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Environmental Risks in Mining Projects on Water Resource Contamination and Infrastructure Damage

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Abstract

This study examined the environmental risks associated with mining activities in Chingola, Zambia, with a focus on water contamination, infrastructure degradation, regulatory effectiveness, and community participation. A mixed-method cross-sectional design was employed, combining quantitative data from 385 residents and qualitative insights from key informant interviews and focus group discussions. Structured questionnaires and interview guides were used to collect data, with quantitative results analyzed using SPSS and qualitative findings analyzed through thematic analysis. Findings revealed that 66.5% (n=256) of respondents observed changes in water quality - including unusual taste, smell, and color - while 52.2% (n=201) reported stomach-related illnesses, 43.1% (n=166) reported skin infections, and 32.2% (n=124) experienced respiratory symptoms. Chi-square tests confirmed statistically significant associations between proximity to mining sites and water-related health effects (p = 0.012). On infrastructure, 71.7% (n=276) of participants reported road cracks and potholes, while 49.9% (n=192) noted bridge deterioration. Significant associations were found between residence proximity and infrastructure degradation (p = 0.021). Despite existing environmental laws, only 33.0% (n=127) of respondents believed they were effectively enforced, and fewer than 30% had seen corporate ecological efforts such as water treatment or waste management. Only 16.1% (n=62) reported active participation in environmental governance, though 80.3% (n=309) supported more vigorous enforcement, 70.4% (n=271) favored awareness campaigns, and 63.4% (n=244) advocated for improved corporate accountability. Qualitative data reinforced these findings, highlighting a weak regulatory presence, poor corporate compliance, and minimal community involvement in monitoring. The study concludes that mining activities in Chingola pose significant environmental and public health risks, exacerbated by weak enforcement, low civic engagement, and minimal corporate responsibility. Recommendations include strengthening institutional capacity, improving safe water infrastructure, rehabilitating damaged roads, and institutionalizing community monitoring and education mechanisms..

Keywords: Mining, environmental risk, water contamination, infrastructure degradation, regulatory enforcement, Chingola, Zambia

1. Introduction

This chapter introduces the study and provides the background, the problem statement, aims, the research questions, importance, scope, and limitations of the study.

Mining has an extensive history of vital but serious environmental dangers around the Globe, primarily through pollution and infrastructure damage. A report by the World Resources Institute (2023) indicates that roughly sixteen per cent (16%) of the World's land-based critical mineral mines are located in areas experiencing high or extremely high water stress. These mining operations exacerbate both water scarcity and limited fresh water supplies in these areas. Contamination of water bodies with heavy metals, such as lead, mercury, and arsenic, compromises aquatic habitats as well as the health of humans (Santana et al., 2020).

Furthermore, infrastructure damage associated with mining remains a broad concern globally. The catastrophic damaging effects of collapsed tailings dams which contain mining waste is a major environmental disaster. The Brumadinho dam disaster in Brazil is an example, which involved the release of 12 million cubic meters of iron waste across a vast area resulting in extensive environmental damage and a loss of life (U.S. Geological Survey, 2023). These occurrences underscore the need for robust environmental regulation and effective monitoring systems to prevent similar catastrophes from occurring worldwide.

While many studies have been completed on the environmental effects of mining, one of the most deficient frameworks of the mining and mining impact landscape is understanding the long-term human impacts of water contamination on communities and infrastructure. The diversity of water interactions in mining, highlights that further investigation into water foot printing, is needed to specifically evaluate, mitigate and manage water use and impacts through improved assessments (Mikosch et al., 2021). This gap in the literature indicates a need for localized studies to inform context-specific data and synthesis of findings. According to Toteu et al. (2020), mining activities are one of the primary drivers of economic growth in Sub-Saharan Africa, but the economic benefits come with immense environmental and health risks due to inadequate environmental governance and no overall ecological assessment. Studies demonstrate that mining activities in Sub-Saharan Africa also operate poorly with no environmental safeguard processes in place, resulting in widespread contamination of water resources and poor maintenance of infrastructure (Félix, 2020).

Water contamination that results from mining activities is one of the most prevalent areas of concern in semi-arid parts of Africa where adverse meteorological conditions have been shown to contribute to the mobilization of heavy metals such as cadmium, lead, and uranium which eventually carry over into vital water sources (Santana et al. 2020). In a study that examined health risks brought on by mining conducted by Banks, Ingoe, and Genc, (2020), rapid transfer of contaminated surface water into boreholes were commonplace and seem to be attributed to the poor construction and management of water infrastructure in areas where mining occurs.

The existing body of literature has focused primarily on the environmental risks associated with big mining operations and have neglected the impacts of small-scale and artisanal miners who also contribute to considerable and widespread environmental degradation. Furthermore, only limited opportunities for social risks to be factored in environmental appraisal (Vyzhva et al., 2023). This research aims to address these gaps in research and analyses in the context of social and ecological risks deriving from mining in Chingola, Zambia.

Chingola, Zambia, found in the Copperbelt Province of Zambia, has a considerable history of mining activities associated with large-scale copper and cobalt mining activities. The activities associated with mining have considerable environmental implications related to water resource contamination and infrastructure damage (Muma et al., 2020). For example, the Kafue River and Mushishima stream in mining areas in Chingola are reported to have dissolved copper and cobalt concentrations that pose potential hazards for human health and aquatic systems (Good Governance Africa, 2023).

Recent studies have continued to promote awareness of ongoing environmental and health issues resulting from mining. Notably, emissions of sulfur dioxide (SO_2) generated by mining activity in regions such as Mufulira and Chingola (Zambia) exceed statutory limits in Zambia and have debilitating effects on air quality and are linked to respiratory illnesses in communities surrounding the site, or in areas where cloud cover is possible. Although newer processes to manage emissions of SO_2 have included better sulfur capture systems, areas where mining occurs are still reporting average SO_2 values that exceed legislative limits. This creates the need for better environmental monitoring and compliance action in mining areas of Zambia in order to improve air quality and public health standards (Muma et al., 2020).

Recent studies have increasingly pointed to the importance of localized assessments to manage the environmental issues within areas such as Chingola, Zambia, where communities and other sub-national jurisdictions are often vulnerable to environmental impacts beyond their thresholds. For example, a study indicated that acid mine drainage remains a substantial risk not only due to water contamination, but also to structural damage in affected communities as well (Nachalwe & Umar, 2021). These localized impacts underscore the need for studies at the site level to provide valuable recommendations and to develop mitigation measures specifically suited for the unique conditions of mining communities.

There is a considerable gap in literature assessing the combined impact of water pollution and infrastructure damage arising from mining activities in Chingola. There is limited literature on existing empirical data assessing the effectiveness of current environmental regulation and remediation measures at mitigating the combined impacts of mining activities. This research study aims to help fill this gap by conducting an assessment of the ecological risks associated with mining activities in Chingola, with an emphasis on water resources contamination and damage to infrastructure.

The environmental risks associated with mining activities - especially with respect to water resource contamination and infrastructure damage - are eminent. The lack of localized studies assessing the combined environmental risks associated with mining operations in Chingola, Zambia, represents an important gap in the literature. This study will address this gap in the literature by focusing on the environmental impacts of mining activities, and implications for decision-making on sustainable mining practices in Chingola, Zambia.

To assess the environmental risks of mining activities in Chingola, Zambia, focusing on the risk of water contamination and infrastructure damage based on information from local residents and experts.

Although numerous studies have explored the environmental impacts of mining, significant gaps remain, particularly regarding the dual effects of water contamination and infrastructure damage in mining communities. Most existing research focuses on either water pollution or infrastructure degradation as isolated issues, without assessing their combined impacts. This limitation makes it difficult to develop integrated environmental management strategies that address multiple risks

simultaneously.
Another major gap in the literature is the lack of localized studies that assess the environmental risks of mining in Chingola. While national and regional studies offer broad insights into Zambia's mining sector, they often fail to capture the specific challenges faced by communities directly impacted by mining operations. Understanding localized dynamics is crucial for developing targeted policy interventions that effectively address community-specific concerns.
Furthermore, there is limited research on the effectiveness of environmental regulations and compliance mechanisms in mitigating mining-related risks in Zambia. While policies and legal frameworks have been established to regulate mining activities, empirical studies evaluating their impact on water quality and infrastructure protection are scarce. It remains unclear whether these regulations are adequately enforced or if gaps in implementation undermine their effectiveness.
Additionally, much of the existing research has primarily focused on large-scale mining operations, with little attention given to the environmental impacts of artisanal and small-scale mining (ASM). ASM activities contribute significantly to environmental degradation, yet due to their informal nature, they are often excluded from policy discussions and regulatory frameworks. A more comprehensive analysis that includes ASM is necessary to provide a complete picture of the environmental risks associated with mining.
Finally, there is a lack of studies incorporating community perspectives on mining-related environmental risks. While technical assessments provide critical data on pollution levels and infrastructure damage, understanding how affected populations perceive these risks and the adaptive strategies they employ is essential for designing inclusive and effective mitigation measures. Addressing this gap would enhance the relevance of environmental policies and improve community engagement in sustainable mining practices.

2. Methodology

The study employed a cross-sectional research design, which was appropriate for the purpose of accumulating rich data at one place in time about the environmental risks caused by mining operations. The cross-sectional design enabled the use of both qualitative and quantitative data to assess the perceptions of residents and expert informants regarding the risks associated with mining operations, specifically in terms of two types of environmental hazards: water pollution and damage to physical infrastructure. The research design also enabled the study to link pollution sources associated with mining operations and assess the effectiveness of environmental regulations (Rahman, 2023).
Research was carried out in Chingola District in Zambia's Copperbelt Province. Chingola is a mining district and the central hub of mining operations in Zambia, which is typically associated with copper and cobalt mining, carried out by Konkola Copper Mines (KCM). The district was selected based on existing and significant evidence of environmental degradation caused by mining operations in the town, particularly with respect to water pollution and damage to infrastructure (Good Governance Africa, 2023). The research study took special interest in communities near mega mining sites, and key informants (such as environmental experts, local authorities and mining practitioners).

2.1 Target Population

The study targeted residents living near mining areas in Chingola, along with environmental experts, mining practitioners, and local authorities. Residents were included for their firsthand experience with water pollution and infrastructure damage, while environmental experts and regulators contributed technical insights on environmental hazards and regulatory practices. Local authorities provided perspectives on policy implementation and governance. Purposive sampling was used for experts and authorities due to their specialized knowledge, whereas stratified random sampling was applied to residents based on their proximity to mining sites to capture varied experiences with environmental risk. The sample size was determined using the Yamane (1967) formula at a 95% confidence level and a 5% margin of error, a method widely accepted for community-based surveys (Adam, 2020).

Sample Size Calculation:

$$n = \frac{N}{1 + N\,(e^2)}$$

where:

n = Sample size
N = Total Population of residents of Chingola Townsips (estimated at 10,000 households living near mining sites)
e = Margin of error (0.05)

Substituting the values:

$$n = \frac{10{,}000}{1 + 10{,}000\,(0.05^2)}$$

$$n = \frac{10{,}000}{1 + 10{,}000 \times 0.0025}$$

$$n = \frac{10{,}000}{1 + 25}$$

$$n = \frac{10{,}000}{26}$$

$$n = 385$$

Total number of the study is 385 residents surveyed and 30 key informant interviews (KII) with experts and authorities totaling 415 participants.

2.2 Data Collection Methods

The study employed both primary and secondary data collection strategies to provide a comprehensive understanding of the research problem. The primary data were collected by means of structured questionnaires, KII, FGD, and observation checklists. The structured questionnaire, which comprised both closed and open-ended questions, was administered to the residents to identify their perception regarding water quality, damage to infrastructure, and their coping strategies. The design of the questionnaire was intended to be simple and easy to understand, and the questionnaire mainly focused on residents lived experience in relation to water contamination and mining-embedded damage to infrastructure (Rahman, 2023).

The KII, which involved interviewing experts from the mining section as well as local authorities, were also used to provide a more nuanced understanding of their perceptions of environmental regulations, sources of water pollution, and their sources of recommended mitigation measures. The approach was semi-structured and flexible to enable the interviewer to probe further if the interviewee mentioned issues of relevance to the research. Focus group discussions were conducted with local residents and community leaders to detail mining related activities and associated impacts on informal community life. Each FGD had 8-10 participants that were selected from a variety of strata identified as proximity-based so that each represented some degree of proximity to the mining activities.

Observational checklists were used to catalogue observable damage to infrastructure (e.g. cracked roads, dilapidated bridges) and evidence of water contamination (e.g. discoloration, presence of runoff points). This process provided additional evidence to support the respondents' reflections and provided objective evidence to support that there are environmental risks associated with mining activities.

Secondary data was obtained from EIA's from the Konkola Copper Mines (KCM), compliance reports from Zambia Environmental Management Agency (ZEMA), peer-reviewed literature, and published research. The secondary data provided context and an additional source of triangulation with the primary data.

2.3 Data Analysis

Data analysis involved both quantitative and qualitative approaches to analysis. Quantitative data that came from the questionnaire was analyzed using descriptive statistics, that included frequencies, percentages, means, and standard deviations. Cross-tabulations and Chi-Square were used to examine relationships in perceptions of water quality and proximity to mining activities. The quantitative analyses were all conducted using SPSS Version 27 to be able to successfully manage the data and complete inferential testing within a relatively short timeframe.

Qualitative data from the KIIs and FGDs were analyzed through thematic analysis. Transcripts were read, coded, and sorted through the emergent themes around sources of pollution, degradation to infrastructure, gaps on enforcement, and community recommendations. The NVivo application was effective for organizing this data and provided tools to identify patterns and consolidate themes.

2.4 Ethical Considerations

The research was completed using the highest ethical standards for research, including informed consent, confidentiality, voluntary participation, as well as institutional approval. Informed consent was acquired, in writing, from all participants. Prior to signing, potential participants were informed regarding the purpose, risks, and benefits of the study. In addition, participants were assured that the responses would be kept confidential. The participants' responses were anonymized before analysis. All participation was voluntary, and the participants could stop participating at any time without any negative consequences. Prior to data collection, ethical clearance was acquired from the University of Lusaka Research Ethics Committee, as well as the Chingola District Council.

3 Results and Discussion

3.1 Demographic Information

Duration of Residence in Chingola

Table 1 shows how long participants lived in Chingola. The majority of participants indicated they have lived for over ten years in Chingola (65.0%, n=250), followed by respondents who identified living in Chingola for 5-10 years (22.3%, n=86), while 12.7% (n=49) of respondents identified having lived in Chingola for a period of less than five years.

Table 1: Duration of Residence in Chingola

Years in Chingola	Frequency	Percentage
<5 years	49	12.7%
5–10 years	86	22.3%
>10 years	250	65.0%
Total	385	100.0%

Distance from Nearest Mining Site

Table 2. outlined what the distance was for each respondent. A combined 52.0% (n=200) of respondents lived within 5 km of mining activities, placing them in high-risk exposure zones. The remainder, though farther from mining sites, may still experience environmental effects such as airborne particles or water contamination via shared water networks.

Table 2: Distance from Nearest Mining Site

Distance to Mine	Frequency	Percentage
<1 km	98	25.5%
1–5 km	102	26.5%
6–10 km	93	24.2%
>10 km	92	23.9%
Total	385	100.0%

3.2 Impact of Mining Use and Awareness of Water Sources

Table 3 describes the proportion of participants who reported using water from rivers or wells located near a mining site. Almost three-quarters (72.2%, n=278) of the participants said they used water from sources near mining operations. The reliance on this water source suggests there is the potential of a risk of exposure to the contaminants associated with mining, as not many could access adequate alternatives.

Table 3: Use of Nearby Water Sources

Response	Frequency	Percentage
Yes	278	72.2%
No	107	27.8%
Total	385	100.0%

Observed Changes in Water Properties

Respondents identified multiple changes in water quality over time. Table 4.2.2 summarizes these observations.Bad Smell (71.4%, n=275) presented the most evident occurrence, likely reflecting the presence of microorganisms or a chemical presence. Unusual Colour (65.5%, n=252) connotes the presence of dissolved metals or sediments. Strange Taste (56.1%, n=216) may indicate possible chemical contamination & where visible particulate (48.8%, n=188), is often indicative of sediment run-off or industry deposits. The characteristics evident, signal moderate to significant degradation in water quality within impacted communities.

Table 4: Types of Changes Observed in Water Quality

Water Quality Issue	Frequency	Percentage
Bad Smell	275	71.4%
Unusual Color	252	65.5%
Strange Taste	216	56.1%
Visible Particles	188	48.8%

Health-Related Outcomes

Table 5 presents the health effects experienced by respondents associated with the use of contaminated water. The most widely reported symptom by residents was stomach issues (52.2%, n=201), most commonly as a result of drinking contaminated water. Skin infections (n=166, 43.1%) indicate some direct physical contact with contaminated water, while respiratory symptoms (n=124, 32.2%) may be attributable to exposure to pollutants in fumes or volatile components surrounding contaminated water bodies.

Table 5: Health Effects Experienced Due to Water Use

Health Issue	Frequency	Percentage
Stomach Problems	201	52.2%
Skin Infections	166	43.1%
Respiratory Issues	124	32.2%

Main Sources of Water Pollution

Participants were asked to identify what they believed were the main sources of water pollution in their area. Mining waste is viewed as the leading contributor to water pollution (89.1%, n=343), supporting concerns over poor waste management practices in mining areas. Industrial discharge (69.6%, n =268) suggests a secondary industrial impact, while domestic waste (57.4%, n = 221) and agricultural runoff (51.4%, n = 198) signifies more localized environmental instigators.

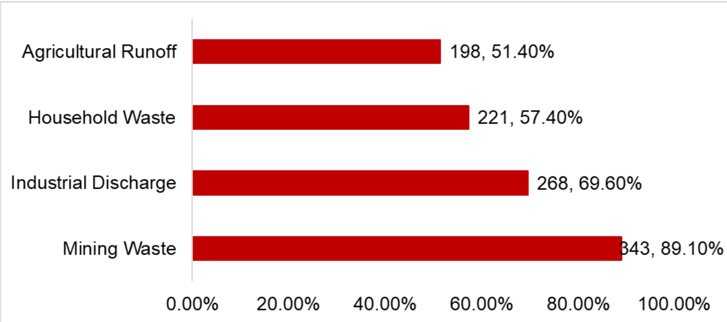

Figure 1: Main Perceived Sources of Water Pollution

Chi-square tests of association were performed to assess statistical relationships between distance to mining sites and reported outcomes. The results from the chi-square tests are displayed in Table 6. Chi-square tests of association were performed to determine if proximity to mining sites was statistically associated with water use, perceived water-use quality, and reported health symptoms experienced by residents. The results, presented in Table 4.3.5, indicate that all three associations were statistically significant at the $p < 0.05$ level: use of nearby water sources ($\chi^2 = 9.46$, $p = 0.024$); noticing water quality changes ($\chi^2 = 8.33$, $p = 0.039$); health-related issues ($\chi^2 = 10.87$, $p = 0.012$). These results suggest that residents living in closer proximity to mining areas are more likely to depend on near water sources, are likely to notice declines in the quality of usable water, and are more likely to relate their ailments to their use or consumption of water. This process could infer a concentrated burden, indicating that the findings imply disproportionate environmental and public health risks are similar for communities closer to mining activities.

Table 6: Chi-Square Test Results

Test Description	Chi-Square Value	p-value	Significant (p<0.05)
Distance vs. Use of Nearby Water Sources	9.46	0.024	Yes
Distance vs. Noticing Water Quality Changes	8.33	0.039	Yes
Distance vs. Health-Related Issues	10.87	0.012	Yes

3.3 Effects of Mining Activities on Infrastructure

Reported Types of Infrastructure Damage

Table 7 indicates the number of problems reported by the respondents associated with infrastructure. Cracks/Potholes in roads (71.7%, n=276) were the most cited problem, which reflects the deterioration of public roads, citing that mining activity caused vibrations and heavy-duty transportation. Damaged Bridges were noted by nearly half (49.9%, n=192) and could also be showing signs of structural fatigue. Land subsidence (41.0%, n=158) and soil loss due to erosion (38.2%, n=147) are likely also caused by the instability of the ground from excavation and blasting activities.

Table 7: Reported Types of Infrastructure Damage

Infrastructure Issue	Frequency	Percentage
Road Cracks & Potholes	276	71.7%
Bridge Deterioration	192	49.9%
Land Subsidence	158	41.0%
Soil Erosion	147	38.2%

Impact on Daily Life

Respondents indicated how their respective infrastructure issues have affected their daily and routine actions of accessing services. The majority of respondents (68.6%, n=264) indicated increased costs in transportation, likely because of their detours caused by road conditions or increased maintenance of their transportation. More than half (57.4%, n=221) indicated that they are late accessing some form of service, such as healthcare or education, in their local community. Half of respondents (50.1 %, n=193) indicated they had interruptions in their business, especially in circumstances that required access to roads for logistics.

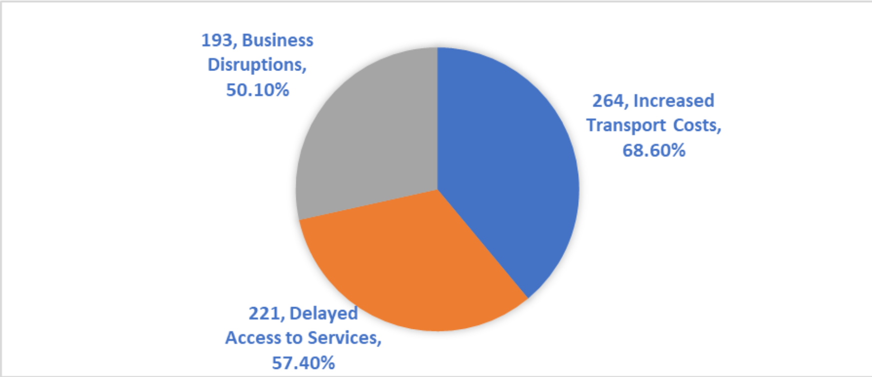

Figure 2: Reported Impacts on Daily Life

Chi-square tests were statistically analysed for associations between all infrastructure issues with respect to two contextual variables: length of time in Chingola; and distance from the mining sites. There was a statistically significant association between length of stay in Chingola, and reported infrastructure issues (χ^2=8.61, p=0.035), perhaps indicating that long-term inhabitants have seen difficulty compound. Similarly, individuals who lived closer to mining sites were more likely to have reported infrastructure issues (χ^2=9.88, p=0.021), perhaps indicating a geographic exposure.

Table 8: Chi-Square Test Results – Infrastructure Impacts

Test Description	Chi-Square Value	p-value	Significant (p<0.05)
Infrastructure Issues vs. Length of Stay	8.61	0.035	Yes
Infrastructure Issues vs. Distance from Mining Sites	9.88	0.021	Yes

3.4 Effectiveness of Environmental Regulations and Corporate Compliance

Community Awareness of Regulations

Table 9 outlines the indicated levels of public awareness with respect to environmental regulations and perceived government enforcement of these laws. Just over half (51.4%, n=198) of respondents stated that they were aware of environmental regulations. Yet, only 33.0% (n=127) felt that government enforcement of these laws was effective. Based on these two metrics, we observe a gap between awareness and implementation, which may indicate a weak institutional capacity, inadequate monitoring, or limited visibility into enforcement outcomes.

Table 9: Awareness and Perceived Government Enforcement of Environmental Regulations

Indicator	Frequency	Percentage
Aware of Environmental Regulations	198	51.4%
Believe Enforcement is Effective	127	33.0%

Perceived Corporate Environmental Actions

Respondents were asked to evaluate the efforts of mining companies in mitigating environmental damage. Table 10 summarizes their responses. Only 29.9% (n=115) of respondents indicated that they observed the implementation of water treatment initiatives from mining companies. A slightly smaller proportion (26.2%, n=101) indicated support items related to road maintenance, and just 23.1% (n=89) recognized waste management programs. This suggests that either corporate social responsibility initiatives are inadequate or the messaging is not effectively reaching the public.

Table 10: Perceptions of Mining Company Environmental Actions

Corporate Action	Frequency	Percentage
Water Treatment Initiatives	115	29.9%
Road Maintenance Support	101	26.2%
Waste Management Programs	89	23.1%

The Chi-square test of association was conducted to assess whether or not awareness of environmental regulations was associated with perceptions of compliance related to the mining company. The chi-square test (χ^2=10.43, p=0.015) indicated a significant association between awareness of ecological regulations and perceived compliance with mining companies. This implies that better-informed communities could be more critical or observant of environmental practices and thus more likely to make assessments regarding corporate accountability.

Table 11 Chi-Square Test Results – Regulation Awareness vs. Compliance Perception

Test Description	Chi-Square Value	p-value	Significant ($p<0.05$)
Awareness vs. Perceived Compliance	10.43	0.015	Yes

Level of Community Involvement

Lastly, respondents were asked on how involved they feel in the environmental protection efforts in Chingola. Overall, the majority of respondents (58.4%, n=225) felt they were not involved in protecting the environment. Just 16.1% (n=62) indicated that they were actively involved, and 25.5% (n=98) indicated that they occasionally participated. This raises a considerable gap when considering civic engagement and inclusion in environmental decision processes.

Table 12: Community Involvement in Environmental Protection

Involvement Level	Frequency	Percentage
Actively Involved	62	16.1%
Occasionally Involved	98	25.5%
Not Involved	225	58.4%

Recommended Actions

Most of the respondents (80.3%, n=309) expressed support for stronger regulation enforcement as the best solution, followed by community awareness campaigns (70.4%, n=271) and corporate ownership of more environmental responsibility (63.4%, n=244). Overall, these responses reflect public consensus to support multi-stakeholder action to mitigate environmental decline.

Respondents were asked to clarify on a 5-point Likert scale, from not urgent to extremely urgent, how urgently they felt action was needed to address environmental issues. Regulation enforcement had the highest urgency score (mean = 4.7) as the most important action, while community awareness (4.5) and corporate environmental action (4.3) received very high scores and support. This reinforces previous revealed priorities that respondents are in favour of stronger regulation enforcement and community awareness and participation through grassroots advocacy on actions to address potential risks associated with the mining sector and organisations.

3.5 Qualitative Data (KIIs and FGDs)

Synthesized below are the findings from the Key Informant Interviews (KIIs) with local leaders, environmental officers, and mining officials, and the Focus Group Discussions (FGDs) with community members. Thematic analysis was used to establish Key insights and patterns that were useful in validating the quantitative findings.

Sources and Nature of Water Contamination

Experts interviewed confirmed that water pollution was primarily due to mining effluents that contained heavy metals, including copper, cobalt, and sulfuric acid. Environmental officers advised that open tailing dam and unsealed waste canals allow permeation into surface and ground water systems. Several community members corroborated these findings, describing a water colour that was "brownish or greenish" in colour, they experienced " strong odors (like rotten eggs)" and a "bitter or metallic taste". This phenomenon was similarly reported across FGDs, particularly for communities located near open-pit mining sites and in downstream drainage zones following the flow of the effluents.

Infrastructure Vulnerability

Key informants identified technical causes (factors) including vibration from blasting, acid mine drainage corroding load bearing supports, and heavy trucks on roads that were not suitable for industrial use. Residents described persistent road closures resulting from subsidence and had noted that there have been two recent occasions where minor bridges were collapsed. These infractions led to the challenges of accessing schools and clinics if the infrastructure was damaged. Participants noted that many roads were not rehabilitated following damage, particularly in peripheral settlements.

Regulatory Gaps and Enforcement Challenges

Environmental experts noted that Zambia does have a detailed body of environmental statutes, but the quality of enforcement was deemed to be weak as a result of the low number of permanent staff in government agencies, infrequent site inspections, and a lack of real-time monitoring facilities. Mining industry stakeholders also pointed to overlaps in jurisdiction between local authorities and national regulatory agencies as a source delays. Community narratives expressed frustration over a perception of corporate impunity. A recurrent theme indicated that “companies act mainly when donors come” with some stating that regulators "turn a blind eye."

Community Voice and Recommendations

Participants stressed a desire for planning that includes inclusivity of voices and embraces environmental justice. Numerous suggestions emerged around collaborative community based environmental monitoring training, a push for local watchdog committees, and improved access to public environmental information. There was a call to push accountability beyond just symbolic social corporate responsibility, to enact real and ongoing environmental remediation (for example where operations were large scale and metal leaching was involved). Numerous also proposed grievance and redress mechanisms should be less formal and more based in community, and that environmental reports should be released quarterly and free of charge for access.

Triangulation of Quantitative and Qualitative Findings

This section seeks to compare key findings from quantitative data (n=385), with qualitative evidence from Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs). The point of triangulating the quantitative data with qualitative is to affirm patterns, make meaning and to extract insights for action related to environmental risk management in Chingola.

Water Contamination Patterns and Health Effects

Quantitative data showed that 72.2% (n=278) of respondents were using water sources near the minings and; at least some significant changes in water quality were reported with bad smell (71.4%, n=275), unusual color (65.5%, n=252), strange taste (56.1%, n=216), visible particles (48.8%, n=188). Stomach issues were reported by over that half of the respondents (52.2%, n=201), and 43.1% (n=166) reported skin infections.

These findings were underscored in qualitative interviews, where environmental officers explained that contamination was a result of the slurry of heavy metals - copper, cobalt, and sulfuric acid in particular - present in tailings leaching into open waste canals. Community members described water as tasting "brownish," "greenish," or "metallic," like "rotten eggs." The two data streams combine to show direct and profound environmental health risk.

Infrastructure Damage and Community Mobility Challenges

Quantitative analyses revealed that 71.7% (n=276) residents noticed cracks in roads - potholes or worse, while 49.9% (n=192) saw bridges that were falling apart. Other areas included land subsidence (41.0%, n=158), and soil erosion (38.2%, n=147). The most significant impacts were higher transportation costs (68.6%, n = 264) and delays in accessing basic services (57.4%, n = 221).

Qualitative results support these findings. Experts attributed damage to blasting vibrations and over-loaded trucks. They heard stories of recent collapses of minor bridges that limit access to clinics and schools. Everyone agreed that once roads and bridges were damaged, they tended to remain damaged, especially in fringe settlements.

Understanding of Environmental Regulation and Compliance Perception

Among the survey respondents, 51.4% (n=198) of respondents had some awareness of environmental regulation, whereas only 33.0% (n=127) thought that there were positive outcomes from enforcement of regulations. For all measures of corporate action, the majority of respondents did not see corporate action as positive: 29.9% (n=115) notice that corporate actions to treat the water; 26.2% (n=101) saw support for the maintenance of roads; and 23.1% (n=89) noticed waste management corporate actions.

Environmental officers identified aspects of poor staffing and lack of equipment as barriers to compliance, and mining authorities said that their mandate overlapped upper and lower levels of authorities. Among local members community members suggested that mining companies "only engage when donors are around" and regulators are always "looking the other way". This consensus shows that locals believe there is widespread public distrust and regulatory failure.

Community Engagement and Proposed Solutions

According to survey data, 58.4% (n = 225) of respondents reported feeling uninvolved in environmental protection efforts, with only 16.1% (n = 62) claiming active participation. Yet respondents demonstrated strong opinions on what should be done: 80.3% (n=309) called for stricter enforcement of regulations, 70.4% (n=271) advocated for awareness campaigns, and 63.4% (n=244) supported enhanced corporate responsibility.

Qualitative participants expressed a desire for environmental watchdog committees, community training in ecological monitoring, and localized grievance mechanisms. There was also a call for public access to quarterly ecological reports. These suggestions underscore a deep yearning for inclusion, transparency, and empowerment at the grassroots level.

3.6 Discussion of Findings

Impact of Mining on Water Quality in Chingola

The study found that 72.2% (n=278) of the respondents relied on water sourced near mining operations. This suggests a significant lack of access to safe water, increasing the exposure of respondents to contamination. Furthermore, the majority of respondents reported changes in water quality with 71.4% (n=275) reporting bad smell, 65.5% (n=252) off colour, 56.1% (n=216) strange taste and 48.8% (n=188) visible particulates. The significant responses reflect moderate to severe degradation of water with pollution, potentially associated with mining related contaminates.

The health implications of reported water quality degradation is highlighted by the reported health conditions; 52.2% (n=201) had stomach complaints, 43.1% (n=166) had skin infections and 32.2% (n=124) had respiratory health complaints. The health patterns of were similar to those reported in other mining contexts around Africa. For example, Amoah et al. (2022) found similar health consequences and contamination related concerns in Ghana associated with elevated levels of arsenic and lead, which were attributed to gastrointestinal and dermatological conditions. Inferential analysis through chi-square tests revealed statistically significant associations between proximity to mining sites and water-related variables: use of local water sources (χ^2=9.46, p=0.024), observed changes in quality of water (χ^2=8.33, p=0.039) and health complaints (χ^2=10.87, p=0.012). This corresponds to a concentrated environmental health burden in space, whereby people who live closest to the mining activity are exposed to higher degree of risk, approximately.

While the quantitative data provided useful test results, it was corroborated qualitatively through key informant interviews (KIIs) and focus group discussion (FGDs). Environmental officers pointed to copper, cobalt, sulfuric acid and other heavy metals as pollutants emanating mainly from the tailings dams and unlined waste canals. Residents confirmed the claims and stated that their water looked "brownish," "greenish," or "metallic tasting," and smelling of "rotten eggs." These descriptions connote a certain presence sulfide, and metal ions in contaminated water.

This a reflection of wider literature. Sergeant et al. (2022) in North America linked mine runoff to human health risks and habitat degradation in salmonid-bearing watersheds. Hamor et al (2021) in Central Europe noted that environmental assessment implementation gaps resulted in groundwater contamination. In Zambia, Chikontwe et al (2024) and Kaluba and Banda (2023) detected lead and zinc, and increased turbidity in surface and groundwater samples in areas adjacent to mining activities including Chingola and the Kafue River Basin.

Additionally, Muimba-Kankolongo et al (2021) reported elevated metals concentrations in food and water sources near Chingola, while Muma et al (2020) found ongoing vulnerabilities in water quality in Mufulira. These studies support the understanding that there are continued high risks of water contamination due to lack of effective waste management systems and abandoned mined areas in Zambia's Copperbelt.

The qualitative narratives in the current study also noted that residents had little trust in formal assessments of water safety, relying on subjective indicators (smell, color, and taste) compared to formal testing. This lack of trust highlights a regulatory communications divide, Zulu and Mwansa (2021) echoed this when they found low levels of public awareness and limited capacity or enforcement of environmental legislation in Zambia.

In summary, both the statistical evidence and personal experiences highlighted by the qualitative findings converge to demonstrate an acute environmental health hazard in Chingola, and its association with mining activity. These findings align with the global and regional literature and reinforce the urgency for better monitoring, enforcement, and investment in alternative water infrastructure, as well as consideration for community education and actions through participatory monitoring for equitable and sustainable governance of water safety.

Effects of Mining Activities on Infrastructure

This study provides strong evidence that mining activity in Chingola has had considerable negative impacts on local infrastructure. The quantitative results showed that 71.7% (n=276) of respondents identified road cracks and potholes, which was the most common mention. Nearly half of the respondents (49.9%, n=192) also mentioned damage to their bridges, and 41.0% (n=158) mentioned land subsidence and 38.2% (n=147) mentioned soil erosion. This pattern illustrates how infrastructure can degrade physically from mining activity such as blasting, heavy trucks on the roads, and poor drainage.

The qualitative data supported these observations. Key informants, such as engineers and environmental officers, explained the damage was primarily due to vibrations from using explosives, road overloading by the haulage trucks, and the corrosive effects of acid mine drainage (AMD). Residents provided their own written accounts of road closures, detours, and in some cases, bridge collapses that compromised their ability to get to schools, clinics and markets. One participant said, "We see new cracks on the roads after blasting and there is no one to fix that. This impacts on transport to the clinics during emergencies."

These findings are closely related with the findings of Mufungulwa et al. (2022) where they reported from their study in Mufulira and Chingola that mining had created ground instability and that the regular passage of heavy mining equipment caused haulage roads, bridges, and drainage systems to weaken. They identified the lack of rehabilitation and poor planning as primary factors in the issue, which were also reported by the focus group participants, i.e., "peripheral roads are very rarely repaired unless they can be related to the mines".

Comparatively, similar trends have been observed globally. For example, McCulloch et al. (2022) noted that for places like Mount Isa in Australia, with the stresses of underground mining causing stresses on infrastructure highways, and the systems failure of not reinforcing the roads are causing the land subsidence. In addition, Kivinen and Kotilainen (2023) reported that road and irrigation system collapses in Nordic Europe are related to underground mining activity and associated lack of investigations to minimize the risk of internal disruption.

On a continental scale, international literature from West and Central Africa document similar issues, for example Ncube and Mathuthu (2023) found that unregulated small-scale mining activities in parts of Nigeria and Cameroon polluted damaged bridges disrupted transportation routes and flooded roads all contributed to barriers to access for services and ultimately resulted in people paying more.

These infrastructure issues have significant socio-economic implications in Chingola, as approximately 68.6% (n=264) reported transportation costs had increased, which is likely due to longer travel times, detours, and damaged vehicles. Also, 57.4% (n=221) had reported they delay meeting schools, clinics, or markets, while approximately half of businesses reported (50.1%, n=193) interruptions to business especially where they relied upon using the road network to deliver or sell goods.

These phenomena can also be statistically correlated. There was a statistically significant relationship between number of years living in Chingola and whether a person reported infrastructure issues ($\chi^2 = 8.61$, $p = 0.035$), which suggests that people who have lived in Chingola longer are experiencing cumulative infrastructure degradation. Further, people who lived closer to areas involved in mining activity were statistically more likely to report damage ($\chi^2 = 9.88$, $p = 0.021$), which provides more support for geographical vulnerability perspective.
As Zulu and Mwansa (2021) observed, while Zambia has introduced updated environmental laws aimed at strengthening compliance, enforcement remains weak, especially in relation to infrastructure protection and spatial planning. In this study, participants noted that once damaged, roads and bridges in remote areas are often left unattended, reflecting implementation gaps in urban-rural infrastructure equity.
In conclusion the impacts of mining operations have clearly generated infrastructural obsolesce in Chingola, which has uneven impacts on transportation, access to services, and local economic activity. This mirrors earlier findings in Chingola, and broadly, as well as underscoring the immediate need for proactive geotechnical assessments, and carefully targeted infrastructure investment and compliance to a spatial planning framework to protect public infrastructure in mining affected areas.

Effectiveness of Environmental Regulations and Corporate Compliance

The survey indicated that only 51.4% (n=198) of respondents are aware of the environmental regulations in Zambia, and even fewer (33.0%, n=127) believe these laws are enforced effectively. Such data point to a considerable gap in implementation and perceptions, where legal frameworks exist but operationalizing them is weak or erratic. These findings suggest issues of institutional capacity, limited public engagement, and poor visibility of enforcement mechanisms.
In qualitative interviews, environmental officers reaffirmed perceptions of challenges faced in enforcing environmental regulations, such as low staffing levels, limited inspections, and a lack of real-time monitoring systems being applied to determine and check compliance. One official stated, “Our officers are not able to be present everywhere. We just do not have the capacity to conduct regular compliance checks, ” and respondents from mining companies cited confusion in enforcement instructions and delays due to overlapping jurisdictions - most often between the national regulatory authorities and local government.
These findings, mirror findings from Zulu and Mwansa, (2021) in Zambia, who noted that while legal reforms have occurred recently, the enforcement of environmental laws, especially in peri-urban and mining-dense areas, is often weak or inconsistent. They observed a lack of independent audits to check compliance and the failure of government agencies to coordinate, matching closely with the findings of the current study. On corporate compliance, only 29.9% (n=115) of respondents had observed water treatment actions, while a lesser 26.2% (n=101) recognized road maintenance by mining corporations, and only 23.1% (n=89) recognized waste management programs. The lack of an acceptable measure of CSR may imply either an unwillingness on the part of the corporations to invest in environmental mitigation measures or a lack of adequate communication and transparency by firms about what is currently being undertaken.
Community stories reiterated, “mining firms only act when a donor comes and sees”, and accused regulatory officers of “looking the other way” - indicating the mistrust and unsolicited impunity in CSR, which can severely hinder environmental responsibility in the longer-term.
The study found a statistically significant correlation between the level of awareness of the laws around environmental concerns and perceived compliance by mining companies ($\chi^2 = 10.43$, $p = 0.015$), suggesting that the more the communities knew about environmental issues and regulations, the better it was for them to critically oversee the actions of mining firms, which aligns Social-Ecological Model , an extra-organizational factor underlying the communities having more awareness to influence outcome at the organizational level.
Similar patterns are unfolding at the continental level too. For example, in the countries of Kenya and Uganda, Kibera and Opiyo (2024) found community-led monitoring projects resulted in better responsiveness from corporations and environmental compliance by mining companies particularly in more remote mining regions. These results indicate the potential value of local monitoring and citizen science to enforce environmental performance standards. These mechanisms are underdeveloped in Zambia.
On the global level, the US EPA (2023) emphasizes the need for climate-integrated mining regulations and digital monitoring platforms to enable timely enforcement. Similarly, Hamor et al. (2021) argued that while strict regulatory frameworks exist in Europe, institutions leave enforcement gaps which are unfilled without community vigilance or coordination between institutions during critical lapses in enforcement, particularly after EIA standards are met.
Furthermore, the findings established in this research speak alot about regulatory status in Zambia: the regulations are, arguably, legal, however the effectiveness is weak because of enforcement, lack of public transparency, and lack of community participation as awareness for compliance. There are some clear and significant capacity and institutional gaps here. To address Zambia's existing regulatory context, the way forward will likely include some legal reform, building regulatory capacity, adopting digital means of compliance monitoring, institutionalizing public environmental reporting mechanisms which enable affected communities to participate in environmental governance.
Overall, while regulations exist, a lack of meaningful enforcement in Chingola reflects greater systemic issues that require stricter environmental accountability. Meaningful enforcement means engaging communities in improved environmental governance. This will require legal reform, institutional engagement, collaboration across multi-stakeholders, and demand for genuine public participation in the governance of environment.

Community Participation and Suggested Solutions

The majority of respondents (58.4%, n=225) reported feeling excluded from practices surrounding environmental protection in Chingola. Only 16.1% (n=62) of respondents reported taking part in such practices, and only 25.5% (n=98) reported often participating in them. The finding indicates a significant gap in community engagement and community inclusion in processes involved in environmental decisions and towards protecting what they see as their environment. These findings are aligned with those of Mufungulwa et al. (2022) who indicated that most communities afflicted by mining in Zambia, are usually excluded from formal regulatory discussions and planning forums, which ultimately leads to feelings of mistrust and community disempowerment.

In a similar study in Tanzania, Akabana and Luhanga (2021) found that absence in environmental governance compound residents' feelings of abandonment and inhibit the effectiveness of community responses. Their study concluded that interventions aimed at engaging communities in the environment, cannot effectively deliver the protective characteristics that they seek to protect, without community involvement, regardless of good planning.

In the present study, respondents overwhelming indicated support for stronger interventions. 80.3% of respondents (n=309), indicated support for enforcement or regulations; 70.4% (n=271) indicated support for community awareness campaigns; and, 63.4% of respondents (n=244) were in favour of increased corporate social responsibility. These preferences indicate the way residents consider the need for a multi-layered response of institutional, grassroots and private sector responses to their perceived and greater environmental threats and risks.

Qualitative responses supported these sentiments, as informants repeatedly alluded to links to environmental justice and increase inclusion in planning. Recommendations included establishing local community environmental watchdog groups, information transparency, and establishing training opportunities for residents to conduct grassroots environmental monitoring. One individual added, "We need more than meetings. We need to be part of the solution."

These stories resonate with scholarship in other contexts. For example, Ahmed and Tewari (2023), discussed how inclusive environmental governance policy in mining-contaminated communities in India resulted in better implementation and compliance from firms when communities ultimately had environmental literacy and platforms to raise their...

In South Africa, Marais and Nel (2020) illustrated that participatory planning allowed for more collaboration between mining firms and local residents, reducing conflict, built on trust and accountability.

With regard to urgency, regulatory enforcement was the top solicitation, mean urgency score of 4.7 out of a 5-point scale, followed by community awareness (4.5) and corporate environmental responsibility (4.3). The scores reinforced the findings from Turyahikayo et al. (2021) in Uganda, which indicated, meaningful reform in mining communities began with improving enforcement of environmental laws and investing in awareness programes.

Moreover, the emphasis on corporate accountability in this study indicates that there are growing expectations from the public for corporate social responsibility to include more than token efforts, such as donating to schools or ceremonial clean-ups. Respondents pressed for lasting, evidence based environmental remediation programmes, while advocating for mining firms to prepare public quarterly environmental reports. This is consistent with the recommendations from Chileshe et al. (2020) which suggested, mining companies in Zambia should rely be required by law to report environmental performance indicators and submit to independent audits.

In conclusion, findings indicate that meaningful community engagement is not only preferable, but is necessary for environmental management acceptable in mining conditions. Awareness is slowly improving, but a lot of work remains to meaningfully include community voice in planning, monitoring and evaluation. They demands a clear wrap around, that means community, regulatory enforcement, and company accountability all going towards sustainable environmental conditions.

4 Summary, Conclusion and Recommendations

4.1 Conclusions

The study revealed that mining activities in Chingola have severely affected water quality, infrastructure, and public health. Most residents reported noticeable changes in drinking water, with evidence of heavy metal contamination linked to mining operations. Health problems such as stomach illnesses, skin infections, and respiratory symptoms were strongly associated with proximity to mining sites. Infrastructure has also deteriorated, with widespread reports of road damage, bridge weakening, and soil erosion attributed to blasting and heavy truck movements. Although environmental regulations exist, enforcement is weak, and corporate compliance remains low, with few visible mitigation efforts. Community participation in environmental governance is minimal, despite strong public support for stricter enforcement, increased awareness, and greater corporate accountability. Overall, the findings point to serious environmental governance gaps and emphasize the need for stronger institutions, empowered communities, and proactive corporate responsibility to safeguard public health and ensure sustainable development.

4.2 Recommendations

1) Enhance Enforcement Capacity: Strengthen the operational capacity of the Zambia Environmental Management Agency (ZEMA) and related institutions by increasing human resources, logistical support, and investment in real-

time environmental monitoring technologies. Enhanced capacity will ensure more frequent site inspections, timely enforcement actions, and improved environmental compliance by mining firms.

2) Promote Transparent Corporate Environmental Action: Mandate mining companies to publish quarterly environmental compliance reports that are accessible to the public. These reports should detail key performance indicators, including waste disposal methods, water treatment outcomes, emission levels, and corporate social responsibility (CSR) initiatives related to environmental protection.
3) Improve Safe Water Access: The government, in collaboration with mining firms and development partners, should invest in the construction of boreholes, community filtration systems, and reticulated clean water supply networks. This will reduce community dependence on contaminated sources and mitigate the public health risks associated with mining-related water pollution.
4) Rehabilitate Damaged Infrastructure: Establish public-private partnerships (PPPs) to finance and implement the repair and maintenance of infrastructure damaged by mining operations, including roads, bridges, and drainage systems. Priority should be given to peripheral and high-risk communities that have suffered the most from environmental degradation.
5) Institutionalize Community Monitoring Mechanisms: Establish local environmental monitoring committees comprising trained community members, environmental officers, and representatives from civil society. These bodies should be equipped to conduct regular site assessments, collect environmental data, and report any non-compliance to the relevant regulatory authorities.
6) Launch Environmental Education Campaigns: Implement broad-based awareness campaigns targeting mining-affected communities. Utilize platforms such as community radio, schools, church gatherings, and public forums to educate residents about their environmental rights, health risks, and avenues for reporting environmental violations. These campaigns should also demystify environmental regulations and promote civic responsibility.

4.3 Recommendations for Future Studies

1) Longitudinal Health Impact Assessments: Future research should investigate long-term health outcomes associated with exposure to mining-related pollutants.
2) Comparative Policy Analysis: Studies comparing environmental enforcement in Zambia with other mining countries could offer lessons for regulatory improvement.
3) Digital Monitoring Technologies: Explore the role of digital tools in enhancing real-time environmental monitoring and community engagement.
4) Gendered Impacts of Mining Pollution: Further studies should assess how environmental degradation uniquely affects women and children in mining communities.
5) Effectiveness of CSR Models: Research should evaluate the effectiveness of various CSR strategies employed by mining companies in Zambia, as well as their long-term sustainability.

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The article followed all ethical standards appropriate for this kind of research.

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