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MAINTENANCE AND MANAGEMENT OF WATER INFRASTRUCTURE: A CASE STUDY OF MIDVAAL LOCAL MUNICIPALITY

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Abstract

This study examines the critical challenges of maintaining and managing water infrastructure in Midvaal Local Municipality, South Africa, and their effects on water supply reliability. Persistent issues—such as aging infrastructure, insufficient funding, governance limitations, and inadequate institutional capacity—continue to hamper efforts to provide consistent, quality water services. Employing a mixed-methods approach, the research gathered quantitative and qualitative data, including surveys from over 100 stakeholders and document analysis of municipal records. Findings highlight that deteriorating pipelines, poor preventive maintenance, and governance constraints contribute significantly to water disruptions and substandard quality compliance. Recommended interventions include adopting technologies like smart metering and leak detection to minimize water loss, strengthening governance, improving institutional skills through training, and boosting budget allocations for upgrades. These measures and a call for coordinated, multi-stakeholder involvement—including community engagement—are essential to achieve reliable, sustainable water management in South African municipalities.

Keywords: Water Infrastructure, Maintenance, Management, South Africa, Municipalities, Water Supply Reliability.

1. INTRODUCTION

Access to clean and reliable water is a fundamental human right and essential for sustainable development. South Africa's municipalities face significant challenges in achieving consistent water supply due to a combination of factors, including aging infrastructure, rapid urbanization, and uneven distribution of resources.

These issues are especially prominent in Gauteng Province, where rapid urbanization and limited resources strain the existing infrastructure [1]. Despite having over 5,700 registered dams and extensive water infrastructure networks, municipalities in South Africa often struggle with water scarcity and frequent service interruptions.

The Midvaal Local Municipality, located in Gauteng, serves as a relevant case study due to its unique socioeconomic context and the complexities of its infrastructure challenges [2].

Historically, South Africa's apartheid policies led to inequities in infrastructure development, with urban areas, mainly inhabited by the white minority, receiving a disproportionate share of resources, leaving rural and township areas underserved [1].

Although post-apartheid reforms have aimed to address these disparities, water infrastructure in many areas remains outdated and poorly maintained. This infrastructure decline has resulted in frequent leakages, burst pipes, and significant water losses, further complicating reliable access to safe water in municipalities [3], [4].

The critical issues facing Midvaal Local Municipality include deteriorating infrastructure, lack of regular maintenance, insufficient funding, and fragmented governance structures. These factors collectively exacerbate water service disruptions and affect both residential and industrial users.

The municipality, like many others, encounters difficulties in managing aging pipelines and addressing service delivery issues in a sustainable manner [5], [6]. Effective management and maintenance practices are, therefore, essential to reduce the negative impact of infrastructure failures and ensure a reliable water supply.

Despite the recognition of infrastructure's role in water reliability, there has been limited research on specific maintenance and management strategies that address the unique challenges within South African municipalities. This study aims to fill this gap by examining the factors contributing to infrastructure deterioration in Midvaal and identifying viable interventions. To achieve this, the study addresses the following research questions:

- What are the primary challenges affecting the maintenance and management of water infrastructure in Midvaal Local Municipality?
- How do these challenges impact water supply reliability for residents and businesses?
- What strategies can be implemented to improve water infrastructure management and maintenance in South African municipalities?

By focusing on the unique infrastructure and governance issues in South Africa, this research provides insights into the intersections of maintenance, governance, and resource management. The findings are expected to inform targeted policy and management strategies that can enhance water supply reliability across similar municipalities in South Africa.

2. LITERATURE REVIEW

Water infrastructure in South Africa faces substantial challenges rooted in historical, financial, and governance issues. During apartheid, infrastructure investments favored urban areas with white populations, leaving rural and township regions underserved—a legacy that persists, leading to disparities in access and quality of water services [7].

Despite reforms, many systems are outdated, and frequent service interruptions affect water quality and availability. Globally, countries like Japan and the U.S. have successfully adopted asset management practices to maintain infrastructure reliability, such as regular assessments

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and predictive maintenance, which could be adapted to South African municipalities [5], [8]. However, local financial and institutional barriers complicate the implementation of these strategies, especially where governance structures are fragmented and lack coordination [9].

Aging infrastructure, limited funding, and governance challenges are central to the water supply issues facing municipalities. Many South African water systems exceed their designed lifespan, resulting in increased breakdowns, water losses, and the need for major repairs, which municipalities often struggle to finance [3].

Governance weaknesses, including inadequate accountability and corruption, further impede effective water management, highlighting the need for improved regulatory frameworks and stakeholder engagement [6]. Innovative technologies, like smart leak detection, and stronger institutional capacities could enhance infrastructure performance and minimize water losses if implemented alongside community participation and transparent governance practices [10].

Improving South Africa's water infrastructure requires adopting effective policies and funding models, integrating technology, and engaging local communities to address disparities in water service provision. Although asset management frameworks and technological innovations show promise, further research is needed to evaluate their practical application in South African contexts, especially within municipalities with constrained resources [11].

3. METHODOLOGY

The methodology for this study follows a structured, multi-step approach, employing a mixed-methods framework to comprehensively assess water infrastructure management in Midvaal Local Municipality. The research process is divided into distinct phases, each designed to address specific objectives, as illustrated in Figure 1.

The use of mixed methods is particularly suitable for examining the multifaceted nature of infrastructure management issues, as it combines qualitative insights with quantitative data, offering a more holistic understanding of the research problem [12], [13].

Step 1: Define Research Philosophy and Approach

The research began with establishing a clear philosophical foundation, grounded in pragmatism, which is effective for applied research requiring both qualitative and quantitative data [14]. Pragmatism emphasizes practical problem-solving and the use of diverse methodologies to derive actionable insights. The study also adopted an exploratory and deductive approach to identify under-researched areas and validate existing theories, such as asset management and socio-technical systems theory [15].

Justification: Studies such as those by [12] and [15] have highlighted the benefits of a pragmatic approach, particularly in applied fields like infrastructure management where multiple types of data are necessary to fully explore complex problems.

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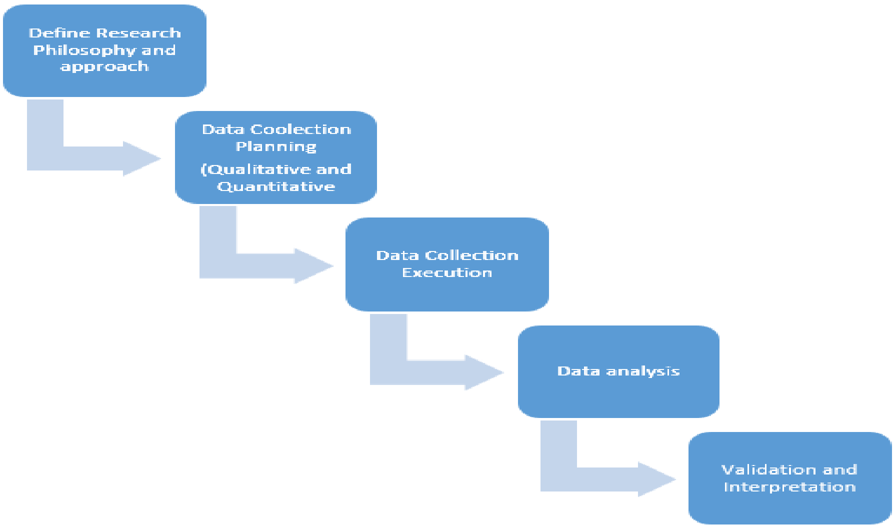

Figure 1: Research Process

Step 2: Data Collection Planning (Qualitative and Quantitative)

Data collection was planned through both qualitative and quantitative strategies to ensure comprehensive coverage of the research questions. The data collection phase was divided into two parallel streams:

Qualitative Data: Document analysis involving municipal records, such as organizational structures, policy documents, water quality reports, and budget histories. The aim was to gather in-depth institutional insights into Midvaal's infrastructure challenges.

Quantitative Data: Surveys designed to target over 100 participants, including engineers and municipal staff involved in water infrastructure management. Likert-scale questions will help gauge participants' satisfaction and perceptions regarding the effectiveness of the existing infrastructure management.

Justification: [12] Emphasized the importance of collecting both qualitative and quantitative data in mixed-methods research to ensure triangulation and robustness of findings.

Step 3: Data Collection Execution

Data were collected in two streams, following the designed plan:

Qualitative Stream: Document analysis was conducted to assess records such as organizational structure documents, water quality reports, infrastructure inventories, and policy documents. This thematic analysis aimed to categorize and identify key operational and institutional challenges [9].

Quantitative Stream: Surveys were administered to municipal staff and other stakeholders. Survey questions addressed key performance indicators such as infrastructure reliability, maintenance effectiveness, and operational constraints. Data from municipal records, including

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water quality and balance reports, were collected to provide quantitative evidence of infrastructure performance.

Justification: Similar studies, demonstrated that the simultaneous collection of data through different streams helps cross-validate the data, enhancing its reliability [12], [15].

Step 4: Data Analysis (Separate and Integrated)

The data analysis phase included separate processing of both qualitative and quantitative data streams before integration:

Qualitative Data Analysis: Thematic analysis was applied to qualitative data to identify patterns in challenges and opportunities related to water infrastructure [9].

Quantitative Data Analysis: Descriptive and inferential statistical analysis was conducted to quantify infrastructure performance metrics and assess relationships between different variables.

Integration of both datasets provided a more complete understanding of the situation. This phase used a convergent parallel design, which ensures that both subjective and objective insights are considered to produce a holistic outcome [13].

Step 5: Validation and Interpretation

The final step focused on the validation and interpretation of the results. Triangulation was used to verify the findings from multiple data sources, thereby enhancing the reliability and validity of the conclusions drawn [12]. Survey instruments were pilot-tested to ensure clarity and to validate the content, while expert feedback was obtained to confirm that the themes captured through qualitative analysis were representative of the actual challenges faced by Midvaal. Justification: Ensuring validity and reliability is crucial for establishing credibility in research findings. The use of triangulation and pilot testing is a well-established method for enhancing the robustness of research, as noted by [12].

4. RESULTS AND ANALYSIS

This section presents the findings of the study, focusing on the current state of water infrastructure in Midvaal Local Municipality. The analysis draws from survey data, Blue Drop compliance reports, water balance assessments, and public notices regarding service interruptions. The findings directly address the key research questions concerning factors contributing to infrastructure deterioration, impacts on communities, and policy interventions needed to mitigate these issues.

4.1 Survey Results

4.1.1 Respondent Demographics

The survey gathered responses from a wide range of professionals, with a substantial portion working in engineering and technical roles, accounting for 60% of the respondents. Other

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significant sectors represented include healthcare, finance, and law, which contributed to diverse perspectives on water infrastructure challenges.

Most respondents had at least a bachelor's degree, with 41.5% holding such qualifications, reflecting the technical and managerial expertise of the participants. Figure 2 illustrates the distribution of respondents (118 respondents) by education level, showcasing a predominance of higher educational backgrounds, which adds credibility to the insights provided.

4.1.2 State of Water Infrastructure

Respondents were asked to rate the state of water infrastructure in Midvaal. The findings indicate a significant level of dissatisfaction, with 44.9% rating the infrastructure as "Fair" and 30.5% rating it as "Poor". The main dissatisfactions were the aging infrastructure, insufficient maintenance, and frequent service disruptions. Figure 3 provides a visual representation of the respondents' ratings of water infrastructure.

4.1.3 Challenges Identified

The survey highlighted several key challenges impacting water infrastructure management in Midvaal. Lack of maintenance was the most cited issue, with over 75.4% of respondents indicating it as a major problem. Aging infrastructure, affecting 59.3% of the respondents, was identified as another major challenge, alongside governance issues (58.5%), lack of skilled personnel (35.6%), and vandalism (39.8%).

Africa's extreme water insecurity is significantly exacerbated by poor infrastructure maintenance, insufficient investment, and inefficient governance structures, all of which contribute to unreliable water supply [16]. Figure 4 shows these challenges.

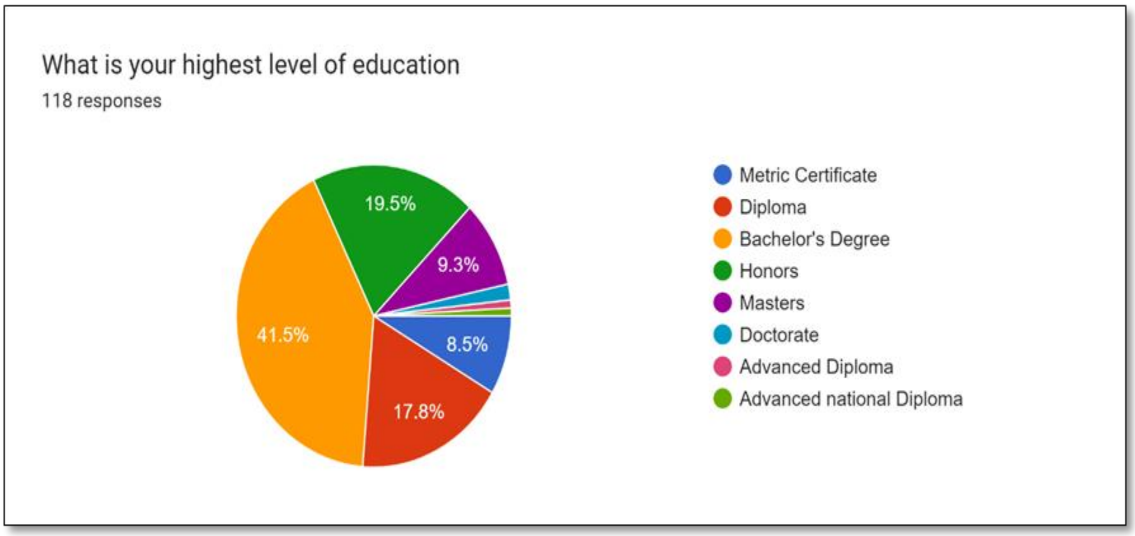

Figure 2

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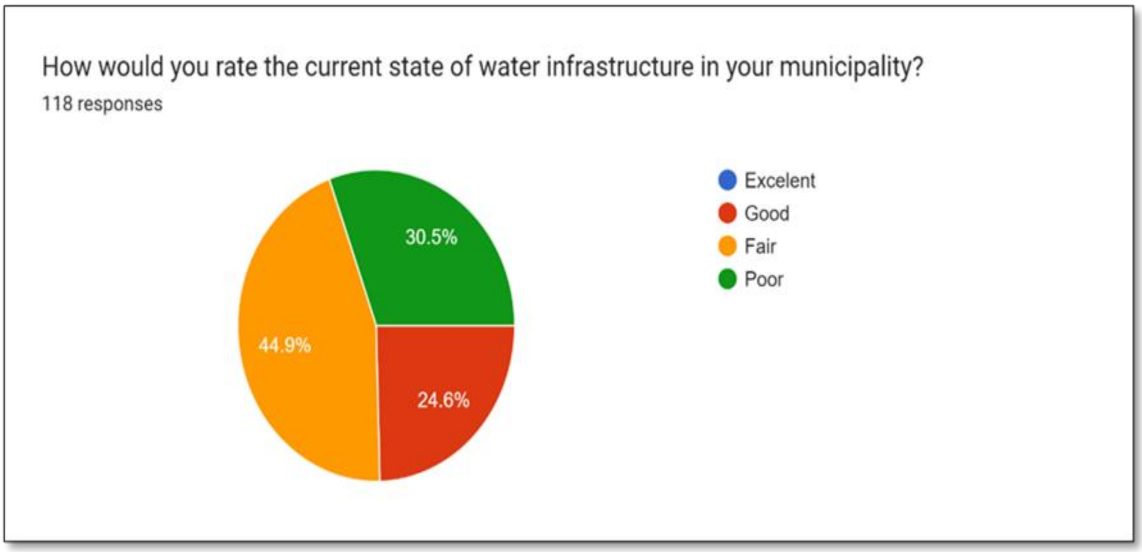

Figure 3

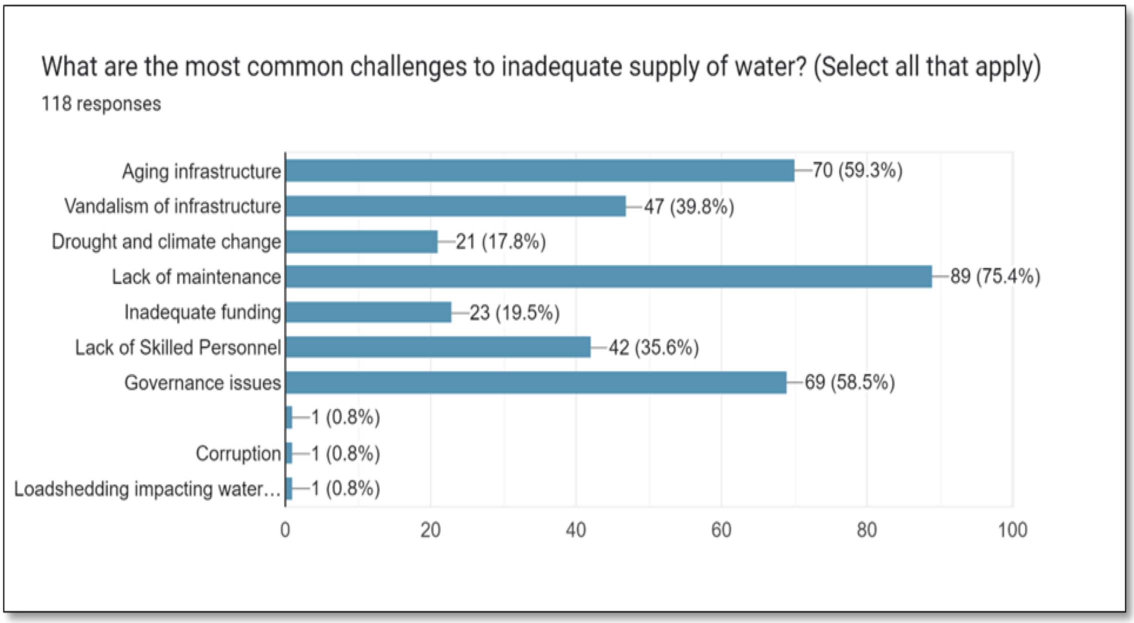

Figure 4

4.2 Water Infrastructure Performance in Midvaal Municipality

4.2.1 Blue Drop Compliance Analysis

The Blue Drop compliance reports for Midvaal Local Municipality from October 2023 to June 2024 reveal varying compliance levels. The Vaal Marina Water Treatment Works (WTW) achieved consistent 100% compliance for microbiological and physical parameters, ensuring a safe water supply. In contrast, the Vaal Marina Reservoirs and Distribution Network displayed

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recurring issues, particularly in maintaining adequate chlorine levels. In several months, chlorine concentrations at certain distribution points fell below the minimum safe levels, posing a public health risk due to potential microbial contamination.

Figure 5 shows the compliance of Vaal Marina WTW from the blue drop compliance reports of Midvaal local municipality, while Figure 6 illustrates the non-compliance issues in the Vaal Marina system from the same report. This discrepancy highlights the need for balanced resource allocation to ensure consistent water quality across all facilities.

Category	Physical and Aesthetic						Microbiological	
Parameter	pH	Conductivity	Free Chlorine		Turbidity		*E. coli*	SPC
Limit	5 – 9.7	≤ 170 mS/m	≤ 5 mg/l	≥ 0.1 mg/l	≤ 1 NTU	≤ 5 NTU	0 MPN/100ml	≤ 1 000 colonies/ml
Limit Type	Operational	Aesthetic	Chronic Health	Operational	Operational	Aesthetic	Acute Health	Operational
Week 1	7.2	26.1	2.0		0.58		< 1	1
Week 2	7.7	25.9	2.0		0.42		< 1	0
Week 3	7.6	24.3	1.9		0.30		<1	0
Week 4	7.8	26.0	1.4		0.39		< 1	0
Average	7.6	25.6	1.82		0.42		< 1	0.25
% Compliance	100%	100%	100%	100%	100%	100%	100%	100%
% Compliance	Physical and Aesthetic Compliance: 100%						Microbiological Compliance: 100%	
Overall Compliance: 100%								

SPC - Standard plate count

Compliance legend: Bad <95% Poor 95-97%, Good 97-99%, Excellent >99%

Figure 5

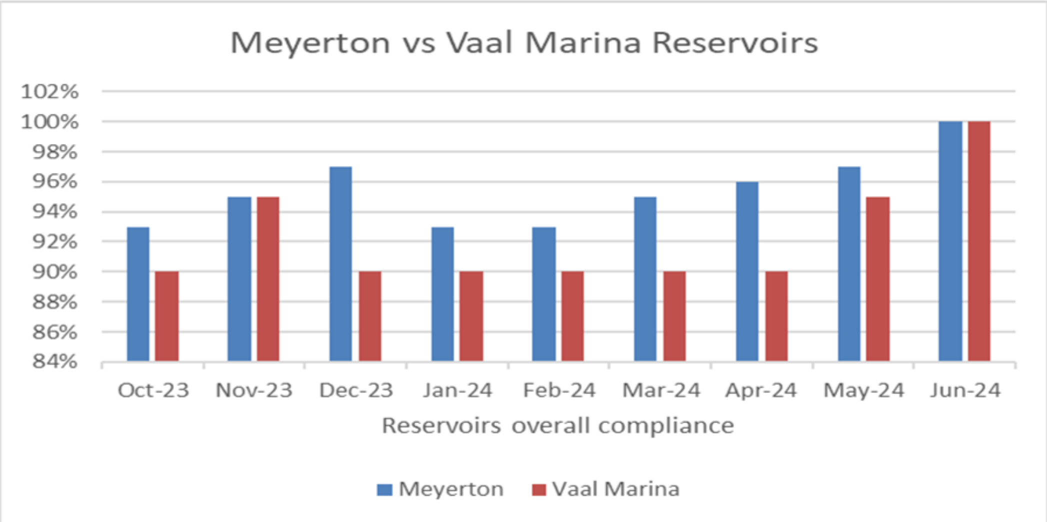

Figure 6

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4.2.2 Water Balance and Infrastructure Losses

The water balance analysis conducted from July 2023 to February 2024 highlights significant non-revenue water (NRW) across the municipality, accounting for 25-30% of total water production.

These losses are largely attributed to leaks, bursts, and unauthorized consumption. The highest losses were reported in older parts of the network, where asbestos cement pipes, which make up 83% of the system, have exceeded their design lifespan, making them prone to frequent leaks and bursts.

Figure 7 presents the water balance reports from July 2023 to February 2024, indicating the scale of water losses, particularly during high-demand periods. Unauthorized consumption also contributes to NRW, underscoring the need for improved metering and monitoring systems. The figure below shows a relationship between the system's total volume (blue), revenue water (green) and non-revenue water (red).

4.3 Service Interruptions and Community Impact

Planned interruptions from Midvaal local municipality were generally due to maintenance activities, such as the installation of bulk water meters and pump station repairs. Despite public notices, many residents expressed dissatisfaction with the contingency measures, such as insufficient water tankers during outages.

Unplanned interruptions from Midvaal local municipality, often caused by bursts in asbestos pipelines, significantly impacted communities, particularly in areas like Randvaal and Eye of Africa. These interruptions as indicated in the public notices were exacerbated by load shedding, which delayed the restoration of services. Vulnerable households without alternative water sources were the hardest hit, underscoring the need for proactive maintenance and better coordination between water and energy systems.

4.4 Proposed Policy Interventions

Survey respondents suggested interventions, including improved governance, capacity building, increased funding, and the adoption of innovative technologies. About 86.4% of participants indicated that enhanced governance and accountability are essential for improving water infrastructure.

Additionally, 68.6% supported the use of innovative technologies like smart metering and predictive maintenance systems, which could significantly reduce water losses and improve infrastructure management.

An article by [17], highlights that poor governance exacerbates water crises, underscoring the need for improved management structures. Similarly, an article from [7], advocates for the adoption of smart metering and other technological interventions to enhance operational efficiency and reduce water losses.

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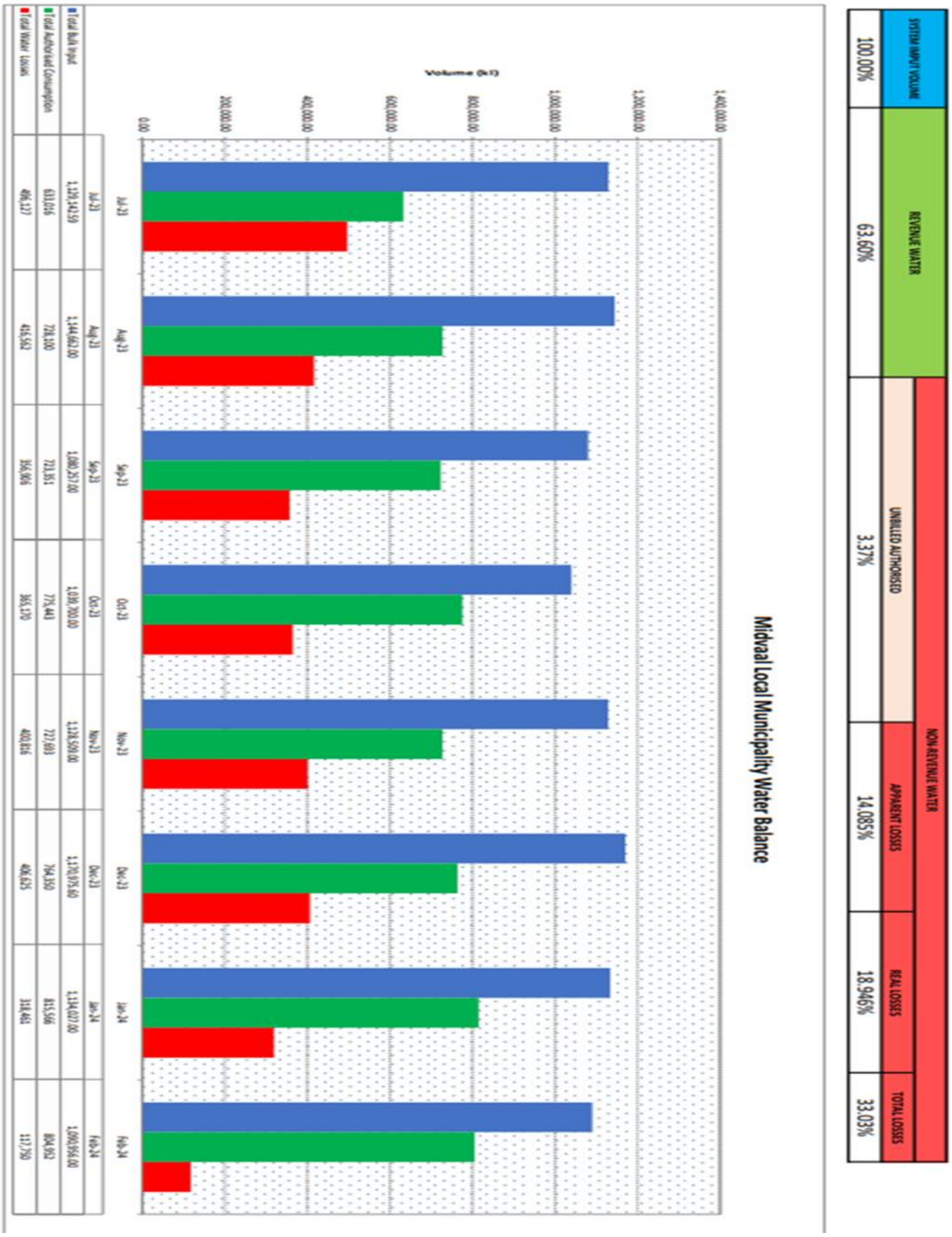

Figure 7

Figure 8 shows the breakdown of suggested policy interventions, highlighting the community's emphasis on governance improvements and technological advancements.

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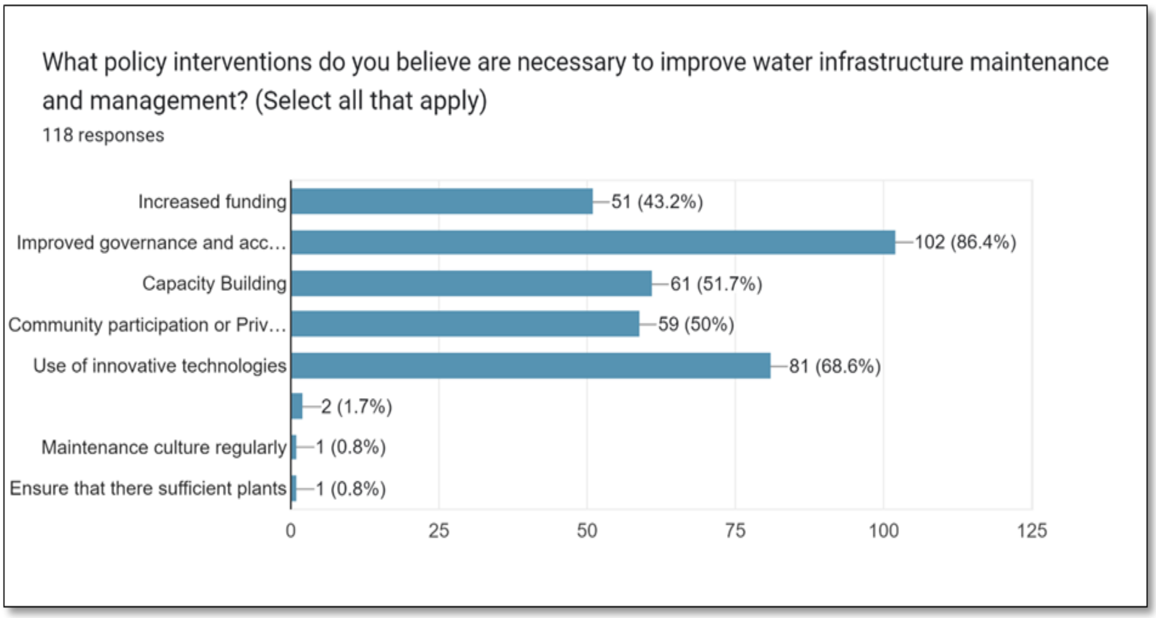

Figure 8

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The primary goal of this research was to evaluate the factors contributing to the deterioration of water infrastructure in Midvaal Local Municipality, assess the impacts of poor infrastructure management on the community, and identify effective interventions. Using a mixed-methods approach, this study combined qualitative and quantitative data to gain a comprehensive understanding of the challenges faced by the municipality. The findings reveal significant issues such as aging asbestos cement pipes, insufficient maintenance practices, governance inefficiencies, and a lack of adequate funding—all of which negatively impact the reliability of water supply.

Research Question 1 focused on identifying the key factors contributing to infrastructure deterioration. The results confirmed that aging infrastructure—specifically asbestos cement pipes comprising 83% of the water network—was a major cause of frequent service interruptions and water losses. Insufficient maintenance and limited capacity in municipal institutions were also highlighted as critical challenges.

Research Question 2 explored the effects of inadequate infrastructure management on the community. Findings indicate that both planned and unplanned interruptions severely disrupt daily activities, particularly in areas such as Meyerton and Randvaal. Issues with Blue Drop compliance, especially regarding chlorine levels, also pose significant public health risks, underscoring the detrimental effects of poor water management on the well-being of residents.

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Research Question 3 sought potential solutions for improving water infrastructure management. Respondents highlighted several key interventions, such as enhancing governance frameworks, adopting innovative technologies like smart metering, fostering community involvement, and implementing capacity-building initiatives to fill skill gaps in water management.

5.2 Recommendations

To address the challenges facing Midvaal Local Municipality's water infrastructure, a comprehensive approach involving infrastructure upgrades, enhanced maintenance and monitoring, governance reforms, and financial and capacity-building support is essential. One of the most pressing needs is the replacement of aging asbestos cement pipes, starting with high-risk areas that frequently experience service disruptions. Additionally, upgrades to water treatment facilities, such as the Vaal Marina Reservoirs, are crucial to maintain adequate chlorine levels and ensure compliance with health and safety standards.

Enhanced maintenance and monitoring are also key components in mitigating water service issues. Structured preventive maintenance schedules should be implemented to reduce unexpected failures and extend the lifespan of infrastructure. Furthermore, the deployment of innovative technologies, such as smart metering and advanced leak detection systems, would improve real-time monitoring, minimize water losses, and boost operational efficiency.

Governance and institutional reforms are necessary to improve water infrastructure management. Strengthening governance frameworks involves clearly defining roles and responsibilities within the municipality to streamline decision-making processes and enhance accountability. Establishing a dedicated water infrastructure management body could provide better oversight and ensure sustained progress. Engaging the community in decision-making is also important to foster transparency, build public trust, and ensure infrastructure initiatives meet the needs of residents.

Financial and capacity-building support will play a critical role in the municipality's ability to manage and maintain its water infrastructure. Exploring alternative funding models, such as public-private partnerships (PPPs), can secure the necessary resources for infrastructure upgrades and bring in private-sector expertise. Additionally, targeted training programs for water system operators, technicians, and engineers should be implemented to build capacity, focusing on technical operations, maintenance, and regulatory compliance skills.

5.3 Limitations of the Study

The study encountered several limitations that influenced the scope and depth of the analysis. One significant limitation was the availability of comprehensive municipal data, which restricted the level of detail that could be achieved in certain areas of the research. Future studies should aim to use more extensive datasets to provide a deeper understanding of water infrastructure issues. Additionally, the relatively small survey sample size limits the generalizability of the findings. Larger and more diverse sample sizes in future research would offer more robust and representative insights.

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Another limitation is the geographic scope, as the study focused solely on Midvaal Local Municipality. Therefore, the findings may not fully represent the challenges faced by other municipalities across South Africa, which may have different contexts and challenges.

5.4 Future Research Directions

Building on the findings of this research, future studies could explore several areas to further enhance understanding of water infrastructure management. Comparative studies between Midvaal and other municipalities in South Africa could help identify best practices and provide a broader perspective on the challenges and potential solutions for managing water infrastructure. Another important area of future research is the investigation of the long-term financial impacts of non-revenue water (NRW) on municipal budgets and service delivery.

Understanding these financial implications could help justify increased investment in maintenance and monitoring technologies. Additionally, the role of digital technologies should be explored, specifically how innovations like real-time data analytics and smart metering could help modernize water infrastructure, particularly in municipalities that face financial and resource constraints. These areas of further investigation could significantly contribute to the development of more sustainable water infrastructure management practices.

5.5 Final Conclusion

The results of this study underscore the need for substantial reforms in water infrastructure management within Midvaal Local Municipality. Addressing aging infrastructure, inadequate maintenance, and governance inefficiencies is crucial to ensuring a reliable water supply. The proposed recommendations—including infrastructure upgrades, stronger governance, the adoption of advanced technologies, and greater community engagement—can collectively enhance the reliability of the water supply and promote resilience within the community.

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