and wage mine labourers (n = 31), small-scale mine claim owners (n = 18), sponsors and equipment suppliers (n = 11), mine managers and supervisors in formalised operations (n = 8), officials of MMMD and EMA (n = 6), and community representatives, namely traditional leaders and residents' association chairpersons (n = 4). Eligibility criteria for each category, reconstructed from the category definitions used in fieldwork, are presented in Table 5.

Table 5 Participant Categories and Eligibility Criteria.

Participant category	n	Inclusion criteria*	Principal contribution
Artisanal and wage mine labourers	31	Working as artisanal miners or as wage/share labourers at an active ASGM site in a study district at the time of fieldwork, without holding mineral rights	Work organisation, remuneration, market access, processing practices (RQ1, RQ2)
Small-scale mine claim owners	18	Registered holders or co-holders of small-scale gold claims in a study district	Title, compliance costs, sponsor relations (RQ1, RQ2)
Sponsors and equipment suppliers	11	Financing ASGM operations, or supplying equipment and consumables to operations, in a study district	Financing terms, output shares, risk (RQ1, RQ2)
Mine managers and supervisors (formalised operations)	8	Holding management or supervisory responsibility at a licensed operation in a study district	Compliance experience, technical requirements (RQ2, RQ3)
MMMD and EMA officials	6	Holding responsibility for mining or environmental regulation relevant to the study districts	Regulatory perspective, enforcement capacity (RQ2, RQ3)
Community representatives	4	Traditional leaders or residents' association chairpersons in mining-affected communities	Community impacts, dispute mediation (RQ2, RQ3)
Total	78	*Reconstructed from category definitions	

No formal exclusion criteria beyond these category-based eligibility requirements were specified in the study protocol. The absence of predefined exclusion criteria is acknowledged as a limitation, because recruitment then depended partly on access and gatekeeper introductions, which may have favoured more accessible and less conflict-affected sites (Section 7.7).

Sample size was judged in terms of information power rather than statistical power [34]: the study aim was broad, but the sample was specific to the phenomenon, combined interview, observation and documentary evidence, and included all actor categories in the production and regulatory chain. Seventy-eight interviews also exceed the number at which code saturation is typically reached in relatively homogeneous samples [35], which was important given the heterogeneity across six districts and six participant categories. Saturation was considered at the level of themes rather than as a numerical threshold. Categories with few participants (officials, n = 6; community representatives, n = 4) are unlikely to have reached saturation independently, and evidence from these groups is used mainly for corroboration.

4.3 Data Collection

Primary data were collected using three main approaches. First, semi-structured interviews were conducted with the 78 participants described in Section 4.2. The interview guides covered four main themes, namely mine operations and management, regulatory experience and formalisation obstacles, environmental management, and mining as a livelihood activity. Interviews were conducted in Shona, Ndebele, or English depending on participants' preferred language, with assistance from interpreters. Second, field observations of active mining (operations management, machinery and infrastructure, extraction and processing methods, and environmental conditions) were recorded at 23 operational sites (see note to Table 4) across the six districts, particularly focusing on the structure of tailings storage facilities, excavations and drainage control systems. Finally, analysis of relevant legislation, namely the Mines and Minerals Act (Chapter 21:05), the Environmental Management Act (Chapter 20:27) and associated EIA regulations, and the Fidelity gold-marketing arrangements, provided the framework for interpreting mining activities and regulations.

4.4 Data Analysis: Coding and Theme Development

The interviews and observations were analysed using thematic analysis [36], drawing codes deductively from the mine management, mineral economics, and ASM governance literature, and inductively from field data. The analytical frameworks described in Section 3 supplied the deductive codes.

Analysis followed the iterative phases of reflexive thematic analysis [37]. First, interview records, observation records and documents were read repeatedly for familiarisation. Second, an initial deductive codebook was derived from the frameworks in Section 3, for example, codes for legal standing, capitalisation and market access (formalisation continuum), compliance cost and procedural burden (legalist perspective), benefits of informality (structuralist perspective), remuneration and risk sharing (labour arrangements) and non-state dispute resolution (hybrid governance). Third, codes not anticipated by these frameworks, such as the trilateral production arrangement, unreceipted payments during licensing and coercive enforcement of site control, were added as inductive codes. Fourth, codes were refined by merging overlapping codes, splitting codes that combined distinct processes, and clarifying definitions. Fifth, related codes were clustered into candidate themes, reviewed against the full dataset and across districts and participant categories, and consolidated where they did not remain distinct. Finally, themes were mapped to the research questions. Table 6 presents the resulting thematic framework.

Table 6 Coding Tree and Thematic Framework.

Main theme	Subtheme	Example codes	Code origin*	Principal data sources	RQ
1. Operational heterogeneity	Deposit type and mining method	Reef stopping; oxide open pit; alluvial sluicing	Deductive	Observation; claim owners; managers	RQ1
	Legal standing and capitalisation	Capitalised owner; undercapitalised owner; partial compliance; no rights	Deductive (continuum)	Claim owners; labourers; documents	RQ1
2. Production and labour arrangements	Trilateral financing	Sponsor inputs (fuel, explosives, mercury); output shares	Inductive	Sponsors; claim owners; labourers; observation	RQ1, RQ2
	Remuneration and risk	Daily wage; share of shift production; no OHS provision	Deductive (labour literature)	Labourers; claim owners	RQ1
	Dispute resolution and site control	Negotiation; community intermediation; intimidation and coercion	Inductive and deductive (hybrid governance)	Labourers; claim owners; community representatives; literature	RQ2
3. Formalisation constraints	Financial	Upfront compliance cost; credit exclusion	Deductive (legalist)	All producer categories; regulatory schedule	RQ2
	Procedural	Multi-agency sequencing; delays; lost forms; unreceipted payments	Deductive and inductive	Claim owners; managers	RQ2
	Technical capacity	Absent mine plans; no ground support; plant certification delays	Deductive (mine management)	Observation; claim owners; managers	RQ2
	Institutional capacity	Inspector shortages; reactive enforcement	Deductive	Officials; documents	RQ2

4. Market and environmental practices	Informal marketing	Side-selling; smuggling; royalty and exchange-rate avoidance	Deductive and inductive	Labourers; claim owners; sponsors	RQ2
	Environmental management	Open amalgam burning; unengineered tailings; unstable pit walls	Deductive	Observation records	RQ1, RQ2
5. Governance pathways	Differentiated entry; extension; mercury alternatives	Simplified permits; technical support; technology access	Synthesis	RQ2 findings; documents; comparative literature	RQ3

The procedure used to produce these codes is reported as follows. Coding was carried out manually by the lead author, who coded the full set of interview records, observation notes and documents; qualitative-analysis software was not used. Because a single analyst coded the entire dataset, coding was not conducted independently by more than one coder, and no intercoder reliability coefficient (such as Cohen's kappa or percentage agreement) was calculated; none is reported here, and the study makes no claim to intercoder reliability. Consistency and credibility were instead pursued through the following procedures, a written codebook recording each code, its definition and an anchor example, applied consistently across districts and participant categories; a second pass over material coded early in the process, after the codebook had been refined, to check that earlier records were coded under the final definitions; review of the codebook, the coded extracts supporting each theme and the draft thematic framework by the co-author(s), with divergent readings discussed until an agreed interpretation was reached; and an audit trail linking each theme to the codes and source records from which it was derived, so that the analytical path can be traced. Independent double coding of a subset of records would have strengthened dependability further, and its absence is acknowledged as a limitation (Section 7.7).

4.5 Triangulation and Trustworthiness

Triangulation was conducted across data types (interviews, observation and documents) and across participant categories. For each key finding, the analysis examined whether more than one category reported it, whether observation or documents corroborated it, and whether any category contradicted it. Table 7 summarises this assessment. Where a category's perspective is not reported in the analysis, this is shown explicitly rather than inferred. Two gaps are apparent: officials' views on procedural barriers and informal payments are not reported, and community representatives' perspectives are thin because of their small number. These gaps limit corroboration of findings about bureaucratic friction, which are therefore presented as participant-reported. No explicit contradictions between categories were recorded in the current analysis.

Table 7 Data Triangulation Matrix for Key Findings.

Key finding	Lab	CO	Sp	Mgr	Off	Com	Obs./docs	Interpretation
Workforce stratified; labourers largest stratum	✓	✓	~	~	-	-	✓ observation	Corroborated by producers and observation; officials' views not captured
Trilateral sponsor arrangements with output-sharing	✓	✓	~	~	-	-	✓ all six sites	Corroborated; variable shares indicate negotiated rather than standardised terms
Compliance costs prohibitive	✓	✓	~	~	-	-	✓ regulatory schedule	Raised across locations and workforce strata; officials' position to confirm
Procedural complexity and unreceipted payments	~	✓	~	~	-	-	~	Participant-reported at all six sites; not corroborated by officials
Mine planning and technical capacity gaps	~	✓	-	~	~	-	✓ no ground support	Observation corroborates interview accounts
Inspectorate shortages; reactive enforcement	-	~	-	~	~	~	~	Raised across locations
Informal marketing and smuggling	✓	~	~	-	~	-	-	Reported by a majority of interviewees; magnitude (30-50%) not verifiable
Mercury amalgamation and open burning	✓	~	~	-	~	-	✓ 17 of 23 sites	Strongly supported by observation
Local economic multipliers	~	~	✓	-	-	~	✓ all six sites	Original text cites non-mining businesses, not a sampled category
Coercive site control (Mashurugwi)	~	~	-	-	-	~	Literature	Mainly literature-supported; field corroboration to confirm

Note: Lab = labourers; CO = claim owners; Sp = sponsors and suppliers; Mgr = managers (formalised operations); Off = MMMD/EMA officials; Com = community representatives. ✓ = explicitly reported in the analysis; ~ = implied, category-specific evidence; - = not reported.

5. Findings (RQ1): Mine Structure, Workforce Composition and Production Arrangements

This section addresses RQ1, which asked how mines are structured, how the workforce is composed and managed, and how these vary with deposit type, geological setting and regulatory status. The findings show that heterogeneity is organised along three interacting axes (deposit type and mining method, legal standing, and access to capital) and that production is frequently coordinated through informal trilateral arrangements.

5.1 Workforce Stratification and Operational Hierarchy

Field investigations at the six study sites indicated a complex operational hierarchy, based on uneven access to mineral rights, capital, and technical capacity, directly correlated to the level of management, occupational safety performance, and capacity to comply. This hierarchy served as the primary unit of analysis for formalisation dynamics in the study area.

Claim holders in the small-scale mining sector constituted the topmost operational level in the Mines and Minerals Act context. They hold the sole right to excavate certain minerals over specific plots of land; a registered precious metal block may comprise a single claim or up to ten claims, with a maximum block size of 500 m × 200 m (10 ha). Those with capital that hold claim blocks predominantly extract reefs, working to vertical depths of up to 120 m and working faces typically measuring between 0.8 and 2.5 m in width. Operators with sufficient capital operating on oxide sites predominantly use excavator- or truck-and-shovel methods, processing run-of-mine ore through carbon-in-pulp circuits or gravity concentration where the necessary equipment and facilities exist.

A second significant operational level was the partially formalised operator who has begun but not completed the formalisation process. In most instances, they have registered a mining business and received some permits but have become blocked by a secondary compliance measure. They are visible to regulators, and therefore exposed to enforcement, yet have not attained full legal protection. Their underground workings are technically similar to those of informal labour-based operations: drilling is done via handheld drills or jackhammers and transportation is carried out via wheelbarrows, with processing through small gravity concentration circuits, such as jigs or sluice-boxes.

The largest workforce stratum across all sites was wage labourers: individuals without mining rights or operating capital who work on claims with the holder's permission and are paid either daily or as a share of gold produced. These labourers receive USD 3-12 per day or 20-35% of the mass of their shift's production, under informal, non-contracted work agreements. They receive no occupational health and safety provisions and no formal means of marketing gold to the official buyer, FGR, and therefore rely on informal channels where they are susceptible to price reductions and legal issues.

Beyond geographical and geological variation, the ASGM workforce is internally stratified by legal standing, capitalisation, and access to the formal gold market. The three operational levels described above are disaggregated here into five strata by distinguishing capitalised from undercapitalised claim owners, and labourers attached to registered claims from informal seasonal labourers. Applying the continuum-of-formalisation model [5], the field data were used to distinguish five operational strata ranging from fully licensed, capitalised claim owners to informal

seasonal labourers. Table 8 summarises the operational characteristics associated with each stratum.

Table 8 Operational Characteristics by ASGM Workforce Stratum.

Operational Stratum	Legal Standing	Typical Mining Method	Access to Formal Gold Market	Estimated % of Workforce
Licensed claim owner (capitalised)	Full, Mines & Minerals Act	Open-pit excavator; mechanised underground stopping	Direct, FGR (formerly FPR)	~8%
Licensed claim owner (undercapitalised)	Full, mineral rights only	Subcontracts to sponsor/artisanal arrangement	Indirect via sponsor	~12%
Partially formalised operator	Partial incomplete compliance	Manual open-pit; hand-drilling reef	Limited/informal	~15%
Wage labourer (attached to a registered claim)	None (works under holder's title)	Hand-drilling; wheelbarrow ore transport	None via claim owner	~25%
Wage labourer (informal/seasonal)	None	Panning; sluicing; manual pitting	None informal market	~40%

As Table 8 indicates, legal formalisation and economic capacity do not neatly coincide: only around 20% of the workforce (the two licensed claim-owner categories combined) holds full legal standing, yet even within this group, a substantial undercapitalised segment must subcontract its mineral rights to access production. The indicative data suggest an inverse relationship between formality and workforce size, with the largest stratum (around 40%) comprising informal, seasonal labourers who operate entirely outside the legal framework and sell into informal markets. This concentration of the workforce at the informal end of the continuum illustrates that formalisation is not a binary status but a graduated spectrum, with most miners occupying intermediate or wholly informal positions. These findings underscore why regulatory interventions targeting only licensed operators are unlikely to reach the bulk of the ASGM workforce.

5.2 Informal Trilateral Production Arrangements

A defining feature of ASGM operations in the study area is the largely undocumented informal trilateral production relationship between claim owners, artisanal miners and external financiers (as consistently observed across the six study sites and across numerous deposit types). This feature cannot be ignored in any meaningful attempt to theorise the formalisation pathway, as it describes the informal mechanism of mine governance of many mining operations active today in the study area.

In essence, a registered claim owner who cannot finance operationalisation or continuing production enters into an informal agreement with a sponsor who finances mining operations. Sponsors are generally local businessmen (most commonly local traders, although sometimes agriculturalists, or those involved in Zimbabwean diaspora entrepreneurship, or informal financing);

the sponsor finances working capital in return for a certain share of gold production. This working capital typically covers fuel, drilling consumables, explosives, gravity-concentrating apparatus, and mercury for amalgamation. The share given to sponsors typically varies from 40-60% of total gold production, while the share allocated between the claim owner (10-30%) and labour-providing artisanal miners (20-35%) varies with the type of deposit and relative bargaining strength between the parties involved. The exact proportions vary greatly between sites and deposits.

These arrangements are undocumented in all cases encountered and unenforceable at law. Conflicts over production measurement, gold weight, and gold yield share were frequently reported and were resolved through informal negotiation, community intermediation, or even physical intimidation and coercion. The appearance of organised physical enforcement of territorial claim rights by machete gangs (colloquially known as Mashurugwi) in both the Shurugwi and Kwekwe areas since roughly 2016 is the most extreme manifestation of contested control over informal production and site access [14]. Its governance implications are examined in Section 7.3.

Interpreted against the labour-arrangements literature, these patterns are not unique to Zimbabwe. Output-sharing between capital providers, title holders and labourers is widespread in ASGM, and studies in the Philippines and the Democratic Republic of Congo show that workers occupy heterogeneous positions and may prefer output-based over standardised remuneration [6, 29]. What is distinctive in the study area is the central role of external sponsors who finance production on registered claims that title holders cannot work themselves, creating a de facto separation of mineral title, capital and labour. As Section 7.2 argues, this separation has important implications for whom formalisation reaches.

5.3 Upstream and Downstream Linkages of Production

Beyond the mine site, ASGM production in the study districts is supported by a large, interlocking set of upstream and downstream economic activities that represent an enormous local multiplier to employment [38]. At all six study sites, extensive ancillary economic activities supporting the mining were observed: jackhammer, compressor, small equipment (processors) sales and repair; generator and compressor fuel suppliers; suppliers of explosives for drill and blast/stope activities; sellers of mercury and buyers of gold; suppliers of ore transport and worker transport; and a wider array of goods and services, including sellers of food, unofficial providers of finance (money changers, moneylenders), accommodation providers and retailers.

6. Findings (RQ2): Formalisation Constraints and How Operators Navigate Them

This section addresses RQ2, which asked what technical, financial and institutional constraints impede formalisation and how operators navigate or avoid them. Five constraints were identified (financial, procedural, technical, institutional and market-related), together with environmental practices that reveal the compliance gap in material form. For each, the section reports how operators respond, which is central to understanding whether informality is imposed, chosen or both.

6.1 Financial Barriers and Capital Access Constraints

Of all constraints, the one most consistently raised across field locations and workforce strata was the high cost of regulatory compliance relative to artisanal operators' limited financial capacity. Formalising a small-scale mining claim under the Mines and Minerals Act involves a cascade of financial commitments that together far exceed the annual earnings of most artisanal miners: these include the cost of registering a claim, a cadastral survey fee, the cost of drawing up an Environmental Impact Assessment (EIA) document and submittal through a registered environmental consultant, the cost of drawing up and certification of the mine plan, equipment registration and certification fees, and continuous payment of royalty fees based on the value of gold sold via formal routes.

Field research found that a small-scale mining claim, depending on claim size, mineral type, and level of environmental assessment, can incur an upfront cost of around USD 2,500-8,500 in the study area. This is equivalent to roughly 0.6-7.8 years of a wage labourer's earnings at USD 3-12 per day (assuming earnings on all 365 days of the year; fewer working days would lengthen this period), placing formal title beyond the reach of individual labourers. Even for the semi-formalised operators and claim owners, access to formal credit instruments that will enable them to close this compliance cost gap is virtually unavailable, as the formal commercial banking sector does not extend loans to non-registered mine operations, and micro-finance institutions do not provide credit facilities appropriate to the development of a small-scale mining project. Operators navigated this barrier in two main ways: undercapitalised claim holders obtained working capital from sponsors (Section 5.2). In contrast, labourers without title worked under another holder's claim rather than acquiring their own.

6.2 Regulatory Complexity and Bureaucratic Friction

Beyond these financial costs, formidable process-complexity barriers exist within the procedural structures of formalising small-scale mining in Zimbabwe. For an individual small-scale gold mining operation to satisfy all regulatory requirements in a timely fashion necessitates traversing several distinct agencies, including MMMD, EMA and ZIMRA, in a step-by-step fashion, each with a separate set of forms to complete, fees to pay, portals to log into and forms to submit and separate processing queues to pass through. Respondents at all six sites described time lags, lost forms, competing and conflicting advice from various levels of officialdom, and the strong sense that this complexity was being used as an excuse to demand additional unreceipted payments. Where approvals stalled, operators continued to work in a partially formalised state (Section 5.1), and some respondents perceived that informal payments were expected to move applications forward.

A licensed claims owner in Kwekwe (at that time producing 3.2 kg gold per month) gave an example of a four-year formalisation process which he suggested involved more time and cost invested in getting the required paperwork done than actually excavating his claims, requiring numerous journeys to MMMD offices in Harare and Gweru, three different EIAs to be submitted until they were acceptable to EMA, and an 18-month backlog in having his processing plant certified, with equipment to test it unavailable in the region. This account was consistent with testimony at other sites that administrative procedures themselves act as a barrier to formalisation.

6.3 Mine Planning and Technical Capacity Gaps

A third, and perhaps less recognised, formalisation barrier is the lack of mine planning and technical competence among most artisanal operators. Formal compliance with the Mines and Minerals Act and related regulations entails the design of mine plans, ventilation designs for underground workings, ground control and support specifications, and the design of the processing plant to be undertaken by competent persons, which implicitly entails the engineering know-how and the funds to employ the services of such persons that most artisanal operators do not have. In its absence, underground workings are constructed more or less intuitively, without formal stability assessment, structured development planning and the adequate design of the stope support, contributing to ground falls and working-face collapses that account for many accidents in the sector.

This disparity between the engineering specifications for formal mine management and the way mining is undertaken in the sector is a first-order safety and operational efficiency issue, and not just a compliance one. Mine workings dug out without mine planning designs often intersect abandoned mine workings, run into dead-end unventilated workings containing high levels of methane or carbon dioxide, and have pillars arranged in a configuration which has never been formally assessed for stability. Fatality rates in ASGM, widely considered to be several times higher than in formal mining, are plausibly linked in part to the absence of competent mine design.

6.4 Regulatory Architecture and Institutional Capacity

Participants' experiences of these barriers reflect a regulatory framework largely shaped by large-scale, corporate mining operations. The Mines and Minerals Act (Chapter 21:05), the primary legislation concerning mineral rights and mining management, specifies regulatory compliance standards that can only be satisfied through the availability of professional engineering expertise, lawyers, and financial bonds and insurance, which are generally unavailable to artisanal and small-scale operators. Applying a uniform regulatory standard to operations that differ by orders of magnitude in scale, capitalisation and technical sophistication tends to lead to pervasive non-compliance (where a given standard is impossible to meet), or to regulatory capture and a process of nominal compliance, or selective enforcement. The Environmental Management Act (Chapter 20:27) faces similar structural constraints in relation to ASGM operations. Where required before start-up, a formal EIA is a conceptually suitable tool for the management of environmental externalities. Yet for informal ASGM, its application is administratively infeasible. A formal EIA by a registered environmental practitioner was reported to cost USD 3,000-15,000, which is prohibitive for most individual artisanal operators and disincentivises formalisation. EIA requirements for small-scale operators have also shifted over time, including reported relaxations [25].

The extent to which MMMD can regulate activities within the broad and fragmented ASGM environment of the study area is severely hampered by lack of resources. Mine inspectorate offices serving the study districts, including those in Gweru and Kwekwe, lack a full contingent of trained mine inspectors to inspect the hundreds of active ASGM sites in the study area methodically. Regulatory contact with informal operators therefore tends to be reactive rather than proactive, instigated by reported deaths, community complaints, or gold smuggling cases, rather than planned systematic compliance monitoring. This pattern of enforcement is neither effective deterrence nor dependable assistance for operators pursuing compliance.

6.5 Informal Gold Marketing and Leakage

Official production statistics capture only the portion of ASGM output that passes through official channels. At all six sites, a majority of interviewees reported that a significant percentage of the gold produced under informal circumstances is not sold to licensed dealers but is smuggled across national borders (primarily, according to participants, to South Africa, the United Arab Emirates and the Democratic Republic of Congo) to avoid royalties and other deductions and to obtain more favourable exchange rates than those offered through official channels. Participants estimated that 30-50% of ASGM output leaves through unofficial channels; this figure could not be independently verified but, if broadly accurate, implies that official statistics substantially understate the sector's production and economic contribution.

Comparative evidence helps interpret these findings. Continental analyses indicate that large volumes of African ASGM gold are exported without declaration, much of it to the United Arab Emirates, and that export taxes, gold prices, exchange rates and institutional quality drive export misreporting and smuggling [39]. In Burkina Faso, illicit gold markets are sustained by protection rackets linked to political competition rather than by weak enforcement alone [30], and Zimbabwean studies similarly locate gold trading within patronage networks [8]. Three implications follow. First, side-selling is a form of regulatory arbitrage in which producers compare the net returns of official and unofficial channels; formalisation that raises compliance costs without improving net prices strengthens the incentive to leak gold. Second, because informal buyers offered more favourable exchange rates, as participants reported, leakage is embedded in value-chain relationships rather than in isolated transactions. Third, where illicit trade is politically protected, technical formalisation measures are unlikely to be sufficient on their own.

6.6 Mercury Use and Amalgamation Practices

Amalgamation with mercury remained the most widely used gold-recovery technique among artisanal miners observed at the six locations, despite national and international commitments to reduce it. The Minamata Convention on Mercury does not prohibit mercury use in ASGM outright; rather, Article 7 and Annex C require Parties with more than insignificant ASGM to develop National Action Plans to reduce and, where feasible, eliminate mercury use, and to eliminate whole-ore amalgamation, open burning of amalgam, burning of amalgam in residential areas, and cyanide leaching of sediment, ore or tailings to which mercury has been added without first removing the mercury. Nationally, mercury is regulated as a hazardous substance under the Environmental Management Act and SI 12 of 2007, and Zimbabwe's ASGM NAP sets mercury-reduction objectives [4]. Mercury amalgamation is a technically uncomplicated and therefore relatively easily implemented technology in the absence of the gravity concentration and cyanidation facilities that larger capital-intensive mines can access. The lack of required capital equipment, a power source, and technical expertise makes mercury amalgamation the de facto technology for the majority of artisanal miners interviewed in this study.

Field visits established the commonality of open burning of amalgam without mercury recovery devices at 17 out of the 23 operational sites observed, indicating that at most observed sites mercury vapour is released directly to the working atmosphere and ambient air. Literature estimates of mercury lost per unit of gold produced are approximately 1.3 g Hg per g Au (a mass ratio of 1.3:1) where only gravity concentrates are amalgamated, and about 3:1 or more where

whole ore is amalgamated [40]; estimated regional averages are about 1.96:1 for Africa [41]. Gravity-cyanidation circuits do not use mercury, so a numerical multiplier relative to cyanidation cannot be calculated; the previously reported comparison has therefore been withdrawn. Cyanide leaching of mercury-contaminated tailings is, however, itself a practice to be eliminated under the Minamata Convention [42]. The environmental evidence reported in this article is therefore observational. An exploratory reconnaissance of riverbed sediments was undertaken during fieldwork, but it covered only two rivers, was not replicated across the six districts and was not supported by a documented sampling and analytical protocol of the standard required for environmental reporting. Those results have consequently been withdrawn from this article and are not used to support any claim; they are reserved for a dedicated environmental study designed with an appropriate sampling design, chain of custody, accredited analysis and quality control. The analysis below rests on the direct observation of amalgamation and open amalgam burning at the study sites, which is sufficient to establish the exposure pathway at issue without inferring environmental concentrations.

These observations are consistent with the wider literature. ASGM is the largest anthropogenic source of mercury emissions and releases globally [43]. Burning amalgam in the open exposes miners and nearby residents to elemental mercury vapour, and a comprehensive review documents neurological, renal and other health effects among ASGM communities [44]. Earlier work documented mercury contamination associated with small-scale gold mining in Zimbabwe and Tanzania [45]. The persistence of open amalgam burning at 17 of 23 observed sites therefore indicates a significant exposure pathway, but quantifying emissions or ecological risk would require systematic sampling beyond the scope of this study.

6.7 Geotechnical Instability and Land Disturbance

The geotechnical consequences of “ad hoc” artisanal open-pit and underground mining across the study districts constitute a growing environmental and safety risk to the local community. Open-pit workings that were not designed to meet established slope design parameters possess vertical or sub-vertical 8-25 m-high pit walls in the weathered and saprolitic horizon and bench geometry that responds to mine working expediency rather than design considerations. Gradual deterioration of pit walls during subtropical weather combined with seasonal water table rise during the October-March wet season has produced repeated pit wall failure at a significant percentage of working and abandoned mines. MMMD records deaths from highwall failures at informal ASGM sites annually, although such incidents are likely to be under-reported [10]. Comparable geotechnical hazards were identified in underground workings constructed with no mine design principles; observed stope spans were greater than can be self-supported in the very weak and heavily fractured rocks of shallow greenstone belts, and no timber or rock-bolt support was identified in the artisanal workings. Goafs with overlying ground subsidence over old workings were observed at 3 sites in Kadoma and Kwekwe, with associated surface manifestations of circular 2-8 m diameter depressions and small escarpments over caved stope roofs.

6.8 Tailings Management and Fluvial Contamination

At the sites surveyed, mineral processing tailings were, in all but one case, disposed of in unengineered dumps on flat to gently sloping ground next to the mineral processing plants. Good

practice, and the pollution-prevention objectives of Zimbabwe's environmental regulations, call for tailings storage facilities (TSFs) designed on the basis of geotechnical stability analysis, with seepage control and rehabilitation at closure; such a facility was observed at only one site, which was a semi-formalised site near Kwekwe with active Ministry of Mines monitoring. Tailings dumps were seen to have accumulated in low-lying topography adjacent to drainage lines at all, but the formal site and tailings were observed to be worked by gravity into surface watercourses during rainfall; transport of cyanide- and mercury-rich tailings into the watersheds of the Munyati (Umniati) and Sebakwe rivers, of importance as agricultural and domestic water resources to downstream areas, constitutes a non-point source pollution route of significant concern.

Taken together, the RQ2 findings indicate that constraints are cumulative and unevenly distributed across strata: labourers are excluded primarily by cost, undercapitalised claim holders by cost and technical capacity, and partially formalised operators by procedural sequencing. Environmental noncompliance is the material expression of these constraints but, as Section 7 argues, cannot be attributed to exclusion alone.

7. Discussion: Heterogeneity, Noncompliance and Segmented Formalisation

7.1 Heterogeneity and the Limits of Uniform Formalisation

A central implication of the findings is that the current regulatory framework governing ASGM in the study area is fundamentally mismatched to the manner in which the sector actually operates, and its financial and technical capabilities. The existing framework, developed to address and regulate capitalised corporate operators cannot, without modification, bring subsistence-level artisanal miners into its fold; applied uniformly, it tends to produce exclusion rather than compliance.

This finding aligns with evidence from Ghana, where a generic licensing framework has failed to match the diversity and mobility of ASM operations [11], and with the legalist critique that bureaucratic requirements create informality [5]. The Zimbabwean data, however, show that heterogeneity matters in more than one way. Operators differ not only in their capacity to pay compliance costs, but also in the functions informality performs for them, who controls access to sites, and their environmental risk profiles. Formalisation must therefore respond to differences in incentives as well as in capacity.

7.2 Strategic Informality and the Functions of Trilateral Arrangements

The legalist account captures the situation of labourers, for whom formal title is unaffordable. It is less convincing for claim holders and sponsors, some of whom have resources to comply. For these actors, informality may be at least partly strategic [27]. The trilateral arrangement allows a claim holder to derive income from title without investing capital; allows a sponsor to obtain a large share of output (40-60%) without holding title or entering formal contractual obligations; and allows production to begin without the delays reported in Section 6.2. Because agreements are undocumented, they may also offer flexibility to adjust or exit as conditions change, while output-based remuneration shifts production risk onto labourers, who are paid only when gold is recovered. Informal marketing adds a further margin through more favourable exchange rates (Section 6.5).

These arrangements should not be read only as dysfunctional. They mobilise capital that formal lenders do not provide (Section 6.1), keep claims productive and give labourers access to work and to a share of output, consistent with evidence that ASGM workers may prefer output-based remuneration [6]. Their costs are also real: the absence of written terms makes disputes over weights and shares common, labourers bear occupational risk without protection, and mercury supplied as a sponsor input embeds amalgamation in the financing model. The analytical point is that formalisation competes with a functioning informal institution. A formal pathway that offers title but not capital, or compliance but not faster approvals, offers little to actors for whom the informal arrangement already solves these problems.

This interpretation qualifies the argument that informality is simply imposed by regulation. The evidence suggests a continuum of motivations: exclusion-driven informality among labourers, constrained but partly strategic informality among undercapitalised claim holders, and more discretionary informality among sponsors. The data do not permit estimates of how many actors occupy each position, and sponsors' reasons for remaining informal were not systematically elicited, which limits the strength of this inference.

7.3 Mashurugwi, Coercion and Privatised Governance

The emergence of machete gangs known as Mashurugwi in Shurugwi and Kwekwe is commonly interpreted as evidence of the absence of accessible formal dispute resolution [14]. The hybrid governance literature suggests an additional reading. Where formal dispute resolution is inaccessible and agreements are unenforceable, coercive actors can supply functions that resemble governance: controlling access to rich sites, enforcing shares, extracting payment for protection and adjudicating disputes by force [31]. Such arrangements can coexist with, and be tolerated or used by, political and state actors, as shown for protection rackets in Burkina Faso's gold sector [30] and for patronage-based control of gold sites in Kwekwe [8]. Four modes of governance can be distinguished in the study area: state governance through MMMD, EMA, the police and the gold-marketing framework; community and customary governance through traditional leaders and local intermediaries who mediate disputes; informal contractual governance embedded in trilateral agreements; and coercive private governance exercised by armed groups. This study records community intermediation and coercion as dispute-resolution mechanisms, but it does not provide evidence on the internal organisation of specific groups or their relationships with state actors, and it makes no claims. The implication for formalisation is that granting title does not by itself secure access: where coercive private governance determines who can work a site, formal rights may be unenforceable without credible state protection and accessible dispute resolution.

7.4 Lessons from Previous Formalisation and Gold-Mobilisation Initiatives

Zimbabwe has attempted to formalise ASGM and increase official gold deliveries through several instruments. In the 1990s, district-administered licensing and capacity building were internationally praised, but authority over alluvial panning was later recentralised and barriers to licensed primary-ore mining increased [13]. Later measures reduced some permit fees and relaxed EIA requirements for small-scale miners, alongside moves towards decriminalisation [25]. Since 2020, policy has emphasised gold mobilisation through pricing and payment incentives administered by FGR and the Reserve Bank of Zimbabwe. In May 2020, a new gold-trading framework introduced a flat payment

rate for ASGM deliveries, reported as US $45 per gram [46]; in 2021, an incremental export incentive scheme entitled producers delivering above their average monthly output to retain 80% of foreign-currency proceeds on the incremental portion, and the scheme was discontinued in February 2023 [47]. Official deliveries rose after the incentives were introduced, with June 2021 deliveries reported at roughly double those of June 2020 [47]. The government has also promoted gold service centres intended to provide small-scale miners with equipment and working capital.

Assessed against the findings of this study, these initiatives rest on three assumptions. First, they treat leakage primarily as a price and payment problem. This addresses one driver of side-selling (Section 6.5) but not the upstream cost, procedural and technical barriers reported in Sections 6.1-6.3. Second, they operate at the point of sale and therefore reward whoever delivers gold, often buyers, sponsors or larger producers, rather than the labourers who form the largest stratum; journalistic reporting has alleged that incentive benefits were captured by large gold buyers rather than artisanal producers, although these allegations have not been independently tested. Third, incentive schedules have changed frequently, which, combined with the policy oscillations documented by [13], weakens the credibility of long-term commitments to formal channels. Formalisation has therefore remained incomplete not because incentives were absent, but because they targeted the marketing end of the value chain while leaving title, capital, technical capacity and site security largely unaddressed.

The segmented model proposed below responds to these shortcomings by addressing the production end of the value chain, linking obligations to capacity, and making benefits conditional on progressive compliance rather than on delivery volume alone.

7.5 Towards Segmented Formalisation: An Empirically Derived Three-Tier Model (RQ3)

RQ3 asked which mine planning, environmental management and governance measures could support sustainable extraction. The preceding analysis establishes why a single, uniform formalisation system is inadequate: (i) operations differ by orders of magnitude in capital and technical capacity (Section 5.1); (ii) barriers differ by stratum (Section 6); (iii) informal arrangements provide benefits that formal alternatives must match (Section 7.2); and (iv) site control is sometimes exercised by non-state actors (Section 7.3). Tiered or reclassified regimes have been proposed elsewhere, including a multi-tier reclassification of ASM in Ghana [11] and taxation-led formalisation in Zambia [2]. The model presented here adapts this logic to the strata identified in this study (Figure 1).

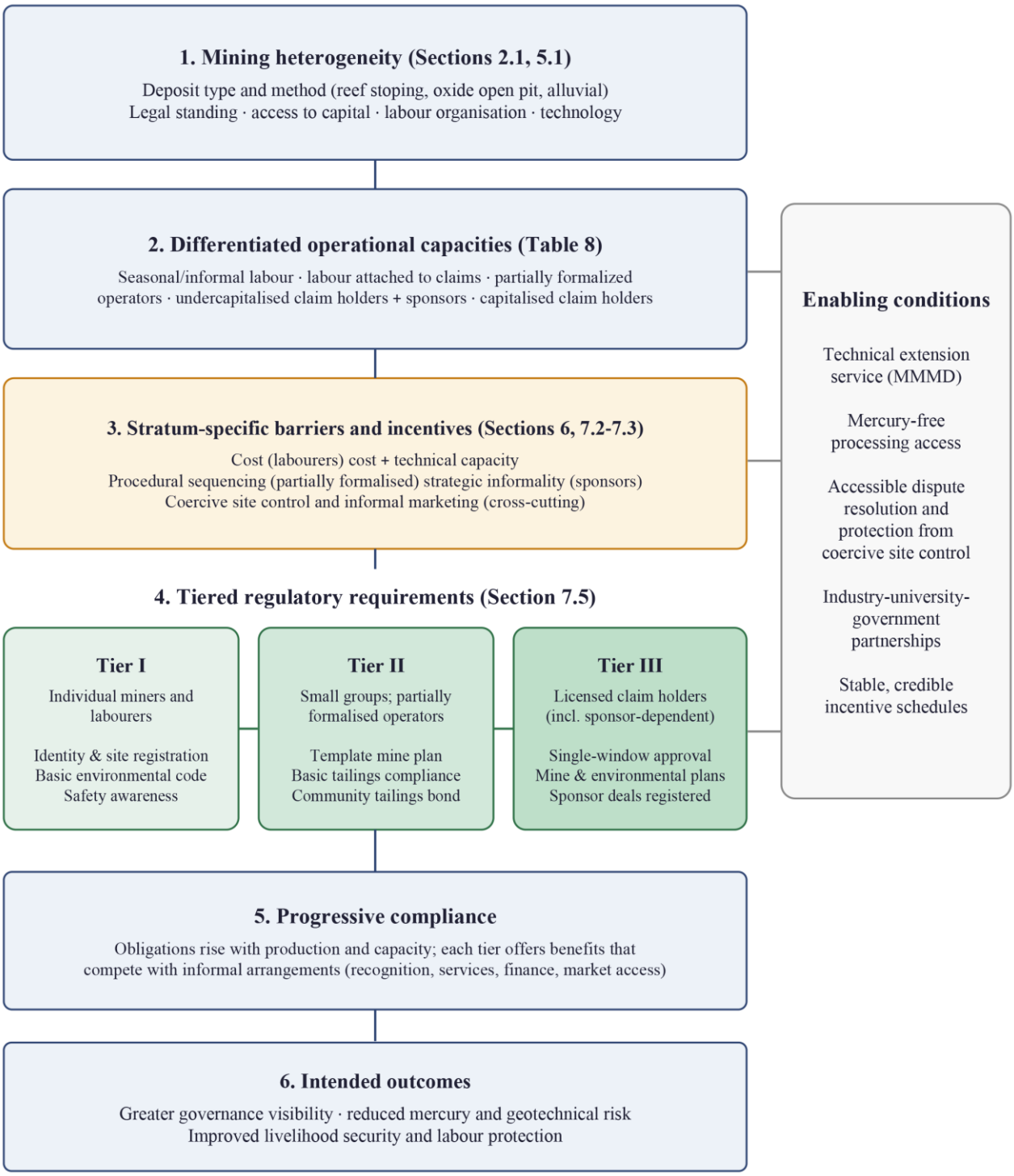


Figure 1 Conceptual model of segmented (three-tier) ASGM formalisation derived from the study findings (proposed; not empirically tested).

The authors propose a three-tier scheme derived from the field findings and informed by comparative formalisation frameworks. Tier I would cover individual artisanal miners and wage labourers (the two labourer strata in Table 8). I would require only registration of their identity and the location of their mining claim, a commitment to follow a basic environmental code of practice, and attendance of a safety awareness workshop. Tier II would cover small group artisanal operations and partially formalised operators, and would require completion of a simple mine plan based on

standardised templates created by the MMMD, basic tailings management compliance, and contributions to a community tailings management bond. Tier III, covering licensed claim owners including those currently dependent on sponsors, would reflect the current structure of small-scale mine licensing but would have streamlined single-window approval processes and offer technical assistance in the development of mine plans and environmental management plans for all licensed operators.

Three design features link the model to the findings. First, movement between tiers is progressive: obligations increase as production and capacity grow, so that compliance is attainable at entry rather than deferred indefinitely. Second, each tier offers benefits that compete with informal arrangements: recognition and protection from arbitrary enforcement at Tier I, access to shared technical and processing services at Tier II, and single-window approvals and eligibility for finance and marketing incentives at Tier III. Third, trilateral arrangements would be recognised through simplified registration of sponsor-claim holder agreements, building on the tribute-agreement provisions of the Mines and Minerals Act, so that output shares, safety responsibilities and mercury use become visible without prohibiting the arrangement. The model's feasibility depends on institutional capacity, credible protection against coercive site control and safeguards against elite capture of Tier III benefits; these conditions are not guaranteed and should be tested through piloting.

7.5.1 Indicators, Elite-Capture Safeguards and Pilot Evaluation

The model set out above is a conceptual proposition derived from the findings; it has not been implemented or tested, and no claim is made that it improves compliance, environmental performance or livelihoods. To make it falsifiable rather than merely plausible, Table 9 specifies, for each tier, the mechanism it is intended to activate, two to three indicators that could be observed during a pilot, a design feature intended to limit capture of tier benefits by intermediaries or elites, and what a pilot evaluation would measure. The indicators follow from the mechanisms identified in the findings: Tier I addresses the exclusion of labourers by cost (Section 6.1), Tier II the technical and procedural barriers facing partially formalised operators (Sections 6.2 and 6.3), and Tier III the capital dependence of licensed but undercapitalised claim holders on sponsors (Section 5.2). All indicators would require a baseline measured before implementation and a comparison group of non-participating operations, since gold output and incomes also respond to price, grade and seasonal factors.

Table 9 Proposed Indicators, Elite-Capture Safeguards and Pilot Evaluation Measures for Each Tier.

Tier	Intended mechanism	Observable indicators (pilot)	Elite-capture safeguard	What a pilot evaluation would measure
Tier I: individual miners and labourers	Low-cost recognition that removes cost as the barrier to entry and reduces exposure to arbitrary enforcement	(i) Registration rate: registered individuals as a proportion of the estimated working population at pilot sites, disaggregated by stratum and sex; (ii) Enforcement experience: reported incidents of confiscation, eviction or unreceipted payment per registered miner per quarter; (iii) Retention: proportion of registrants who renew at the end of the first cycle	Registration is issued directly to the individual, free or at nominal cost, and is not mediated by a claim holder, sponsor or buyer, so that it cannot be withheld as a condition of employment; registers are published at district level so that non-registration of working miners is visible	Whether registration reaches the informal and seasonal labour strata rather than only those already attached to registered claims, and whether registration is associated with fewer coercive enforcement incidents
Tier II: small groups and partially formalised operators	Template-based planning, shared services and basic tailings compliance that lower technical and procedural barriers	(i) Adoption: operations submitting a template mine plan and holding a current permit, as a proportion of eligible operations; (ii) Practice change: sites using retorts or mercury-free concentration, and sites with contained tailings, observed against baseline; (iii) Processing time: median elapsed time from application to decision	Shared processing and tailings facilities are governed by a user committee with places reserved for non-titled operators, and use is not conditional on selling gold to a particular buyer; the community tailings bond is held and accounted for locally with published statements	Whether operators move from Tier I to Tier II within the pilot period, whether observed mercury practice changes, and whether processing times fall relative to the pre-pilot baseline

Tier III: licensed claim holders, including sponsor-dependent holders	Single-window approval, registered sponsor agreements and eligibility for finance and marketing incentives	(i) Registration of sponsor-claim holder agreements, and the share of output recorded as accruing to labour; (ii) Distribution of incentive payments between claim holders, sponsors, buyers and labourers; (iii) Deliveries to official channels per licensed operation, and the share of licensed operations with a compliant mine plan	Incentives are paid directly to the registered producing entity rather than to intermediaries; eligibility requires a registered sponsor agreement stating output shares and safety responsibilities; payment distribution is reported publicly in aggregate; concentration limits or graduated benefits cap the share of incentive value accruing to any single buyer or sponsor; an independent grievance channel allows labourers and claim holders to contest capture	Who actually receives the incentive value, since Section 7.4 indicates that earlier gold-mobilisation incentives were reported to benefit large buyers rather than artisanal producers; and whether registered agreements alter output shares or remain a formality

Tier III requires the most explicit safeguards, because it is the tier at which benefits are most valuable and therefore most likely to be captured. The gold-mobilisation incentives reviewed in Section 7.4 operated at the point of sale and rewarded whoever delivered gold, which is why the reported gains appear to have accrued to buyers and larger producers rather than to the producers the schemes were intended to reach. The design proposed here shifts the point of benefit delivery from the transaction to the registered producing entity, ties eligibility to a registered sponsor agreement that makes output shares visible, and exposes the distribution of payments to public reporting. These are design responses to an observed risk rather than tested remedies: whether they would in practice prevent capture is precisely what the indicators in Table 9 are intended to test, and the model should not be adopted at scale before such a pilot has been evaluated.

7.6 Enabling Measures: Technical Extension, Mercury Transition and Partnerships

Formalisation at all three tiers would be enabled by accessible technical assistance in mine planning, geotechnical safety, and environmental management. Field observations at the study sites highlight that a gap in technical and financial capacity, is a key cause of non-compliance. A mining

technical extension service similar to the agricultural extension model could provide ASGM operators access to qualified mine planning, ground control assessment and environmental management expertise through a network of field-based extension agents from the MMMD district offices. Standardized mine planning templates tailored for dominant deposit type/mining method pairs in the study area (narrow-reef underground stopping, small-scale open-pit oxide mining and alluvial working) would substantially reduce the technical and financial barriers to Tier II compliance.

The environmental legacy of uncontrolled ASGM in the study area requires an environmental remediation program of significant scale and long duration. Key environmental management measures that emerge from field observations include, in the short-term: comprehensive closure and remediation of active open pits with slopes presenting stability risks to nearby settlements; provision of engineered intermediate containment at existing processing sites, prior to transition to the standard TSFs; and adoption of a mercury-free gravity concentration technology, and low-cost cyanidation to replace amalgamation, provided that cyanidation is not applied to mercury-contaminated tailings. The latter is partly a supply-side problem of providing affordable technology to operators who want to adopt cleaner processes but lack the means. Because prohibition without viable alternatives is unlikely to eliminate mercury use, the Minamata Convention frames ASGM obligations around reduction strategies within National Action Plans rather than an immediate ban (UNEP, 2013).

The governance challenge in ASGM in the study area is so large and complex that it cannot be successfully addressed by a single institutional entities. A formalised partnership framework that encompasses the MMMD, EMA, the provincial government, universities with mining engineering and environmental science disciplines, the industry association(s) and community representative bodies is essential. Universities in the region with mining engineering curricula can leverage such a framework to serve as technical assistance providers to ASGM communities and fulfil Education 5.0 mandates through a formal university-community-based extension partnership.

7.7 Limitations

Several limitations qualify these findings. The sample is purposive and not statistically representative, and the workforce percentages and smuggling estimates are indicative. Officials and community representatives were few, limiting corroboration of findings about bureaucratic friction and informal payments. Eligibility, exclusion and saturation procedures were not fully formalised in advance. The environmental evidence is observational: it establishes the prevalence of amalgamation and open amalgam burning but does not measure emissions, environmental concentrations or ecological risk, and the exploratory sediment reconnaissance has been withdrawn for the reasons given in Section 6.6. A single analyst also carried out coding, so no intercoder reliability statistic is reported (Section 4.4). Finally, formalisation policy and gold-marketing incentives in Zimbabwe change frequently, so the institutional context may have changed since fieldwork.

8. Conclusions

This paper has provided an in-depth, multi-site examination of the operational structures, formalisation barriers, economic contributions, and environmental risks associated with artisanal and small-scale gold mining across six districts in Zimbabwe's Midlands and Mashonaland West

provinces. It has been concluded that ASGM is characterised by a multi-layered employment hierarchy heavily comprised of wage labourers who have no mineral rights, no employment protection, and no independent market access to their minerals, as well as widespread use of an informal trilateral partnership between claim holder, artisan and external financier as a de facto mine management model. Formalisation processes have been overwhelmingly hindered by the high cost of access to the compliance architecture, the burdensome multi-agency negotiation of regulatory compliance, and the lack of technical assistance for mine planning and environmental management for small-scale operations. These constraints are not experienced uniformly: they affect labourers, undercapitalised claim holders, partially formalised operators and sponsors differently, and for some actors informality is partly strategic rather than wholly imposed.

The sector's economic significance (accounting for a majority of official gold deliveries in recent years, supporting several hundred thousand livelihoods and providing a stabilising source of income during Zimbabwe's prolonged economic crisis) demands that it be regulated sustainably rather than repressed and dismissed. Sustainable management of ASGM in the study area necessitates, first and foremost, that the regulatory framework be restructured from an exclusionary approach centred on forced compliance that has been developed for corporate actors toward a supportive, enabling framework to guide incremental formalisation based on the unique operational and economic conditions faced by the artisanal sector. The segmented formalisation model proposed in this article, which links differentiated licensing to extension services, mercury-transition support and multi-institution partnerships, is derived from these field findings and should be tested against Zimbabwe's economic and institutional realities.

Given the geology, the operational communities, and the proximity to the university and governmental institutions in Gweru and Kwekwe, the study area is well placed to pilot the above recommendations for sustainable ASGM regulation. Piloting the proposed approach there could generate lessons for other ASGM contexts in Zimbabwe and sub-Saharan Africa, subject to rigorous evaluation. Sustainably managing the sector's economic benefits is a national development imperative.

Theoretically, the article contributes by linking operational heterogeneity to differentiated explanations of noncompliance, combining legalist accounts of exclusion with structuralist accounts of strategic informality and hybrid-governance accounts of site control. Future research should systematically elicit sponsors' and officials' perspectives, quantify output-sharing and gold leakage, and undertake rigorous environmental monitoring in order to evaluate the environmental dimension of the proposed model.

Author Contributions

Hagreaves Kumba conceived the study, conducted interviews, contributed to the analysis and interpretation of the findings, prepared the first draft, and finalized the manuscript for submission. Francis Mafuratidze supervised the research and provided overall guidance on project development and implementation. Rejoice Moyo and Erasmus Madzudzo conducted interviews and contributed to data collection. Lawrence Ndhlovu contributed to the study design and interpretation of the findings. Ratidzo Pasipamire contributed to data management and analysis. Victor Tambaoga contributed to the interpretation of the findings and critical revision of the manuscript. All authors reviewed, revised, and approved the final version of the manuscript.

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AI-Assisted Technologies Statement

During the preparation of this manuscript, Grammarly AI was used to assist with proofreading and improving language clarity. Its use was limited to suggestions concerning grammar, punctuation, sentence structure, style, and readability. All suggestions were carefully reviewed by the authors and incorporated only where they preserved the intended meaning. Grammarly AI was not used to generate research content, formulate research questions, design the methodology, analyse data, interpret findings, or generate references. Its use did not influence the conceptual, methodological, or analytical aspects of the research. The authors verified the revised text and take full responsibility for the accuracy, originality, and integrity of the manuscript, including all findings and interpretations.

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