

Water Governance and Infrastructure Resilience Risk Governance and Resilient Water Infrastructure Delivery in Mufulira District, Zambia: A Qualitative Case Study

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ABSTRACT

Reliable water infrastructure is a natural-resource-management priority in mining and industrial districts, where service systems are exposed to financial, technical, environmental, institutional and operational uncertainty. This study examined how risk-management practices shape water-infrastructure delivery and service reliability in Mufulira District, Zambia. An interpretivist qualitative case study used semi-structured interviews with 25 purposively selected participants: five water engineers, five project managers, five municipal engineers and ten community members. Documentary review and contextual observation supported triangulation. Interview material was organised in Microsoft Excel and analysed thematically through familiarisation, coding, categorisation, theme development and interpretation across stakeholder groups. Participants reported that feasibility studies, site assessments, expert consultation, risk registers, budget adjustments and contingency planning were in use, but their application was inconsistent across the project lifecycle. Financing delays, design and equipment problems, incomplete front-end investigations, environmental and climate pressures, specialist-skill shortages, weak communication, fragmented coordination and political or administrative interference were associated with schedule disruption, cost escalation, rework, quality deficiencies and unreliable services. Community participation was particularly limited during early risk identification, reducing access to local knowledge about service patterns, access constraints and social concerns. The findings show that water-infrastructure risk management is most effective when treated as a continuous governance system rather than a one-time compliance exercise. Stage-gated review, explicit risk ownership, risk-based contingency, community risk intelligence, early-warning indicators and operational resilience measures can connect project control with sustainable service outcomes. The single-case, cross-sectional design limits statistical generalisation, but the study offers transferable management lessons for urban water projects in comparable resource-dependent settings.

Keywords: water infrastructure; risk governance; climate resilience; stakeholder participation; project performance; Zambia

INTRODUCTION

Water infrastructure converts a shared natural resource into a dependable public service. Its performance therefore depends not only on engineering delivery but also on governance, financing, environmental conditions, stakeholder relationships and the capacity to operate and maintain assets after commissioning. These dependencies are especially important in mining and industrial districts, where water demand, source-water quality, energy requirements and institutional responsibilities intersect. When uncertainty is managed poorly, project delays and cost overruns can become service interruptions, public-health exposure and reduced confidence in resource-management institutions.

Infrastructure risk management provides a structured way to incorporate uncertainty into decisions about scope, design, procurement, construction and operation. ISO 31000 frames the process around context,

identification, analysis, evaluation, treatment, monitoring and communication, while the Project Management Institute places uncertainty within an integrated delivery system spanning schedule, cost, quality, procurement and stakeholders (International Organization for Standardization [ISO], 2018; Project Management Institute [PMI], 2021). This perspective is broader than maintaining a risk register. It requires decision rights, accountable owners, funded responses and continual learning as conditions change.

Mufulira District provides a pertinent case. It is an urban and mining environment in Zambia's Copperbelt where pumping-dependent infrastructure, ageing assets, environmental exposure and multiple implementing actors create linked risks. The supplied study reports evidence that water-service constraints have included maintenance and rehabilitation gaps and reduced pumping during electricity load-shedding, followed by public financing for standby generation (National Assembly of Zambia, 2025). At national level, investment in urban water systems has not always produced proportional service gains, leading recent reforms to emphasise utility accountability, operational efficiency, water-loss reduction, financial sustainability and climate resilience (World Bank, 2022, 2025). These conditions show why construction completion is an insufficient measure of water-infrastructure success.

The study addressed three questions: how risk-management practices affect perceived time, cost, quality and service outcomes; which factors constrain effective implementation; and which practices can reduce performance risk. This article reframes the dissertation as a natural-resources-management contribution by linking project risk controls to lifecycle resilience, community risk intelligence and reliable water services. It argues that the decisive issue is not whether formal risk tools exist, but whether they influence resource allocation, technical decisions, stakeholder coordination and operational preparedness throughout the infrastructure lifecycle.

BACKGROUND OF THE STUDY

Risk governance across the infrastructure lifecycle

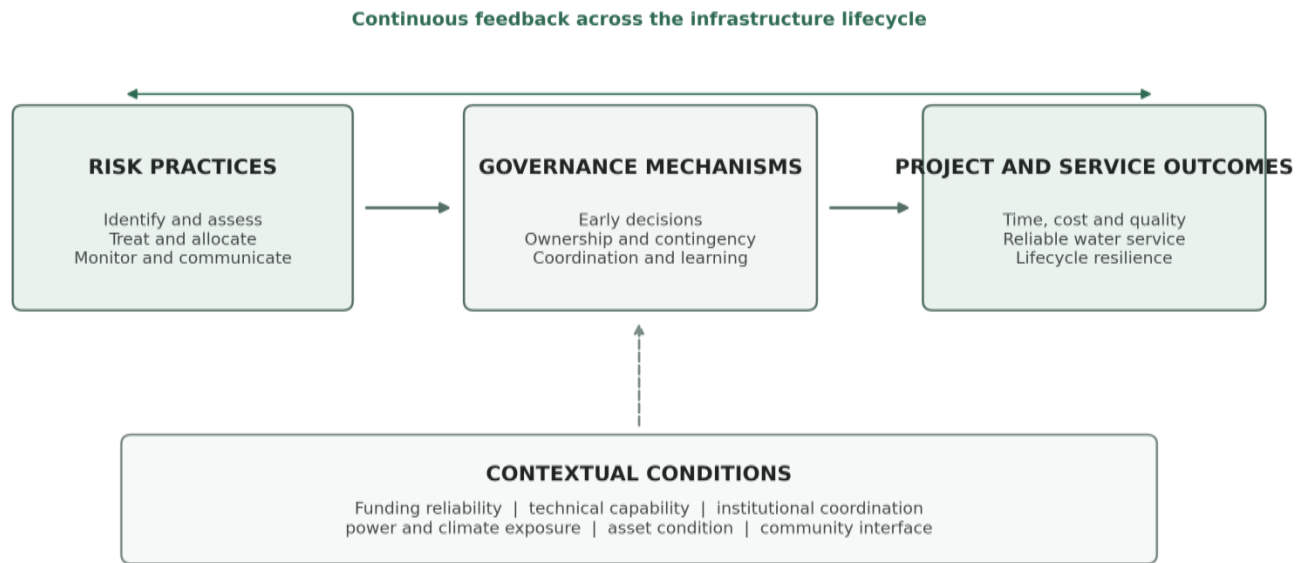
Risk-management theory treats uncertainty as manageable when organisations identify threats and opportunities, estimate their consequences, select responses and monitor residual exposure (Chapman & Ward, 2011; Hillson, 2009). The lifecycle dimension is essential for water infrastructure because early assumptions about source security, power supply, ground conditions, demand, access, asset interfaces and maintainability can shape both construction performance and decades of operation. Preventive investigation is generally less costly than redesign, emergency procurement, contract claims or post-commissioning failure.

Risk governance extends the technical cycle by specifying who may make decisions, how high exposures are escalated and how accountability is maintained across organisational boundaries. Public water projects often distribute authority among sponsors, utilities, municipalities, consultants, contractors, regulators and communities. A technical issue may require a funding decision; a procurement delay may require executive intervention; and an access or service concern may require community liaison. Governance quality therefore determines whether identified risks are converted into timely action.

Systems resilience and stakeholder risk intelligence

Systems theory explains why local failures can propagate across infrastructure networks. A pumping interruption affects storage, pressure and service continuity; weak maintenance increases equipment vulnerability; late financing can delay procurement and contractor mobilisation; and poor communication can prevent one actor's warning from reaching the decision-maker able to respond (von Bertalanffy, 1968; Kerzner, 2017). Under this view, resilience is the capacity of the coupled technical, institutional and social system to anticipate disruption, absorb shocks and sustain or restore service.

Figure 1. *Risk-governance framework for resilient water-infrastructure delivery*



Note. The framework synthesises ISO 31000, project-management and systems perspectives with the study's emergent themes. Arrows indicate an iterative relationship rather than a statistically tested causal model.

Stakeholder participation is a source of risk information, not simply a procedural obligation. Engineers and project managers can identify design, cost and contract exposure, while residents can identify service patterns, informal access routes, vulnerable users, recurring local failures and potential social conflict. Excluding community knowledge from early risk identification narrows the evidence base and can shift problems into construction or operation, where remedies are more expensive and trust is harder to rebuild.

STATEMENT OF THE PROBLEM

Ideally, water infrastructure projects should be completed within the planned time, budget, and quality standards to effectively meet the needs of the population. Effective risk management practices are expected to identify potential risks early and implement appropriate mitigation strategies to ensure project success.

However, water-service delivery in Mufulira has continued to face operational and infrastructure constraints that illustrate the practical consequences of unmanaged or inadequately controlled risk. In July 2025, the National Assembly of Zambia reported that Mulonga Water Supply and Sanitation Company, which serves Mufulira, Chingola and Chililabombwe, had experienced a major production decline after years of inadequate maintenance and rehabilitation of treatment facilities. The same report noted reduced pumping hours in parts of Mufulira because of climate-induced electricity load-shedding, prompting Government funding for standby generators (National Assembly of Zambia, 2025). These conditions demonstrate how asset-condition, energy-supply, financing and operational risks can directly affect continuity of water services.

The wider Zambian water sector has also faced persistent efficiency and governance challenges. The World Bank (2022) observed that substantial investment in urban water infrastructure had not translated into equivalent gains in service coverage, partly because institutional and utility-management weaknesses reduced the effectiveness and sustainability of infrastructure investment. More recent sector reforms have therefore placed emphasis on accountability, operational efficiency, reduction of physical and commercial water losses, climate resilience and stronger utility governance (World Bank, 2025).

If these challenges are not addressed, they may lead to inefficient use of resources, reduced access to clean water, and negative impacts on socio-economic development. Therefore, it is important to assess the role of risk management practices in influencing the performance of water infrastructure projects in Mufulira District.

METHODOLOGY

Study design

The research used an interpretivist qualitative case-study design to examine risk management in its organisational and local setting. Mufulira District was the bounded case, and water-infrastructure projects together with the stakeholders involved in delivery or affected by service outcomes formed the units of inquiry. A case study was appropriate because infrastructure risk cannot be separated cleanly from financing, institutional arrangements, power supply, asset condition, contractor capability, environmental conditions and community relationships (Yin, 2018).

The design was cross-sectional and exploratory. Data were collected during a six-month study period, with participants drawing on current practice and retrospective experience across project stages. The study sought analytical depth rather than numerical prevalence or statistical generalisation (Creswell & Poth, 2018).

Participants and data collection

Purposive sampling selected 25 information-rich participants with direct technical, managerial, institutional or community experience. Interviews continued until the researcher judged that thematic saturation had been reached. The sample deliberately combined professional and service-user perspectives, as shown in Table 1.

Table 1. Participant profile

Participant category	Number	Share (%)
Water engineers	5	20
Project managers	5	20
Municipal engineers	5	20
Community members	10	40
Total	25	100

***Note.** Participants were selected purposively; percentages describe the qualitative sample and are not population estimates.*

Semi-structured interviews were the principal source of evidence. A guide aligned questions with the three study objectives while allowing role-specific probing and unexpected issues to emerge. Document review and contextual observation provided supporting evidence on sector conditions, institutional arrangements and the physical setting. The combination enabled comparison across participant categories and evidence types rather than reliance on a single professional viewpoint.

Data analysis, trustworthiness and ethics

Interview material was transcribed and organised in Microsoft Excel. Analysis followed a thematic sequence of familiarisation, initial coding, grouping related codes into categories, developing and reviewing themes against the source material, and interpreting patterns across stakeholder roles (Braun & Clarke, 2006). The process was primarily inductive but iterative: concepts from project, risk-management and systems theory informed the interview guide and interpretation without forcing all accounts into predetermined categories.

Credibility was supported through multiple stakeholder categories, comparison of accounts, documentary and contextual triangulation and direct evidence. Dependability and confirmability were addressed through consistent use of the interview guide, systematic coding and an audit trail of analytical decisions. Contextual description supports transferability to comparable urban water settings, although it does not establish statistical representativeness.

Participants provided informed consent, participation was voluntary, confidentiality was maintained and respondents could decline questions or withdraw without penalty. No institutional ethics-approval reference

was reported in the supplied dissertation; the relevant committee name and approval number should be added before journal submission if applicable.

FINDINGS

A connected risk landscape

Participants identified financial, technical, environmental and planning-related risks as the dominant threats to water-infrastructure delivery. Financing shortages and delayed releases affected procurement, contractor payment, technical investigation and the ability to implement planned responses. The consequence was cumulative: delayed mobilisation or long-lead procurement affected later activities, while inflation, claims and emergency purchases increased cost exposure. One project manager summarised the issue directly: “Funding delays are one of the biggest risks affecting project completion.”

Technical exposure included design adequacy, equipment reliability, site conditions, ageing infrastructure and limited access to specialised personnel. Participants linked these conditions to redesign, rework, breakdowns and reduced performance after commissioning. Environmental exposure included weather variability, source-water conditions, pollution and site-specific disruption. Weak front-end planning cut across these categories because unrealistic schedules, incomplete investigations and poor coordination amplified risks that might otherwise have been manageable.

Identification was professionally led but socially narrow

Feasibility studies, site assessments and expert consultation were the most frequently described identification practices. These approaches captured physical access, existing assets, ground conditions, environmental constraints and specialist concerns. Community members, however, were rarely involved at a comparable stage. Consequently, early reviews could miss knowledge about service patterns, social concerns, access constraints and historical failures.

“They do not tell us anything when they come to install the water facilities; we only see them arrive.”

Community participant, translated from Bemba

The account illustrates an information and legitimacy gap. Limited consultation reduces the project's ability to identify community-facing risks and leaves residents to experience decisions after key design or siting choices have been made.

Formal tools existed, but implementation was uneven

Participants referred to risk registers, budget adjustments and contingency planning as common assessment and mitigation tools. Their value depended on whether the register remained current, high risks had named owners, treatments had resources and progress was reviewed. In some cases, assessment was described as superficial or constrained by time, indicating that the presence of documentation did not necessarily change decisions.

Monitoring showed a similar implementation gap. Participants supported regular review, but limited specialist capacity, fragmented communication and competing operational demands weakened follow-through. Risks could therefore be recognised without a clear response deadline, escalation threshold or confirmation that residual exposure had fallen.

Risk management influenced project and service performance

Participants associated effective risk management with improved time, cost and quality performance. Early identification supported preventive actions such as advancing long-lead procurement, changing activity sequences, undertaking additional investigations and escalating funding needs. Risk-based contingency and early treatment reduced exposure to rework, claims and emergency procurement. Design review, supervision,

inspection, testing and explicit acceptance criteria were described as quality safeguards.

Poorly managed exposure was associated with delay, cost escalation, incomplete work, defects and reactive problem solving. These effects extended beyond the construction triangle. Equipment unreliability, inadequate power resilience, weak commissioning and unresolved asset interfaces could reduce water-service continuity after handover, making operational reliability a lifecycle performance outcome.

Governance and capability constrained action

Four implementation barriers recurred across accounts: limited and unpredictable funding, shortages of practical risk-management and specialist skills, weak communication among institutions and stakeholders, and political or administrative interference. Funding determined whether treatments could be implemented; skills affected the quality of assessment; communication affected whether warnings reached decision-makers; and interference could compress schedules or bypass technical controls. Table 2 consolidates the six themes and their natural-resources-management significance.

Table 2. Thematic findings and implications for water-resource management

Theme	Evidence from participants	Management significance
Risk landscape	Financing, design, equipment, site, environment, climate and weak planning interacted.	Manage interdependencies rather than isolated risk categories.
Risk identification	Feasibility, site assessment and expert input were common; community input was limited.	Combine technical evidence with local service and access knowledge.
Assessment and mitigation	Registers, budget adjustment and contingency were used, sometimes superficially.	Link each major risk to an owner, funded action, due date and residual rating.
Performance pathways	Early action supported schedule, cost and quality; weak control produced rework and disruption.	Measure service reliability and maintainability alongside delivery targets.
Implementation barriers	Funding, skills, communication, coordination and interference constrained treatment.	Strengthen governance capacity and escalation authority.
Improvement priorities	Earlier planning, participation, training and continuous monitoring were recommended.	Institutionalise lifecycle review and learning.

Note. Themes represent patterned qualitative accounts. No frequency ranking or statistical effect size was inferred.

DISCUSSION OF FINDINGS

From compliance documentation to continuous governance

The findings support a distinction between possessing risk-management tools and governing risk. Registers and contingencies were familiar, but their effect depended on timing, ownership, resources and escalation. This is consistent with ISO 31000 and risk-management theory, which treat monitoring, communication and continual improvement as integral rather than optional (ISO, 2018; Hillson, 2009). A static register can satisfy an administrative requirement while leaving the project exposed; a live register changes priorities, budgets, procurement and technical decisions.

Funding was not merely another risk category. It was an enabling condition for almost every treatment. Additional investigation, backup equipment, specialist advice, accelerated procurement and contractor mobilisation all require accessible resources. Risk-based contingency should therefore be calculated from identified exposure and controlled transparently, while cash-flow risks need early commitments and escalation routes. Otherwise, accurately identified risks remain untreated.

Infrastructure resilience requires systems thinking

The Mfulira case demonstrates that water-project performance depends on systems outside the immediate construction boundary. Electricity availability affects pumping, storage recovery and service continuity; ageing

assets affect the interface with new works; environmental and source-water conditions affect treatment and reliability; and institutional capacity affects maintenance after handover. The reported load-shedding response illustrates the cost of treating energy continuity as an operational emergency rather than a feasibility and design criterion (National Assembly of Zambia, 2025).

A lifecycle approach broadens the definition of project success. Time, cost and construction quality remain important, but infrastructure contributes to natural-resource management only when it can be operated, maintained and adapted. Backup power, redundancy, maintainability, spare-parts strategies, operator training, asset manuals and funded maintenance should therefore be considered before commissioning. This aligns with national reform priorities that connect physical investment to utility governance and sustained service performance (World Bank, 2022, 2025).

Participation is a risk-control mechanism

The limited early involvement of community members is analytically important. Professional stakeholders hold technical and contractual knowledge, but residents hold distributed knowledge about actual service use, access, vulnerable households, historical faults and community response. Participation can therefore improve identification quality and reduce late objections, unsafe access, avoidable redesign and mistrust. It should be designed around decisions that require local evidence, with documented feedback and responsibility for response.

Communication also functions as an infrastructure control. Because responsibility is distributed, a risk can persist at an interface even when one actor recognises it. Regular cross-institutional review, clear decision routes and a grievance mechanism make information actionable. They also help distinguish legitimate public priorities from informal pressure that bypasses evidence, scope control or procurement discipline.

MANAGEMENT IMPLICATIONS

The study's recommendations can be operationalised as a stage-gated framework that joins project delivery to long-term resource and service outcomes. Table 3 identifies the minimum review focus and leading indicators at each lifecycle stage.

Table 3. Lifecycle risk-governance framework for water infrastructure

Lifecycle gate	Required controls	Leading indicators
Concept and feasibility	Assess source security, demand, asset condition, mining interfaces, power, climate, access, environmental and social exposure; assign top-risk owners.	Unresolved assumptions; missing surveys; unfunded studies; absent stakeholder groups.
Design and procurement	Independent review for high-risk designs; lifecycle-cost and maintainability review; allocate contract risk; identify long-lead items and contingency.	Open design queries; procurement lead-time variance; unallocated risks; contingency without a risk basis.
Construction	Monthly live-register review; change and claims control; quality and safety assurance; community feedback and documented escalation.	Overdue actions; unpaid certificates; non-conformances; incidents; grievances; contingency drawdown.
Commissioning and handover	Test performance under realistic conditions; close defects; confirm spares, manuals, operator training, backup power and residual-risk transfer.	Failed tests; unresolved defects; incomplete training; missing spares; high residual operational risks.
Operation and learning	Monitor reliability, losses, energy exposure and maintenance; capture lessons and feed them into new projects.	Service interruptions; power-related downtime; maintenance backlog; repeat failures; unresolved complaints.

Note. Gate approval should be conditional on named owners and credible treatments for critical risks. Indicator thresholds should trigger escalation before material impact occurs.

Implementing agencies and utilities should assign every high-priority risk a cause, event, consequence, owner, treatment, due date, residual rating and escalation threshold. Review should be integrated into ordinary progress and cost meetings, not conducted as a parallel exercise. Senior management should track unresolved high risks and overdue actions, while closed risks should retain lessons for future schemes.

Capability development should emphasise coached application on live projects. Priority areas include facilitated risk workshops, schedule and cost uncertainty, procurement and contract-risk allocation, environmental and social risk, commissioning and operational resilience. A roster of specialist support can help small project teams respond when geotechnical, electrical, environmental or commercial exposure exceeds internal expertise.

Community representatives should participate in selected risk-identification sessions during feasibility and before disruptive construction. A simple feedback and grievance system should record service, safety, access and environmental issues, assign responsibility and specify response deadlines. This turns engagement into traceable management evidence rather than ceremonial consultation.

LIMITATIONS AND FUTURE RESEARCH

The findings are based on a single district, a cross-sectional design and purposive qualitative sampling. They represent stakeholder interpretations and thematic patterns, not statistical estimates of prevalence or causal effect. The professional categories are broad, and confidentiality limits project-specific attribution. Documentary and contextual sources strengthened interpretation but did not constitute an independent quantitative performance audit.

Future studies should compare several Copperbelt districts, follow projects longitudinally from feasibility into operation and connect risk-management maturity to verified schedule variance, cost variance, defects, downtime and service interruption. Focused research is also needed on climate, energy and mining-related environmental interdependencies, as these risks are central to the resilience of Copperbelt water systems.

CONCLUSION

Water-infrastructure risk management in Mufulira is recognised in practice, but implementation is inconsistent across the lifecycle. The study identified a connected risk landscape in which financing, design, equipment, environmental conditions, planning, skills, communication and governance shaped both project delivery and service reliability. Feasibility studies, site assessment, expert consultation, registers and contingency provide a workable foundation, yet they add value only when they change decisions and receive resources.

For natural-resources management, the central implication is that risk control must join infrastructure delivery to resilient service. Stage-gated review, explicit ownership, risk-based contingency, community risk intelligence, early-warning indicators and operational preparedness can reduce avoidable disruption and protect lifecycle performance. The objective is not more risk documentation; it is a governance culture in which uncertainty is identified early, treated transparently and continuously reassessed from concept through operation.

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