

Beyond the Lease Boundary: Governing Post-lease Operational Risk Territories in Blasting-based Quarry Operations

Emmanuel Amoako

eamoako20@yahoo.com

University of Mines and Technology

Bright Afum

University of Mines and Technology

Article

Keywords: quarry governance, blasting safety, operational risk, land administration, spatial planning, Ghana, Post-Lease Operational Risk Territories

Posted Date: August 12th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10420030/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Blasting-based quarry operations often generate safety effects that extend beyond legally defined mining concessions, yet the governance of quarrying remains largely organised around fixed lease boundaries. As urban expansion increasingly brings settlements into closer proximity with active quarries, this disconnect between legal jurisdiction and operational influence has become more pronounced. While concession boundaries determine where extraction is permitted, blasting safety is managed through engineering assessments of ground vibration, air overpressure and other operational parameters that frequently extend beyond those legal limits.

This study examines that governance challenge through an exploratory qualitative case study of the Yongwa Limestone Quarry in Ghana. Drawing on statutory analysis, stakeholder interviews, field observations and operational blast-monitoring records, the study investigates how land outside a quarry concession may become functionally constrained by engineering safety while remaining under existing ownership and tenure arrangements. Ghana provides an appropriate setting because mineral rights are vested in the Republic, whereas much of the country's land is held under customary tenure, requiring coordination among mineral regulators, planning authorities, environmental agencies and customary land custodians. Blast-monitoring records from Yongwa indicate that routine measurements were undertaken at receptor locations approximately 230–750 m from active blast sites, illustrating that operational safety management routinely extends beyond the immediate extraction area.

Building on these findings, the paper introduces the concept of Post-Lease Operational Risk Territories (PORTs) to describe land located outside legally surveyed quarry concessions but within the operational influence of blasting activities. It further develops diagnostic criteria for identifying PORTs, proposes a classification framework for prioritising governance responses, introduces Renewable Tenure Restraint (RTR) as a flexible land-use management mechanism, and presents an Adaptive Operational Risk Governance (AORG) framework that links engineering evidence with land administration and spatial planning.

Rather than treating concession boundaries as the sole basis for quarry governance, the study argues that effective governance should also recognise the changing spatial extent of operational influence. By distinguishing legal extraction space from operational risk space, the proposed framework provides a new way of understanding and managing land-use conflicts associated with blasting-dependent quarry operations and offers a governance approach that is potentially transferable to other rapidly urbanising extractive landscapes.

1. Introduction

The accelerating expansion of cities, together with the growing demand for construction materials, is reshaping landscapes worldwide. Urban growth is steadily bringing residential, commercial and industrial land uses into closer proximity, often in places where extractive activities have operated for decades. Forecasts suggest that urban land cover will continue to increase substantially over the

coming decades, with consequences for biodiversity, ecosystem services and land-use competition [1]. At the same time, demand for aggregates such as sand, gravel and crushed stone has reached unprecedented levels as countries continue to invest in housing, transport infrastructure and industrial development [2–4]. One consequence of these parallel trends is that many quarries that were once relatively isolated now find themselves operating within increasingly complex human landscapes.

For blasting-dependent quarries, this changing context presents a governance challenge that extends beyond conventional questions of mineral extraction. Although excavation remains physically confined to the leased area, the effects of blasting are not. Ground vibration, air overpressure, flyrock and noise propagate according to geological conditions, blast design and charge weight rather than cadastral boundaries [5–8]. In practice, quarry operators manage these effects by monitoring conditions at surrounding receptors, many of which lie outside the concession itself. Operational safety, therefore, is determined by engineering evidence rather than by the limits shown on a cadastral plan.

This distinction is well established in blasting engineering. Foundational work by the United States Bureau of Mines demonstrated that structural response depends on measurable parameters such as peak particle velocity and vibration frequency rather than distance alone [5]. Subsequent studies have refined prediction methods and monitoring approaches, while the *ISEE Blasters' Handbook* continues to emphasise blast design, monitoring and operational control as the basis for safe practice [6–8]. These studies provide robust guidance for managing blast effects, but they are primarily concerned with engineering performance. They say comparatively little about how institutions should govern land that lies outside a quarry concession yet falls within the operational influence of blasting.

By contrast, mining governance has developed around legally defined concessions. Concession boundaries determine where extraction rights apply and provide the basis for licensing, environmental regulation, compensation and regulatory oversight. This legal framework offers certainty to governments, operators and investors, but it also assumes that operational influence broadly coincides with legal jurisdiction. That assumption becomes increasingly difficult to sustain where settlements expand towards active quarries. Previous studies have shown that environmental and social risks translate directly into operational and financial risks for mining projects, while the social licence literature has demonstrated that statutory approval alone rarely resolves tensions between operators and neighbouring communities [14–17]. Yet these studies generally treat the concession as the principal unit of governance.

Research from several disciplines has touched different parts of this problem without bringing them together. Engineering research explains how blast impacts are measured and controlled [5–8]. Environmental governance studies draw attention to the sustainability implications of aggregate extraction [2–4]. Mining governance examines conflict, legitimacy and social licence [14–17], whereas land administration research focuses on the interaction between statutory and customary tenure systems and the institutions responsible for managing them [9, 18]. What remains largely unexplored is the governance of land that is legally outside a mining concession but functionally influenced by quarry

operations. That omission becomes increasingly important as urban growth narrows the separation between extraction sites and surrounding communities.

Ghana provides an instructive setting in which to examine this issue. Mineral resources are vested in the Republic under the Minerals and Mining Act, while much of the country's land remains under customary ownership [9, 10]. Responsibility for mineral regulation, spatial planning, environmental protection and land administration is therefore distributed across multiple institutions operating under different statutory mandates [10–13]. These arrangements have generally worked well for regulating extraction within concession boundaries. Less clear, however, is how they should respond when operational safety requirements extend beyond those legally defined limits.

The Yongwa Limestone Quarry offers an opportunity to investigate this mismatch. Routine blast monitoring undertaken between January and March 2023 recorded peak particle velocity, vibration frequency, air overpressure and blast noise at receptor locations approximately 230–750 m from active blasting areas. These monitoring records indicate that operational safety is managed across a wider spatial area than the concession alone would suggest. They also raise a broader governance question: if engineering practice recognises operational influence beyond the lease, should governance continue to rely exclusively on the concession boundary?

This paper argues that the answer is no. The recurring tensions observed around blasting-dependent quarries are not adequately explained by encroachment, regulatory non-compliance or compensation alone. Instead, they reflect a more fundamental disconnect between two spatial systems: one defined by law and the other by engineering practice. Where those systems diverge, land may remain legally available for allocation and development while simultaneously being constrained by operational safety considerations. This study describes that condition as Post-Lease Operational Risk Territories (PORTs) and explores its implications for quarry governance.

Against this background, the study pursues four objectives. It first examines how operational safety extends beyond legally defined quarry concessions. It then investigates how existing institutions govern land affected by operational safety outside mining leases. Building on these findings, the paper develops diagnostic and classification criteria for identifying PORTs before proposing governance mechanisms that integrate engineering safety, land administration and spatial planning. In doing so, the study introduces PORTs as a new governance concept, proposes Renewable Tenure Restraint (RTR) as an adaptive land-use mechanism and presents an Adaptive Operational Risk Governance (AORG) framework for coordinating institutions where operational influence extends beyond legal boundaries.

2. Materials and Methods

2.1 Research Design

An exploratory qualitative case study design was adopted to investigate how operational blasting safety interacts with land governance beyond legally defined quarry concession boundaries. A qualitative case

study was appropriate because the issue under investigation is embedded within its institutional and operational context and cannot be meaningfully separated from the legal, engineering and governance systems in which it occurs [19]. Rather than focusing on a single technical variable, the study examines how operational safety, mineral legislation, customary land tenure, spatial planning and institutional coordination intersect in practice.

The research followed an abductive approach, moving iteratively between empirical observations and existing theory. Concepts emerging from statutory analysis, stakeholder accounts, field observations and operational blast-monitoring records were continually interpreted alongside literature on extractive governance, land administration and adaptive governance. Consequently, the framework of Post-Lease Operational Risk Territories (PORTs) emerged through the analytical process rather than being specified before the investigation commenced.

2.2 Case Selection and Study Area

The Yongwa Limestone Quarry in Ghana's Eastern Region was selected because it provides an information-rich setting in which to examine the relationship between blasting operations and post-lease land governance. The quarry supplies limestone for cement production and occupies a concession of approximately 216.21 acres, although active extraction is confined to only part of that area. Its reliance on routine blasting, proximity to surrounding communities and location within a landscape governed simultaneously by statutory and customary institutions make it particularly suitable for examining the mismatch between operational safety and legal concession boundaries.

The case was selected for analytical rather than statistical reasons. It combines four conditions central to the research question: active blasting operations, customary land ownership beyond the concession, overlapping institutional responsibilities and the availability of detailed operational monitoring records. Such characteristics make it well suited for theory development and analytical generalisation, which are consistent with qualitative case study methodology [19, 20]

2.3 Data Sources

The analysis draws on four complementary sources of evidence: statutory and policy documents, semi-structured interviews, field observations and operational blast-monitoring records.

Statutory documents were reviewed to establish how Ghanaian legislation allocates responsibility for mineral rights, blasting safety, environmental regulation, compensation and spatial planning. Particular attention was given to the extent to which existing legislation addresses land outside quarry concessions that nevertheless falls within operational safety zones. Key legal instruments included the Minerals and Mining Act, 2006 (Act 703), the Minerals and Mining (Compensation and Resettlement) Regulations, 2012 (L.I. 2175), the Minerals and Mining (Explosives) Regulations, 2012 (L.I. 2177), the Environmental Protection Act, 2005 (Act 1124), and the Land Use and Spatial Planning Act, 2016 (Act 925) [10–13].

Interview evidence was drawn from the doctoral research on which this article is based. Participants represented quarry management, regulatory agencies, planning authorities, traditional authorities, landholders and surrounding communities. Semi-structured interviews provided a common set of themes while allowing participants to elaborate on governance experiences specific to their institutional roles.

Field observations complemented the interview material by documenting the physical relationship between quarry operations, surrounding settlements and land-use change. Particular attention was given to quarry infrastructure, operational areas, settlement proximity and visible patterns of land development around the concession.

Operational blast-monitoring records covering January to March 2023 provided the engineering evidence underpinning the governance analysis. These records contained measurements of peak particle velocity (PPV), vibration frequency, air overpressure, audible blast noise and receptor distance. They were examined to determine the spatial extent over which operational safety was routinely managed rather than to develop or validate predictive blasting models.

2.4 Data Analysis

The analysis combined thematic interpretation with institutional and descriptive analysis.

Interview transcripts and documentary material were analysed using reflexive thematic analysis [21, 22]. Initial coding focused on recurring ideas relating to operational safety, institutional responsibility, land allocation, planning and governance. These codes were refined iteratively into broader themes as the analysis progressed.

Legislative documents were examined through institutional coding, with attention directed to the spatial unit regulated, institutional responsibility, treatment of operational safety beyond concession boundaries, compensation provisions and requirements for inter-agency coordination. This facilitated direct comparison between statutory provisions and empirical evidence from the case study.

Blast-monitoring records were analysed descriptively. Rather than assessing engineering compliance, the analysis focused on the locations at which monitoring occurred and the operational significance of those measurements. The objective was to establish whether routine engineering practice extended beyond the extraction area and therefore supported the distinction between legal extraction space and operational risk space.

Evidence from the four datasets was then triangulated. The conceptual framework of Post-Lease Operational Risk Territories (PORTs) was developed only where statutory analysis, operational monitoring, field observations and stakeholder evidence consistently pointed to the same governance condition. This iterative comparison strengthened the credibility of the resulting framework [19].

2.5 Trustworthiness and Quality Assurance

Several measures were adopted to strengthen the trustworthiness of the study. Credibility was enhanced through triangulation of documentary evidence, stakeholder interviews, field observations and operational monitoring records. Transferability was supported by providing detailed contextual information on the Ghanaian governance setting and the Yongwa Limestone Quarry. Dependability was strengthened through a transparent analytical process linking empirical observations to conceptual development, while confirmability was promoted by grounding interpretations in multiple independent sources of evidence rather than any single dataset [23].

The thematic analysis also followed contemporary guidance emphasising transparency in coding, interpretation and theme development [21, 22]. Throughout the analysis, descriptive findings-such as monitoring distances or statutory responsibilities-were distinguished clearly from the conceptual interpretations derived from them.

2.6 Ethics Statement

This study formed part of doctoral research approved by the University of Mines and Technology (UMaT), Ghana. All methods involving human participants were performed in accordance with the relevant institutional guidelines and regulations. Participation in the semi-structured interviews was voluntary, informed consent was obtained from all participants before data collection, and confidentiality and anonymity were maintained throughout the research.

2.7 Scope and Limitations

The study is based on a single in-depth case and therefore aims for analytical transferability rather than statistical generalisation. Blast-monitoring records were interpreted from a governance perspective and were not used to construct engineering prediction models. In addition, the proposed governance framework has been developed within Ghana's legal and institutional context; its application elsewhere will require adaptation to local regulatory and land-tenure systems. These limitations are consistent with the purpose of the research, which is to develop an empirically grounded governance framework rather than estimate the prevalence of PORTs across the wider quarry industry.

3. Results

3.1 Operational Context: Spatial Convergence Between Quarry Operations and Surrounding Land Uses

Field observations, operational records and documentary evidence show that the Yongwa Limestone Quarry functions within a landscape that has become progressively more complex over time. Quarry operations, customary land tenure and expanding settlement now occupy the same geographic space, bringing engineering activities into closer interaction with surrounding communities than was originally the case. Although mineral extraction remains confined to the legally surveyed concession, the practical influence of quarry operations extends beyond those boundaries.

The concession covers approximately 216.21 acres within the Lower Manya Krobo and Yilo Krobo Municipalities. Within this area, production activities include drilling, controlled blasting, excavation, crushing, stockpiling and the transport of limestone for cement manufacture. While these operations are physically concentrated inside the lease, routine blast monitoring is undertaken at receptor locations outside the immediate extraction area, reflecting the wider area over which operational safety must be assessed.

The surrounding environment is characterised by a mixture of customary settlements, agricultural land and transport infrastructure. Land outside the concession remains largely under customary ownership and continues to be allocated through traditional tenure arrangements. At the same time, planning decisions are made by statutory authorities, environmental oversight is exercised by the Environmental Protection Agency and mineral operations are regulated by the Minerals Commission. As a result, land ownership, operational safety, environmental regulation and planning are governed through overlapping institutional systems rather than a single spatial framework.

Three patterns became evident during fieldwork.

The first concerns quarry operations themselves. Extraction progresses through successive working faces, meaning that blasting locations change as production advances. Operational influence therefore shifts over time rather than remaining fixed.

A second pattern relates to surrounding development. Because land beyond the concession remains legally available for allocation, residential and agricultural activities continue to expand towards the quarry. The separation between operational areas and neighbouring land uses has consequently become progressively narrower.

Finally, operational safety management is itself adaptive. Blast design, monitoring locations and engineering controls are adjusted in response to changing operational conditions. The area requiring active safety management therefore evolves alongside quarry development.

Taken together, these observations indicate that the operational landscape is dynamic, whereas the legal framework governing extraction remains largely static. That distinction provides the context for the analyses that follow.

3.2 Operational Blast Monitoring Demonstrates That Safety Management Extends Beyond the Concession

The operational monitoring records provide direct evidence that blast management extends beyond the active extraction area. Quarterly reports covering January, February and March 2023 document routine measurements of peak particle velocity (PPV), vibration frequency, air overpressure and audible blast noise at receptor locations surrounding the quarry.

Across the monitoring period, receptors were located approximately **230–750 m** from active blasting locations. These measurements were collected after production blasts to evaluate operational performance and verify compliance with engineering requirements. The placement of monitoring stations reflects established blasting practice, in which safety is assessed at sensitive receptors rather than only at the blast source.

Table 1 summarises the operational monitoring programme.

Table 1
Summary of Operational Blast Monitoring

Monitoring Period	Engineering Parameters	Approximate Monitoring Distance	Governance Significance
January 2023	PPV, vibration frequency, air overpressure, audible blast noise	230–750 m	Safety monitoring extended beyond the extraction footprint
February 2023	PPV, vibration frequency, air overpressure, audible blast noise	230–750 m	Dynamic monitoring of operational influence
March 2023	PPV, vibration frequency, air overpressure, audible blast noise	230–750 m	Continued engineering assessment outside the active blast area

Source: Quarterly blast monitoring reports.

Although measured values differed between blasting events, the monitoring programme consistently extended well beyond the excavation face. This reflects the nature of blasting itself. Operational influence is shaped by interacting factors such as charge weight, geology, blast geometry and receptor distance rather than by a fixed exclusion distance [5–8].

The implications extend beyond engineering practice. By routinely monitoring receptors outside the concession, quarry operators implicitly acknowledge that operational responsibility reaches further than the legally acquired extraction area. In effect, engineering practice recognises a broader spatial domain than that defined by the cadastral boundary.

To clarify this relationship, Fig. 1 presents a conceptual representation of the operational blast environment at the Yongwa Limestone Quarry. The figure combines the quarry operational area, the concession boundary and the principal blast influence envelopes derived from routine monitoring. Unlike legal boundaries, these operational envelopes change with engineering conditions and therefore represent functional zones of influence rather than fixed property limits.

Figure 1 illustrates the central spatial mismatch identified in this study. Blasting originates within the concession, yet the operational safety envelope extends into surrounding land that remains under existing ownership. The extent of that influence depends on engineering variables-including blast design,

geological conditions, charge weight and receptor location-rather than cadastral limits. Consequently, land outside the lease may remain legally available for development while simultaneously becoming subject to operational safety considerations. This observation provides the empirical basis for the governance discussion developed in the following sections.

3.3 Statutory Governance Remains Concession-Centred

The review of Ghana's statutory framework shows that responsibilities for mineral extraction, blasting safety, environmental management and land-use planning are clearly defined. What is less evident is a mechanism for coordinating governance where operational influence extends beyond the concession itself.

The Minerals and Mining Act establishes the legal basis for mineral rights and quarry operations, while the Explosives Regulations and Compensation and Resettlement Regulations govern blasting practices and compensation mechanisms. Environmental oversight is exercised under the Environmental Protection Act, and spatial planning falls within the Land Use and Spatial Planning Act [10–13].

Despite these complementary mandates, three common characteristics emerged from the statutory review.

First, responsibilities are allocated according to institutional mandate rather than operational influence.

Second, statutory authority is tied primarily to legal or administrative boundaries.

Third, none of the legislation reviewed explicitly addresses land outside quarry concessions that nevertheless falls within the operational safety envelope created by blasting.

Table 2
Institutional Responsibilities Identified Through Statutory Analysis

Institution	Primary Statutory Responsibility	Spatial Basis
Minerals Commission	Quarry licensing and mineral regulation	Quarry concession
Environmental Protection Agency	Environmental compliance	Project approval and environmental permit
Lands Commission	Land administration	Registered land and public land
Metropolitan / Municipal Assembly	Spatial planning and development control	Planning jurisdiction
Traditional Authorities	Allocation of customary land	Customary land ownership

The statutory framework therefore appears comprehensive when viewed institution by institution. However, when considered alongside the engineering evidence presented earlier, an important gap

becomes apparent: responsibility for coordinating governance across the operational safety area is not explicitly assigned to any single institution.

3.4 Stakeholder Evidence Reveals Institutional Fragmentation

Interview data reinforced the patterns identified through statutory analysis and field observations. Participants rarely questioned the statutory mandates of individual institutions. Instead, they consistently described uncertainty about how those institutions interact once operational safety extends beyond the concession. Four themes recurred across stakeholder groups.

Theme 1. Development continues outside the quarry lease

Participants reported that land beyond the concession remains available for allocation under customary tenure despite increasing interaction with quarry operations therefore development continues on land outside the quarry lease because customary allocation processes remain active.

Theme 2. Operational safety changes over time

Operational safety changes as quarry faces advance, requiring continuous engineering assessment rather than fixed separation distances.

Theme 3. Responsibility becomes uncertain beyond the concession

Institutional responsibility becomes less certain once operational influence extends beyond the legally acquired concession. Stakeholders consistently described uncertainty regarding which institution should coordinate governance where operational safety influences land outside the mining lease.

Theme 4. Existing governance mechanisms are largely reactive

Participants observed that existing governance arrangements tend to respond after disputes emerge rather than identifying potential conflicts before development occurs.

Although expressed from different institutional perspectives, these themes were remarkably consistent across quarry personnel, regulators, traditional authorities and community representatives. The convergence suggests that the challenge is structural rather than the result of isolated administrative shortcomings.

3.5 Integrated Evidence and Emergence of Post-Lease Operational Risk Territories (PORTs)

The integration of operational monitoring, statutory analysis, field observation and stakeholder evidence demonstrates a consistent governance pattern.

Operational monitoring confirms that engineering safety extends beyond the physical extraction footprint. Statutory analysis shows that governance remains principally organised around concession boundaries. Stakeholder evidence indicates that customary land allocation, planning approval and operational safety continue to evolve independently. Field observations demonstrate that settlement expansion progressively reduces separation between quarry activities and surrounding land uses.

Taken individually, these findings describe different aspects of quarry operations.

Taken together, they reveal a previously unrecognised governance condition in which land simultaneously exhibits four characteristics:

- 1. It lies outside the legally surveyed quarry concession.
- 2. It falls within the operational influence of blasting activities.
- 3. Ownership remains unchanged under existing land tenure arrangements.
- 4. Functional land-use constraints emerge because of engineering safety requirements.

These four characteristics collectively define what this study conceptualises as Post-Lease Operational Risk Territories (PORTs).

Table 3
Diagnostic Criteria for Identifying PORTs

Criterion	Empirical Evidence	Supporting Source
Outside legal concession	Statutory boundary	Documentary analysis
Within operational safety envelope	Blast monitoring	
Ownership unchanged	Customary and statutory land administration	Documentary review; interviews
Functional operational constraints	Stakeholder evidence and field observations	Interviews; observations

The convergence of four independent evidence streams provides the empirical basis for the conceptual framework developed in the Discussion. Rather than interpreting the observed governance issues solely as encroachment, regulatory failure or compensation disputes, the findings suggest that they arise because engineering systems govern operational influence whereas legal institutions govern cadastral space. The divergence between these spatial logics creates a governance domain that existing institutional arrangements do not explicitly recognise.

4. Discussion

4.1 Reframing Quarry Governance Beyond the Concession Boundary

The findings suggest that the governance challenges associated with blasting-based quarry operations cannot be understood fully through the traditional lens of concession-centred regulation. Although Ghana's legal framework provides clear institutional responsibilities for mineral licensing, environmental oversight, land-use planning and blasting regulation, those responsibilities remain tied primarily to legally surveyed boundaries. Operational safety, however, follows a different logic. It is shaped by engineering conditions that change as quarry operations progress and therefore extends across space in ways that cadastral boundaries cannot fully capture.

This distinction is more than a technical observation. Concession boundaries remain indispensable for defining mineral rights, investment security and regulatory authority. The evidence from Yongwa nevertheless indicates that they should not be treated as synonymous with the area requiring operational governance. Routine blast monitoring already recognises a wider operational space, even though existing governance arrangements continue to rely largely on legal boundaries. The mismatch becomes increasingly important where settlements expand towards active quarries, reducing the separation that once existed between extraction and surrounding land uses.

Similar tensions have been reported elsewhere. Studies of industrial land-use compatibility have shown that legal project boundaries often fail to represent the wider area influenced by industrial activities [24–27]. The present study extends that discussion by demonstrating that blasting operations generate a dynamic governance space that evolves alongside quarry development rather than remaining fixed throughout the life of the concession.

Seen in this way, quarry governance involves two overlapping but distinct spatial systems. One is legal and defines where extraction is authorised. The other is operational and reflects where engineering safety must be actively managed. Much of the friction observed around quarry development appears to arise where these two systems no longer coincide.

This interpretation also helps explain why disputes can emerge even when institutions are performing their statutory responsibilities appropriately. Quarry operators may comply with approved blast designs, planning authorities may approve development lawfully, traditional authorities may allocate land according to customary practice and regulators may fulfil their statutory mandates. Yet conflict persists because each institution is acting within a different spatial frame of reference. The issue is therefore less one of institutional failure than of institutional alignment.

4.2 Institutional Misfit in Blasting-Based Quarry Governance

The divergence identified in this study closely reflects what institutional scholars describe as problems of institutional fit. Young argued that governance arrangements are most effective when they correspond closely to the characteristics of the systems they are intended to regulate [28]. Later work on adaptive governance and common-pool resources has reinforced this argument by showing that

institutional effectiveness depends not only on regulatory capacity but also on how well governance structures reflect the dynamics of the systems under management [29–31].

The Yongwa case illustrates a particular form of spatial misalignment. Operational safety is inherently dynamic. Monitoring locations shift, blast designs change and extraction progresses through successive quarry faces. By contrast, the principal legal instruments governing quarrying are organised around relatively fixed jurisdictions. Planning authorities work within administrative boundaries, customary institutions manage land through traditional tenure systems and mineral regulators oversee legally defined concessions. Each arrangement is internally coherent, yet each describes space differently.

The monitoring records provide a practical illustration of this divergence. Receptors located between approximately 230 and 750 m from active blasting areas were routinely monitored as part of normal engineering practice. These locations were operationally significant because they informed decisions about blast performance and safety. However, the statutory review identified no equivalent governance mechanism that explicitly recognises these areas once they fall outside the concession boundary.

It is important not to interpret this as evidence of regulatory inadequacy. Rather, it reflects the historical evolution of extractive governance. Mining legislation developed primarily to regulate mineral rights, investment certainty and environmental obligations within concession boundaries. Engineering practice evolved to address operational safety. Urban expansion has brought these systems into closer interaction than they were originally designed to accommodate. The governance challenge therefore stems from changing spatial realities rather than from shortcomings in any single institution.

4.3 Post-Lease Operational Risk Territories (PORTs): A New Governance Domain

The central conceptual contribution of this study is the recognition of Post-Lease Operational Risk Territories (PORTs) as a distinct governance domain. The empirical evidence indicates that land beyond a quarry concession may remain under existing ownership while simultaneously falling within the operational influence of blasting. Existing concepts address elements of this condition but none captures it in its entirety.

PORTs differ from planning buffer zones because they are not predetermined planning instruments. Conventional buffers are generally established through planning policy and remain relatively stable until formally revised [26, 27]. The spatial extent of a PORT, by contrast, emerges from operational conditions. It changes as quarry development, blasting patterns and surrounding land use evolve.

They also differ from compulsory acquisition. Acquisition transfers legal rights in land and is typically accompanied by compensation [32, 33]. Within a PORT, ownership remains unchanged. The governance issue is not the transfer of title but the emergence of operational constraints that influence how land can realistically be used.

Nor should PORTs simply be equated with encroachment. Development beyond a quarry concession may occur entirely lawfully under customary or statutory tenure systems. Describing every resulting conflict as encroachment overlooks the institutional conditions that allow legitimate land allocation to coexist with operational safety requirements. The PORT concept shifts attention from questions of legality to questions of governance.

Seen in this way, PORTs are best understood as an operational governance domain rather than a new tenure category. They identify situations in which operational influence and legal jurisdiction diverge, creating coordination challenges that existing institutional arrangements do not explicitly address.

4.4 Comparison with International Governance Approaches

Although this study is grounded in Ghana, the governance issues identified are consistent with international trends. In Australia, strategic land-use planning increasingly seeks to protect extractive resources while managing urban encroachment through compatible land-use policies and designated resource protection areas [26]. Canadian provinces have adopted aggregate resource planning approaches that integrate long-term extraction with municipal planning, although these remain largely concession and zoning based [34]. In Brazil, quarry expansion near metropolitan regions has similarly highlighted tensions between mineral development, environmental licensing and urban growth [35]. South Africa has also documented challenges associated with balancing mining rights, environmental governance and community development within rapidly changing landscapes [36].

Despite differences in legal systems, these jurisdictions exhibit a common characteristic: governance mechanisms continue to rely predominantly on legal boundaries, zoning instruments or environmental approvals. None explicitly conceptualises land outside mining concessions but within operational safety envelopes as a distinct governance domain. The PORT framework therefore contributes an additional analytical dimension by integrating engineering evidence directly into land governance.

Table 4
Comparison of Existing Governance Approaches and the PORT Framework

Governance approach	Primary governance unit	Dynamic operational risk recognised?	Explicit governance beyond concession?
Concession-based mineral governance	Mining lease	Limited	No
Planning buffer zones	Administrative setback	Limited	Partial
Environmental impact assessment	Project footprint	Indirect	Limited
Social licence to operate	Community relationship	Indirect	No
PORT framework (this study)	Operational governance domain	Yes	Yes

The comparison highlights that PORTs do not replace existing governance mechanisms but complement them by recognising an additional spatial dimension that becomes increasingly relevant where blasting-based quarry operations interact with expanding settlements.

4.5 From PORTs to Adaptive Operational Risk Governance

Recognising PORTs is only the first step. The practical challenge lies in determining how such areas should be governed before conflicts become entrenched.

The findings point towards a more adaptive model of governance in which engineering monitoring becomes an input to planning and land administration rather than remaining solely a compliance activity. This idea underpins the Adaptive Operational Risk Governance (AORG) framework proposed in this study. Rather than relying exclusively on fixed legal boundaries, AORG encourages institutions to respond to changing operational conditions through iterative assessment, coordination and stakeholder engagement.

Within this framework, Renewable Tenure Restraint (RTR) offers a practical governance mechanism. Unlike compulsory acquisition, RTR does not require ownership to change hands. Instead, it provides a means of negotiating temporary or renewable restrictions on particular forms of land development where operational evidence indicates that safety considerations warrant them. Because operational conditions evolve, those restrictions can also be reviewed periodically rather than remaining permanent.

Taken together, PORTs, RTR and AORG represent a shift in emphasis. Governance moves from regulating only where extraction occurs towards managing where operational influence exists. This broader perspective aligns closely with contemporary thinking on adaptive governance, which emphasises learning, flexibility and cross-sector coordination in response to changing environmental conditions [29–31].

4.6 Theoretical Contributions

Beyond its practical implications, this study contributes to several strands of scholarship concerned with extractive governance, land administration and adaptive resource management.

First, it challenges the implicit assumption that legally defined concession boundaries adequately represent the full governance space associated with blasting-based quarry operations. Existing governance models have traditionally treated the concession as the primary unit for regulation, planning and oversight. The evidence presented here suggests that this assumption becomes increasingly problematic where operational safety extends beyond the legal lease.

Second, the study introduces Post-Lease Operational Risk Territories (PORTs) as a new analytical concept for understanding this spatial disconnect. Rather than describing a new legal category of land, PORTs identify a governance condition in which operational influence and legal jurisdiction no longer coincide. This distinction provides researchers with a framework for analysing similar situations across

mining, quarrying and other industries where operational effects extend beyond formal administrative boundaries.

Third, the proposed Adaptive Operational Risk Governance (AORG) framework expands adaptive governance theory by integrating engineering evidence directly into land-use governance. Adaptive governance has generally emphasised institutional flexibility, learning and collaboration in response to changing environmental conditions [29–31]. This study extends those ideas by demonstrating how operational monitoring data can become an active component of governance rather than remaining solely a technical compliance tool.

Finally, the introduction of Renewable Tenure Restraint (RTR) contributes to discussions on land governance by proposing an intermediate institutional mechanism between unrestricted land development and compulsory acquisition. The concept broadens the range of governance responses available where operational safety creates temporary or evolving land-use constraints without requiring permanent changes in ownership.

4.7 Policy Implications

The findings point towards several practical implications for regulators, planning authorities, customary land custodians and quarry operators.

The first concerns institutional coordination. Decisions relating to mineral regulation, land allocation, environmental management and spatial planning are often made independently because each institution operates within its own statutory mandate. Where operational safety extends beyond concession boundaries, greater coordination becomes essential. Incorporating operational monitoring information into planning and land administration processes would allow potential land-use conflicts to be identified before development occurs rather than after disputes emerge.

Second, planning systems could benefit from recognising operational influence as a dynamic consideration rather than relying exclusively on static cadastral boundaries. This does not imply replacing existing planning instruments or concession systems. Instead, it encourages planning authorities to consider engineering evidence alongside conventional land-use information when evaluating development proposals near active quarry operations.

Third, quarry operators may derive value from viewing blast monitoring as more than a regulatory obligation. Monitoring records already provide detailed information on how operational influence changes over time. Used strategically, these data can support community engagement, improve transparency and inform collaborative planning with regulators and surrounding landowners.

For customary land authorities, greater awareness of operational safety zones may also assist future land allocation decisions. Providing access to reliable operational information before land is allocated could reduce the likelihood of incompatible development while preserving customary ownership and decision-making authority.

Collectively, these measures shift governance from a reactive model-where institutions respond after conflict has arisen-to a more anticipatory approach grounded in operational evidence and institutional collaboration.

4.8 International Relevance

Although developed from a Ghanaian case study, the governance issues identified here are not unique to Ghana. Rapid urbanisation, increasing demand for construction materials and expanding extractive activities are reshaping landscapes in many parts of the world. Similar interactions between quarry operations and surrounding settlements have been reported across Africa, Asia, Australia, Europe and the Americas [24–36].

The specific legal arrangements governing mineral rights, land tenure and planning differ across jurisdictions, and the governance mechanisms proposed here would require adaptation to local institutional settings. Nevertheless, the underlying distinction between legal extraction space and operational risk space is not confined to any single country or legal tradition. Wherever operational influence extends beyond formal project boundaries, comparable governance challenges are likely to emerge.

For that reason, PORTs should be viewed less as a Ghana-specific solution than as an analytical framework capable of informing comparative research across different extractive sectors. Future studies may explore how the concept applies to surface mining, infrastructure blasting, tunnelling, energy developments or other industrial activities in which operational effects extend beyond formally authorised work areas.

The broader contribution of this study therefore lies not only in proposing a new governance framework but also in encouraging researchers and policymakers to reconsider how operational influence is incorporated into land governance more generally.

5. Conclusions

This study set out to examine how blasting-based quarry operations generate governance challenges that extend beyond legally defined mining concessions. Using the Yongwa Limestone Quarry in Ghana as an exploratory case, it demonstrates that operational safety and legal jurisdiction do not always occupy the same spatial domain. While mineral extraction remains confined to the concession, routine blast monitoring, field observations, stakeholder evidence and statutory analysis show that operational influence frequently extends into surrounding land that remains under existing ownership and administrative control.

These findings suggest that concession boundaries alone are no longer sufficient as the sole organising principle for quarry governance in rapidly changing landscapes. They continue to provide an essential legal foundation for mineral rights and regulatory oversight, but they do not fully capture the wider operational space within which blasting safety is actively managed. As settlements expand towards

active quarries, this divergence becomes increasingly important for land-use planning, environmental management and community relations.

To address this governance gap, the study introduces Post-Lease Operational Risk Territories (PORTs) as a conceptual framework for identifying areas where operational influence extends beyond legal extraction boundaries. Building on this concept, it proposes Renewable Tenure Restraint (RTR) as a flexible mechanism for managing evolving land-use constraints while maintaining existing ownership arrangements, and develops the Adaptive Operational Risk Governance (AORG) framework to strengthen coordination between engineering practice, land administration and spatial planning.

Although developed from a single case study in Ghana, the conceptual issues identified here are relevant to many jurisdictions experiencing increasing interaction between extractive activities and expanding urban development. The framework is intended as an analytical contribution rather than a jurisdiction-specific regulatory model and should therefore be adapted to local legal, institutional and tenure contexts before implementation.

Several limitations should also be recognised. The analysis draws on one quarry operation and therefore aims for analytical rather than statistical generalisation. The proposed governance framework has not yet been tested across multiple jurisdictions or different extractive industries. Future research should evaluate the applicability of PORTs in other mining contexts, compare governance responses under different legal systems, and examine how operational monitoring data can be more effectively integrated into spatial planning and land administration.

More broadly, this study argues that governance should evolve alongside the operational realities of extractive industries. Recognising the distinction between legal extraction space and operational risk space provides a more complete basis for managing land-use conflicts where engineering influence extends beyond formal project boundaries. In doing so, the paper offers a framework that contributes to ongoing debates on adaptive governance, sustainable land management and the future regulation of blasting-dependent quarry operations.

Declarations

Ethics Approval and Consent to Participate

This article is derived from doctoral research conducted at the University of Mines and Technology (UMaT), Ghana. Ethical approval for the broader doctoral research was obtained in accordance with the University's research governance requirements. All methods involving human participants were performed in accordance with the relevant institutional guidelines and regulations and in accordance with the ethical principles of the Declaration of Helsinki. Participation in interviews was voluntary, written informed consent was obtained from all participants before data collection, and confidentiality and anonymity were maintained throughout the study.

Consent for Publication

Not applicable.

Competing Interests

The authors declare that they have no competing interests.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Author Contribution

E.A. wrote and prepared the manuscript. B.O. supervised the work.

Acknowledgement

The authors gratefully acknowledge the management and technical staff of the Yongwa Limestone Quarry, the Minerals Commission, the Environmental Protection Agency, the Lands Commission, traditional authorities, community representatives and all participants who contributed their knowledge and time during the fieldwork. The authors also acknowledge the University of Mines and Technology for academic support provided during the doctoral research from which this article was developed.

Data Availability

The qualitative interview data generated during the study are not publicly available because they contain commercially sensitive operational information and information that could compromise participant confidentiality. Operational blast monitoring records analysed in this article form part of the doctoral research dataset and are reported in aggregated form within the manuscript. Additional anonymised materials may be made available by the corresponding author upon reasonable request, subject to institutional approval.

References

1. Seto, K. C., Güneralp, B. & Hutya, L. R. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad. Sci. U.S.A.* 109, 16083–16088 (2012).
2. Peduzzi, P. Sand, rarer than one thinks. *Environ. Dev.* **11**, 208–218 (2014).

3. Torres, A., Brandt, J., Lear, K. & Liu, J. A looming tragedy of the sand commons. *Science* **357**, 970–971 (2017).
4. United Nations Environment Programme. *Sand and Sustainability: 10 Strategic Recommendations to Avert a Crisis* (United Nations Environment Programme, 2022).
5. Siskind, D. E., Stagg, M. S., Kopp, J. W. & Dowding, C. H. *Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting* Vol. 8507 (U.S. Bureau of Mines, 1980). Report of Investigations.
6. Ozer, U. Environmental impacts of ground vibration induced by blasting at different rock units on the Kadıköy–Kartal metro tunnel. *Eng. Geol.* **100**, 82–90 (2008).
7. International Society of Explosives Engineers. *ISEE Blasters' Handbook* 18th edn (International Society of Explosives Engineers, 2010).
8. Dowding, C. H. *Construction Vibrations* (Prentice Hall, 1996).
9. Kasanga, K. & Kotey, N. A. *Land Management in Ghana: Building on Tradition and Modernity* (International Institute for Environment and Development, 2001).
10. Republic of Ghana. *Minerals and Mining Act, 2006 (Act 703)* (Ghana Publishing Company, 2006).
11. Minerals Commission of Ghana. *Overview of the Minerals and Mining Act, 2006 (Act 703)*. (Minerals Commission of Ghana, n.d.).
12. Republic of Ghana. *Land Use and Spatial Planning Act, 2016 (Act 925)* (Ghana Publishing Company, 2016).
13. Republic of Ghana. *Environmental Protection Act, 2025 (Act 1124)* (Ghana Publishing Company, 2025).
14. Franks, D. M. et al. Conflict translates environmental and social risk into business costs. *Proc. Natl. Acad. Sci. U.S.A.* **111**, 7576–7581 (2014).
15. Owen, J. R. & Kemp, D. Social licence and mining: A critical perspective. *Resour. Policy.* **38**, 29–35 (2013).
16. Prno, J. An analysis of factors leading to the establishment of a social licence to operate in the mining industry. *Resour. Policy.* **38**, 577–590 (2013).
17. Prno, J. & Slocombe, D. S. Exploring the origins of social license to operate in the mining sector: Perspectives from governance and sustainability theories. *Resour. Policy.* **37**, 346–357 (2012).
18. Williamson, I., Enemark, S., Wallace, J. & Rajabifard, A. *Land Administration for Sustainable Development* (ESRI, 2010).
19. Yin, R. K. *Case Study Research and Applications: Design and Methods* 6th edn (SAGE, 2018).
20. Creswell, J. W. & Poth, C. N. *Qualitative Inquiry and Research Design: Choosing Among Five Approaches* 4th edn (SAGE, 2018).
21. Braun, V. & Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **3**, 77–101 (2006).
22. Braun, V. & Clarke, V. Toward good practice in thematic analysis: Avoiding common problems and be(com)ing a knowing researcher. *Int. J. Transgend Health.* **24**, 1–6 (2023).

23. Lincoln, Y. S. & Guba, E. G. *Naturalistic Inquiry* (SAGE, 1985).
24. Healey, P. *Collaborative Planning: Shaping Places in Fragmented Societies* 2nd edn (Palgrave Macmillan, 2006).
25. Geneletti, D. & Zardo, L. Ecosystem-based adaptation in cities: An analysis of European urban climate adaptation plans. *Land. Use Policy*. **50**, 38–47 (2016).
26. Department of Transport and Planning, State Government of Victoria. *Planning Practice Note 89: Extractive Industry and Resources* (State Government of Victoria, 2024).
27. Bacci, D. L. C., Diniz, T. M. R. G. & Bacci, M. C. Mining in urban areas: Methodological proposal for the identification and mediation of socio-environmental conflicts. *REM. Revista Escola de Minas*. **66**, 369–374 (2013).
28. Young, O. R. *The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale* (MIT Press, 2002).
29. Folke, C., Hahn, T., Olsson, P. & Norberg, J. Adaptive governance of social-ecological systems. *Annu. Rev. Environ. Resour.* **30**, 441–473 (2005).
30. Ostrom, E. *Understanding Institutional Diversity* (Princeton University Press, 2005).
31. Dietz, T., Ostrom, E. & Stern, P. C. The struggle to govern the commons. *Science* **302**, 1907–1912 (2003).
32. International Finance Corporation. *Performance Standard 5: Land Acquisition and Involuntary Resettlement* (World Bank Group, 2012).
33. World Bank. *Environmental and Social Framework* (World Bank, 2017).
34. Ontario Ministry of Natural Resources and Forestry. *Aggregate Resources of Ontario Standards: A Compilation of the Four Standards Adopted by Ontario Regulation 244/97 under the Aggregate Resources Act* (Government of Ontario, 2020).
35. Coelho, Y. C. M., Medeiros, P. S., Santos, J. A. & Lucas, F. C. A. Perception of environmental impacts of aggregate mining: A case study from the municipality of Ourém, Pará, Brazil. *Resour. Policy*. **78**, 102825 (2022).
36. Cronjé, F. & Chenga, C. Sustainable social development in the South African mining sector. *Dev. South. Afr.* **26**, 413–427 (2009).
37. Republic of Ghana. *Minerals and Mining (Compensation and Resettlement) Regulations, 2012 (L.I. 2175)* (Ghana Publishing Company, 2012).
38. Republic of Ghana. *Minerals and Mining (Explosives) Regulations, 2012 (L.I. 2177)* (Ghana Publishing Company, 2012).
39. Republic of Ghana. *Land Act, 2020 (Act 1036)* (Ghana Publishing Company, 2020).

Figures

DISTANCE FROM QUARRY BLAST FURNACE

$$D3' = 50 + 50 + 20 + 30 + 200 = 350\text{m}$$

$$D2' = 50 + 20 + 30 + 400 = 500\text{m}$$

$$D1' = 20 + 30 + 600 = 650\text{m}$$

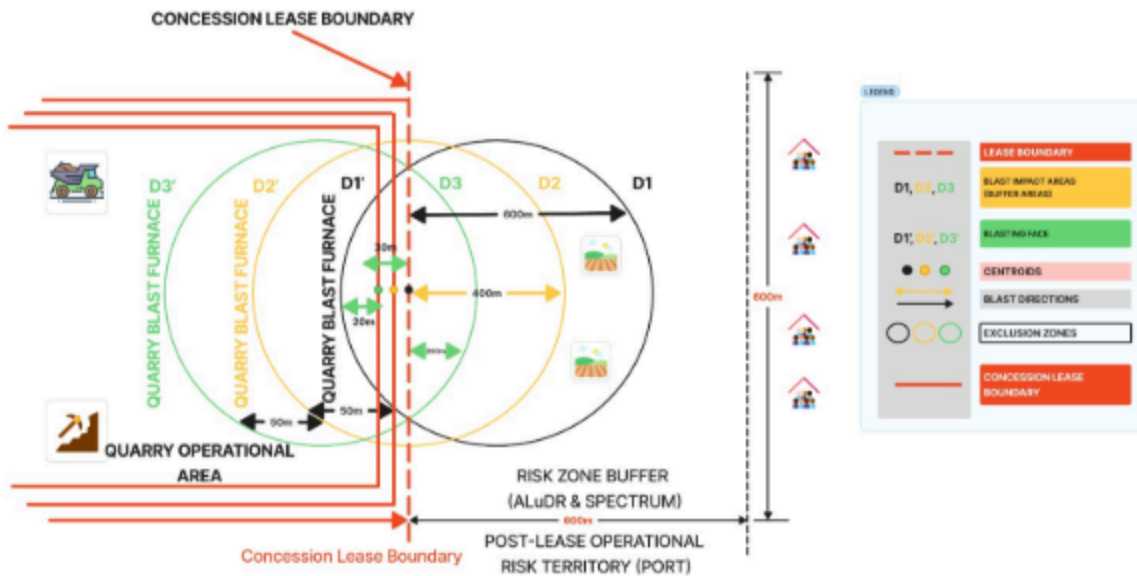


Figure 1

Conceptual representation of the spatial relationship between the quarry operational area, concession lease boundary, blast impact envelopes (D1–D3) and the proposed Post-Lease Operational Risk Territory (PORT). The schematic illustrates how operational safety influence extends beyond the legally surveyed concession through measured blast monitoring distances, creating operationally constrained land while ownership remains unchanged.