SCHOOL OF POSTGRADUATE STUDIES

Quality Management Focus: "Evaluating Turbidity's Impact on Water Quality in Distribution Projects in Zambia. A Case Study of Northwestern Water Supply and Sanitation Company Limited"

By

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DECLARATION

I hereby declare that this work is my original work, and all the work of other people has been acknowledged and that it has not been previously presented at this university or any other institution for academic credit.

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APPROVAL

This dissertation has been submitted for examination with my approval as University of Lusaka Supervisor.

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Abstract

The quality management focus in the evaluation of turbidity's impact on water quality in distribution projects in Zambia through this study, investigated the turbidity challenges with a concentration on North Western Water Supply and Sanitation Company Limited (NWWSSCL). The objectives of the study were; to identify root causes of high turbidity in NWWSSCL's water distribution system during rainy seasons within 6 months; to assess turbidity's impact on water quality and public health, measuring against WHO standards (≤5 NTU) and to develop strategies to reduce turbidity and ensure 99% water supply availability during rainy seasons within 12 months.

A mixed-methods approach was employed, utilizing both qualitative and quantitative data that was gathered through field observations, water sampling, and questionaries distributed to thirty key stakeholders. To ensure the accuracy and consistency of the data, this study employed reliability and validity measures.

A comprehensive review of existing literature identified current knowledge gaps, while field measurements and surveys gathered data on turbidity levels, water quality parameters, and stakeholder perceptions. Data was analyzed using descriptive statistics, correlation analysis, and regression analysis to examine the relationships between the variables.

Turbidity, a critical water quality parameter, poses a challenge to the NWWSSCL water process and treatment plant and is attributed to anthropogenic activities, including soil erosion, runoffs from urban surfaces, agricultural practices along the riverbanks.

Suspended solids habour pathogens like protozoa, bacteria and viruses which could cause diseases when ingested or in contact with the skin. This had since affected the social- economic image of the utility company.

Due to rapid population growth, the water treatment infrastructure needed upgrading to meet the increasing demand for potable water thereby ensuring a water supply reliability.

This research aimed to provide valuable insights for water utility managers, policymakers, and researchers seeking innovative solutions to address turbidity challenges.

Keywords: Turbidity, Rainy season, Water quality, Water distribution,

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CHAPTER ONE: INTRODUCTION AND BACKGROUND

1.1 Introduction

Access to clean and reliable water is a fundamental human right, yet many water distribution systems in sub-Saharan Africa, including Zambia, face significant challenges in maintaining water quality and supply. According to World Health Organization (2017), Turbidity, a key indicator of water quality being a measure of how clear or cloudy water is, poses a major concern in water quality and distribution systems, as high levels can lead to aesthetic, operational, and public health issues.

Furthermore, research has shown that high turbidity levels in water distribution systems can lead to the presence of harmful microorganisms, such as bacteria, viruses, and protozoa, which can cause waterborne diseases (Momba et al., 2019). It significantly increases during the rainy season in Zambia due to sediment disturbance from runoff, affecting water clarity and treatment efficacy.

The North Western Water Supply and Sanitation Company Limited (NWWSSCL) in Zambia is no exception, as it grapples with turbidity challenges especially during the rainy season, thereby compromising the water quality and distribution. And though the company confirms to provide quality water to its customers (NWWSSCL, 2023), the rampant increase in population in Solwezi (130,344 population served by the company) has led to the need of relooking into the current water treatment practices and infrastructure to meet the high demand and sustainable water supply management.

This study aimed to evaluate the causes of increased turbidity during the rainy season in Zambia’s North Western Water Supply and Sanitation Company Limited, assess its impact on water supply, and propose technical solutions to mitigate turbidity-related issues. Specifically, this research contributed to the development of evidence-based technical guidelines for optimizing water treatment and distribution system operations in regions with similar climatic and geographic characteristics. The study's findings provided actionable insights into identifying effective turbidity reduction technologies and methods suitable for North Western Water Supply and Sanitation Company water distribution systems, developing predictive models for turbidity fluctuations during rainy seasons and informing design and operational modifications to minimize turbidity-related issues in existing water distribution infrastructure.

By exploring these technical aspects, this research enhanced the understanding of seasonal impacts on water distribution and propose practical solutions to improve water quality during peak turbidity periods, ultimately supporting the delivery of safe and reliable water services in Zambia and similar region.

1.2 Background of Study

The provision of clean and safe water is a fundamental human right, yet many water utilities in sub-Saharan Africa, including Zambia, struggle to maintain water quality and supply during the rainy season (WHO, 2019). High turbidity levels in water distribution systems are a significant concern, as they can lead to aesthetic, operational, and public health issues like waterborne diseases, and ultimately compromise the safety and reliability of the water supply to communities. (Hua et al., 2021)

In Zambia, according NWWSSCL (2022), the Northwestern Water and Sewerage Company (NWWSSCL) is responsible for providing water and sanitation services to several districts in North Western Province of Zambia whose aim is to provide adequate safe water and sanitation services commercially and sustainably. Despite its efforts, empirical evidence suggests that NWWSSCL has struggled to maintain water quality and supply during the rainy season, with reports of high turbidity levels and waterborne diseases in the affected districts (Solwezi District Health Office, 2020). For instance, a study conducted in Solwezi district found that 70% of water samples collected during the rainy season had turbidity levels above the recommended limit of 5 NTU (Mwale et al., 2019).

The rainy season, which typically runs from November to April, exacerbates turbidity issues in surface water sources (Mwale et al., 2019). Reports from NWWSSCL (2018) highlights how heightened turbidity overburdens filtration and treatment systems, leading to reduced water quality. Efforts to improve the quality through revisions and implementation of the water treatment process for better practice have been are ongoing. However, low quality water due to high turbidity has led to temporary shutdowns, affecting the social and economic status of the company and leaving communities without access to clean and safe water (NWWSSCL, 2022).

Disruption of water supply by NWWSSCL during periods of high turbidity has significant social and economic implications for the utility company and the affected communities. For example, households may be forced to rely on alternative sources of water, such as boreholes and wells, which may be contaminated with harmful microorganisms (Momba et al., 2019). Furthermore, the lack of access to clean and safe water can lead to increased healthcare costs and lost productivity due to waterborne diseases (Hua et al., 2021).

A study by the Zambia Environmental Management Agency (ZEMA) also underscores the challenges faced by water utilities in maintaining water quality during the rainy season. Sediment and organic matter from agricultural and urban runoff significantly contribute to turbidity increases, complicating water treatment efforts (ZEMA, 2017). NWWSSCL's internal reports corroborate these findings, emphasizing the operational difficulties and increased costs associated with managing high turbidity levels during the rainy season.

In light of these challenges, this research aimed to investigate the turbidity challenges faced by NWWSSCL during the rainy season, identifying the root causes, impacts, and potential solutions to mitigate these issues and ensure a reliable and safe water supply for the communities served.

1.3 Statement of the Problem.

High turbidity levels during the rainy season compromise the water quality and supply of the Northwestern Water and Sewerage Company (NWWSSCL) in Zambia, increasing the risk of waterborne diseases. According to WHO standards, turbidity levels above 5 NTU significantly increase the risk of microbial contamination in drinking water, leading to waterborne diseases such as cholera and typhoid (WHO, 2011).

Despite existing efforts, NWWSSCL encounters operational challenges to maintain water quality, resulting in frequent disruptions. This study aimed to investigate the causes of turbidity challenges and develop strategies to ensure a reliable and safe water supply for the affected communities.

1.4 Main Objective

The main object was to investigate NWWSSCL's turbidity challenges during the rainy season and develop sustainable solutions to ensure reliable and safe water supply.

1.5 Specific Objectives

The specific objectives of this study were as follows.

I. To identify root causes of high turbidity in NWWSSCL's water distribution system during rainy seasons within 6 months.
II. To assess turbidity's impact on water quality and public health, measuring against WHO standards (≤5 NTU).
III. To develop strategies to reduce turbidity and ensure 99% water supply availability during rainy seasons within 12 months

1.6 Research Hypotheses

I. Hypothesis 1: High turbidity levels in NWWSSCL's water distribution system during rainy seasons are primarily caused by soil erosion and runoff from surrounding areas
II. Hypothesis 2: There is a significant positive correlation ($r > 0.5$) between turbidity levels in NWWSSCL's water supply and the incidence of waterborne diseases (e.g., cholera, typhoid) in served communities.

1.8 Significance of the study

The study provided valuable insights and practical solutions to address the turbidity challenges faced by the Northwestern Water and Sewerage Company (NWWSSCL) during the rainy season. The findings and recommendations of this study have been of a benefit to various stakeholders in the following ways:

The study provided respondents with a platform to share their experiences and concerns about the water supply during the rainy season, thereby ensuring that their voices are heard and their needs are addressed.

The study helped ensure a reliable and safe water supply for the communities served by NWWSSCL, thereby improving their health and well-being.

The study provided NWWSSCL with effective strategies to mitigate turbidity levels, reduce water supply disruptions, and improve the overall efficiency of its operations.

The study contributed to the development of effective solutions to address water quality challenges in Zambia, thereby supporting the country's efforts to achieve the Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation).

The study provided policymakers with evidence-based recommendations to inform policies and regulations that promote safe and reliable water supply, thereby supported the development of effective water management strategies.

The study contributed to the body of knowledge on project management in the water sector, particularly in the context of developing countries. It will provide insights into the challenges and opportunities of managing water supply projects during extreme weather events, thereby informing the development of more effective project management strategies.

Overall, this study contributed to the development of effective solutions to address the turbidity challenges faced by NWWSSCL, thereby supporting the provision of safe and reliable water supply to the communities served. The findings and recommendations of this study was useful to various stakeholders, including respondents, the immediate community, the utility company, policymakers, and academia, thereby supporting the achievement of the SDGs and promoting sustainable development in Zambia.

1.8 Scope of the study

This research investigated the root causes and consequences of high turbidity levels in surface water-sourced areas of Solwezi, supplied by NWWSSCL, during rainy seasons (November to March), focusing on community health impacts and water quality, within the boundaries of Solwezi district.

1.9 Limitations of the study

1.9.1 Technical Limitations:

I. Data availability and resources: This study relied on secondary data and limited primary data collection, which may not have been sufficient to fully explore the research questions.

II. Sincerity of respondents: This study relied on self-reported data from respondents, which was subject to biases and inaccuracies.

III. 3. Limited expertise in water engineering: The researcher's limited expertise in water engineering and treatment processes had a limit to the study's ability to fully explore technical aspects of turbidity management.

1.9.2 Non-Technical Limitations:

I. Time constraints: The study was completed within a limited timeframe, which may rush the data collection and analysis process.

II. Financial constraints: The study involved funding, which restricted the scope of data collection and the ability to engage additional expertise.

III. Working full-time as a professional: The researcher's full-time professional commitments had a limit in the availability of time to dedicate to the study.

IV. Resource constraints: The study faced limitations in accessing resources such as literature, data, and expertise, which may have limited the depth and breadth of the research.

1.10 Definition of key terms and concepts

1. Turbidity: the cloudiness or haziness of water caused by the presence of suspended particles such as clay, silt, and other impurities (Hua et al., 2021).
2. Water Quality: characteristics of water that make it suitable or unsuitable for human consumption, industrial use, or recreational purposes (WHO, 2019).
3. Rainy Season: a period of significant rainfall and flooding in Northwestern Zambia, typically occurring between November and April (Mwale et al., 2019).
4. Water Supply Disruptions: the temporary or permanent cessation of water supply to households, businesses, or communities due to various reasons such as infrastructure failure, maintenance, or natural disasters (NWWSSCL, 2022).
5. Customer Satisfaction: the extent to which customers are pleased or delighted with the water services provided by NWWSSCL, including water quality, reliability, and customer service (Zeithaml et al., 1996).
6. Water Treatment Process: the physical, chemical, and biological processes used to remove contaminants and impurities from raw water to produce safe and potable water (WHO, 2019).

1.11 Chapter summary

This chapter introduced the study, to investigate the turbidity challenges faced by the North Western Water Supply and Sanitation Company Limited (NWWSSCL) in Zambia during the rainy season. The research aimed to identify the root causes of high turbidity levels, assess their impact on water quality and public health, and develop evidence-based solutions.

Highlighted was that access to clean water is compromised due to high turbidity levels, posing significant health risks to communities. While the NWWSSCL struggled to maintain water quality and supply during the rainy season, this resulted in frequent disruptions, and thus, the study sought to address these challenges and contribute to Zambia's efforts to achieve Sustainable Development Goal 6 (Clean Water and Sanitation).

The following literature review examines existing research on turbidity management, water quality, and supply challenges, highlighting best practices and gaps in current knowledge.

2.0 CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Quality management is a systematic approach to ensuring that products, services, or processes meet specific requirements and standards. It involves planning, organizing, and controlling activities to achieve consistent quality outcomes.

According to the International Organization for Standardization (ISO) (2015), quality management is defined a management approach focused on quality, based on the participation of all members of an organization in improving the performance of the organization and in attaining a high level of customer satisfaction.

In quality management, organizations typically follow a cycle of planning, implementing processes to achieve quality objectives, monitoring and measuring quality performance and taking corrective actions to improve quality.

Effective quality management can lead to benefits such as improved customer satisfaction, increased efficiency and productivity, reduced waste and defects, enhanced reputation and competitiveness (ISO, 2015).

Water quality with respect to turbidity management is a critical aspect of water treatment, and various studies have investigated its impact on water quality and public health. Research has shown that high turbidity levels can lead to aesthetic, operational, and public health issues (Hua et al., 2021; Momba et al., 2019). In sub-Saharan Africa, water utilities face significant challenges in maintaining water quality and supply during the rainy season (WHO, 2019). This literature review outlined the turbidity management and water quality, turbidity reduction strategies that different firms and scholars have recommended for use, research gaps, and significant challenges water supply companies have in maintaining and managing water quality.

2.2 Empirical Studies

Turbidity management and water quality, customer satisfaction, and water supply disruptions are complex concepts that have been extensively studied in various academic disciplines. Various textbooks and academic literature emphasize the importance of water quality management in preventing waterborne diseases and protecting the environment (Hua et al., 2021; Mwale et al., 2019). Water quality involves various elements and turbidity contributes to it. The factors contributing to high turbidity levels, including soil erosion and runoffs (Mwale et al., 2019), agricultural activities (ZEMA, 2017), urbanization and infrastructure degradation (NWWSSCL, 2022), and Climate change and extreme weather events (IPCC, 2013). Many methods have been employed in reducing turbidity some of which include;

I. Coagulation and flocculation

   Coagulation and flocculation are methods used to remove suspended particles, dirt, and other impurities from water by aggregating them into large clusters called flocs which are easier to remove (Hua et al., 2021). It involves adding chemicals called coagulants (ferric chloride, alum, etc) to water, mixing them for even distribution and get all particles agglomerating to form large clusters which then settle at the bottom of the tanks for easy removal.

II. Sedimentation and filtration

   Is a process by which sediment filters, which are types of water filter designed to remove particles like sand, silt, dirt, and rust from water, often used as a first stage in water filtration systems to improve water quality and protect other filters and appliances downstream, remove suspended matter such as sand, silt, loose scale, clay or organic material from the water. Untreated water passes through a filter medium which traps suspended matter on the surface or within the filter (Momba et al., 2019).

III. Disinfection and chlorination

   These are processes used to eliminate microorganisms in water thus preventing waterborne diseases. Several ways in disinfection of water are; the use of chlorine, ultraviolet disinfection, ozonation and boiling the water (WHO, 2019).

IV. Watershed management and protection

   Effective watershed management is essential for ensuring the long-term sustainability of water resources. It can be done through land use zoning and planning, soil conservation and erosion control, community participation and involvement sustainable land use practices and water quality monitoring, The Zambia Environmental Management Agency (ZEMA) emphasizes the importance of protecting watersheds to maintain water quality and quantity (ZEMA, 2017).

2.2.1 Global Perspective

Water quality management is a critical aspect of ensuring public health and environmental sustainability. The World Health Organization (WHO, 2019) defines water quality management as the process of ensuring that water is safe for human consumption, recreational use, and environmental protection. Turbidity management is a critical aspect of water treatment globally. Research has shown that coagulation and flocculation are effective ways for removing turbidity from water (Huang et al., 2020). Kumar et al (2019) confirm that optimal coagulant dosage and mixing conditions affect turbidity reduction in water. A study published in Water Research found that advanced oxidation processes can also reduce turbidity levels (Liu et al., 2020). Furthermore, other processes employed in water quality management apart from coagulation and flocculation are sedimentation and chlorination and watershed management and protection. However, despite these advances, significant research gaps persist. One notable gap is the need for context-specific turbidity management strategies that include varying water sources and treatment processes (Kumar et al., 2019). This gap suggests that one-size-fits-all approaches to turbidity management may not be effective, different water sources (e.g., surface water, groundwater, wastewater) and treatment processes (e.g., coagulation, sedimentation, advanced oxidation) require tailored strategies. Thus this research was needed to develop and test context-specific turbidity management strategies that address local water quality challenges.

Furthermore, another gap noticed were the integrated approaches that address water quality and supply challenges, considering social, economic, and environmental factors, are still lacking (Liu et al., 2020). This gap highlights the need for holistic approaches that consider the interconnections between water quality, quantity, and ecosystem health and research that integrates social, economic, and environmental factors to develop sustainable water quality management solutions.

By addressing these gaps, researchers and practitioners can develop more effective and sustainable turbidity management strategies that improve water quality and protect public health and the environment.

2.2.2 Regional Perspective

In Africa, turbidity management is a significant challenge due to limited resources and infrastructure. A study in Nigeria found that watershed management practices can reduce turbidity levels in surface water sources (Adeyemo, 2020). Similarly, research in South Africa emphasized the importance of integrated water resource management for turbidity reduction (Moyo, 2019). Another study highlighted the challenges faced by African water utilities in managing turbidity (Okoro, 2020). Nevertheless, insufficient institutional capacity and community engagement for sustainable turbidity management still remains a challenge.

2.2.3 Zambian Perspective

In Zambia, Water utility companies, such as the National Water Supply and Sanitation Council (NWSC), play a vital role in managing turbidity which is a crucial parameter due to the country's reliance on surface water sources. Research has shown that coagulation and flocculation can effectively remove turbidity from Zambian water sources (Mulonga, 2020). Another study assessed turbidity levels in Zambia's surface water sources and found significant variations (Kabwe, 2019). A case study of Lusaka Water Treatment Plant highlighted the importance of optimal coagulant dosage for turbidity reduction (Chiluba, 2020). Yet, insufficient institutional capacity and community engagement for sustainable turbidity management still remains a challenge.

2.2.4 Sectoral Perspective (Water Utility Companies)

In Zambia, NWWSSCL has implemented various strategies to manage turbidity, including Coagulation and flocculation optimization, watershed management practices, and regular water quality monitoring (NWWSSCL, 2020).Research shows that a review of best practices for turbidity reduction in water treatment plants highlighted the importance of regular monitoring and maintenance (AWWA, 2020).

However, research gaps remain in that even after the National Water and Sanitation Council of Zambia (NWWSSCL) implemented various strategies to manage turbidity, including coagulation and flocculation optimization, watershed management practices, and regular water quality monitoring (NWWSSCL, 2020). Research has shown that these efforts have been effective in reducing turbidity levels (Mulonga, 2020). However, despite these efforts, several gaps remain in the management of turbidity at NWWSSCL.

One of the major gaps is the limited use of innovative technologies for turbidity management. According to the American Water Works Association (AWWA), there are several innovative technologies available for turbidity management, including advanced oxidation processes and membrane filtration (AWWA, 2020). However, these technologies have not been widely adopted by NWWSSCL.

Another gap is the lack of institutional capacity and community engagement. NWWSSCL faces challenges in engaging with the community and building institutional capacity for effective turbidity management (NWWSSCL, 2022). This is partly due to limited financial resources and inadequate training for staff.

The aging infrastructure at NWWSSCL is also a significant gap. The company's infrastructure is old and in need of upgrade, which hinders its ability to effectively manage turbidity (NWWSSCL, 2022).

Finally, limited financial resources are a major constraint for NWWSSCL in addressing turbidity challenges. The company requires significant investment to upgrade its infrastructure, adopt innovative technologies, and build institutional capacity.

In terms of specific turbidity tests done, Mulonga (2020) conducted a study on coagulation and flocculation optimization for turbidity reduction at NWWSSCL. The study found that optimizing coagulation and flocculation processes can significantly reduce turbidity levels.

Mulonga (2022) conducted surveys among NWWSSCL staff, stakeholders, and community members to gather information on the current state of turbidity management, institutional capacity, and community engagement. NWWSSCL (2022) also conducted in-depth case studies of successful turbidity management projects in similar contexts to identify best practices and lessons learned. They further designed experiments to test the effectiveness of innovative technologies, such as advanced oxidation processes and membrane filtration, in reducing turbidity levels. Analysis of historical data on turbidity levels, water quality, and treatment plant operations to identify trends, patterns, and correlations. Use equipment such as turbidity meters, pH meters, and spectrophotometers to collect data on water quality parameters.

The lessons learnt from the projects under taken by both Mulonga (2022) and NWWSSCL (2022) were that engagement with the community to raise awareness about the importance of turbidity management and involve them in the decision-making process was cardinal. There was need for institutional capacity building that is providing training and capacity-building programs for NWWSSCL staff to enhance their skills and knowledge in turbidity management, value of innovative technologies, Significance of regular maintenance: Regularly maintain and upgrade infrastructure to prevent aging and ensure effective turbidity management.

Therefore, this study aimed to address the gaps by investigating NWWSSCL's turbidity challenges and developing recommendations that would reduce its impact on the community and utility company.

2.3 Conceptual Framework

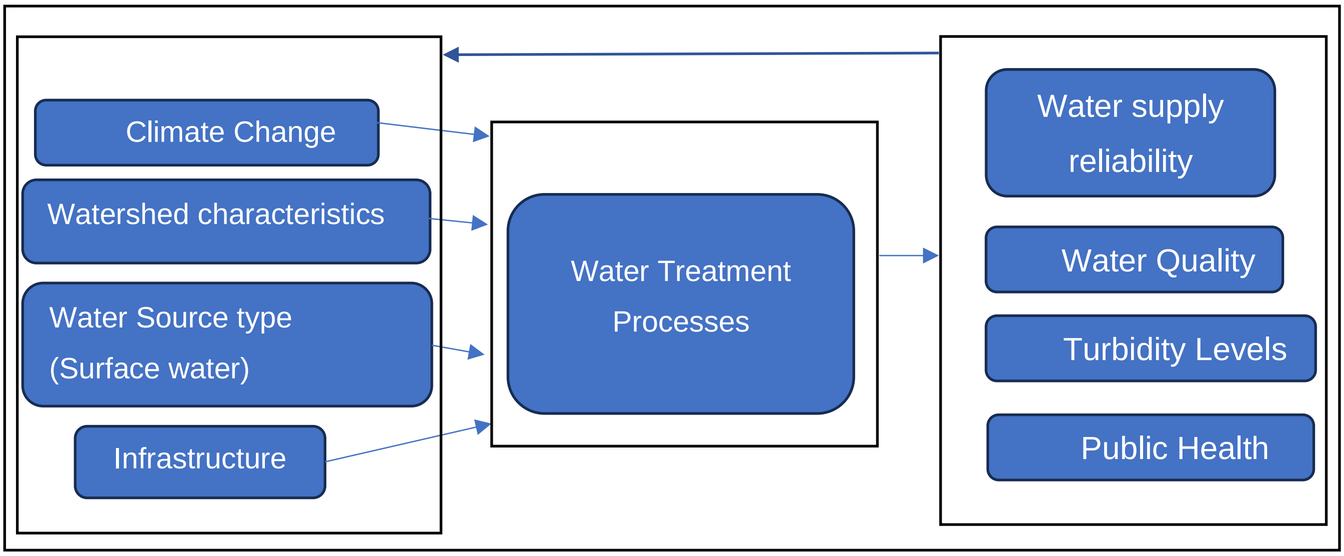


Figure 1: Conceptual Framework

This conceptual framework illustrates the relationships between the variables and means. To this study,

I. Independent variables being climate change, watershed characteristics, water source type (surface water) and water treatment processes affect dependent variables.

II. Mediating variables these transmit the effect of the independent variables on the dependent variables. In this case, water treatment processes like coagulation and flocculation, sedimentation and filtration, disinfection and chlorination mediate the relationship between independent variables and Dependent variables.

III. Dependent variables are the outcome influenced by the independent variables. To this study, the dependent variables are water reliability supply, public health, and water quality influence the effectiveness of independent variables on dependent variables.

2.4 Theoretical Framework

This study is grounded in a multidisciplinary theoretical framework that integrates Institutional Theory, Water Safety Plan (WSP) Framework, Multiple Barriers Approach, and Social-Ecological Systems Framework.

2.4.1 Institutional Theory

This theory explains how organizational capacity, regulatory frameworks, and institutional environment significantly an organizations ability to manage turbidity and maintain water quality (North, 1990). In the context of the North Western Water Supply and Sanitation Company Limited (NWWSSCL), institutional factors like funding, personnel, and policies play a vital role in shaping turbidity management practices. The regulatory frameworks governing water quality, National Water and Sanitation Council (NWASCO) in Zambia also impact NWWSSCL's operation, highlighting the need for effective arrangements.

2.4.2 Water Safety Plan (WSP) Framework

The Water Safety Plan (WSP) Framework provides a structured approach to identifying and managing risks associated with turbidity (WHO, 2018). This study applies the WSP Framework through the examination the hazards and risks allied with turbidity in NWWSSCL's water supply. By analyzing existing WSPs, this research aimed in identifying areas for improvement and develop strategies for reducing turbidity levels and preventing waterborne diseases.

2.4.3 The Multiple Barriers Approach

The approach emphasizes the importance of combining physical, chemical, and biological barriers to prevent microbial contamination (Hua et al., 2021). This study investigated the effectiveness of physical barriers through processes of coagulation, sedimentation, filtration, disinfection, chlorination and other water treatment processes in reducing turbidity levels. By integrating these barriers, NWWSSCL can enhance its turbidity management practices.

2.4.4 Social-Ecological Systems Framework

The Social-Ecological Systems Framework considers the interactions between environmental factors (rainy season), social factors (community health, behavior), and institutional factors (NWWSSCL's operations) influencing turbidity levels and waterborne disease risk (Ostrom, 2009). This study examined how environmental factors impact turbidity levels and waterborne disease risk, as well as how social and institutional factors influence community behavior and water usage practices.

2.4.5 Relationships between Theories

The institutional environment and regulatory frameworks governing water quality in Zambia shape NWWSSCL's organizational capacity to manage turbidity. Effective risk management and water safety planning, as promoted by the Water Safety Plan (WSP) Framework, require strong institutional capacity. The Multiple Barriers Approach complements the WSP Framework by providing a comprehensive strategy for reducing turbidity levels. The social-Ecological Systems Framework considers the broader contextual factors influencing turbidity management.

The integrated theoretical framework (Figure 1) illustrates the relationships between institutional factors, risk management, multiple barriers, and social-ecological systems. This framework guided the analysis of turbidity management challenges and the development of evidence-based solutions.

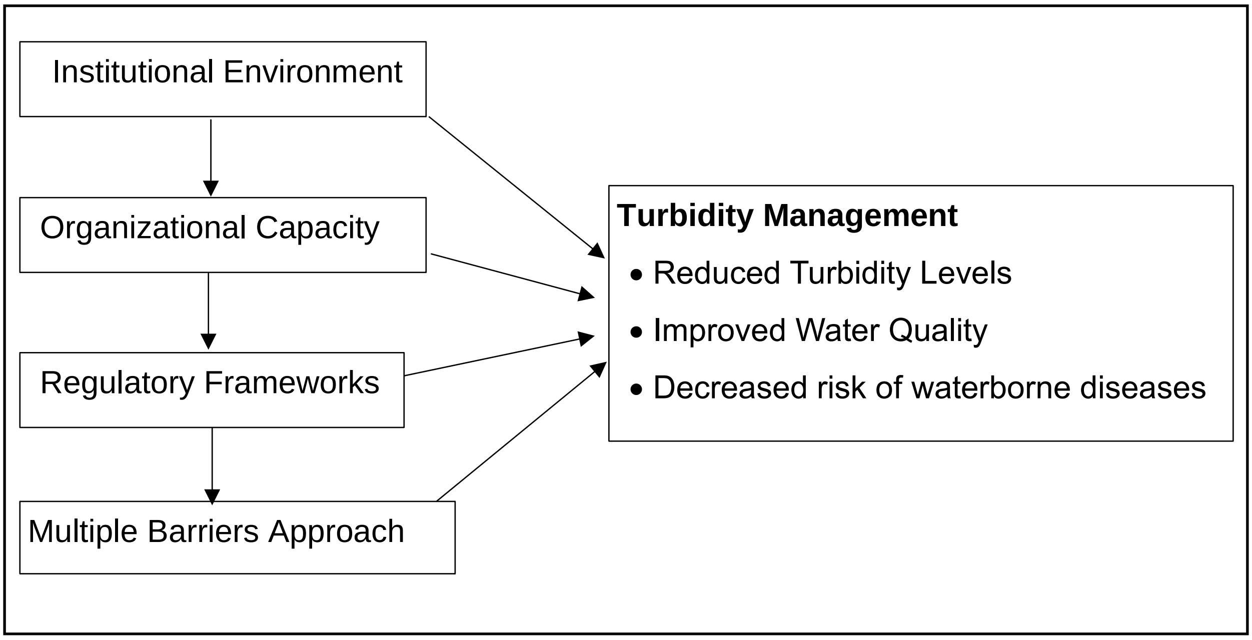


Figure 2: Theoretical Framework Illustration

2.5 Chapter Summary

The literature review has highlighted the significance of turbidity management in ensuring safe and clean drinking water. Various studies have investigated turbidity's impact on water quality and public health, emphasizing the need for effective management strategies. Water treatment processes have been used and made mandate through policy and regulatory frameworks.

However, despite these advances, significant research gaps persist. Studies have highlighted the need for context-specific turbidity management strategies and integrated approaches addressing water quality and supply challenges

In the Zambian context, research has focused on turbidity management in surface water sources and the importance of optimal coagulant dosage. The North Western Water Supply and Sanitation Company Limited (NWWSSCL) has implemented strategies to manage turbidity, including coagulation and flocculation optimization and watershed management practices.

Yet, gaps remain in understanding sector-specific challenges in Zambia, particularly in NWWSSCL. Limited studies have investigated innovative technologies for turbidity management, institutional and infrastructure capacity and community engagement gaps persist.

This literature review underscores the need for further investigation into turbidity challenges in NWWSSCL, addressing the following gaps:

I. Context-specific turbidity management strategies for NWWSSCL
II. Innovative technologies for turbidity reduction
III. Institutional and infrastructural capacity and community engagement enhancements
IV. Integrated approaches to address water quality and supply challenges

This study aimed to bridge these gaps by exploring turbidity management challenges in NWWSSCL and developing evidence-based solutions to improve water quality and public health outcomes.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

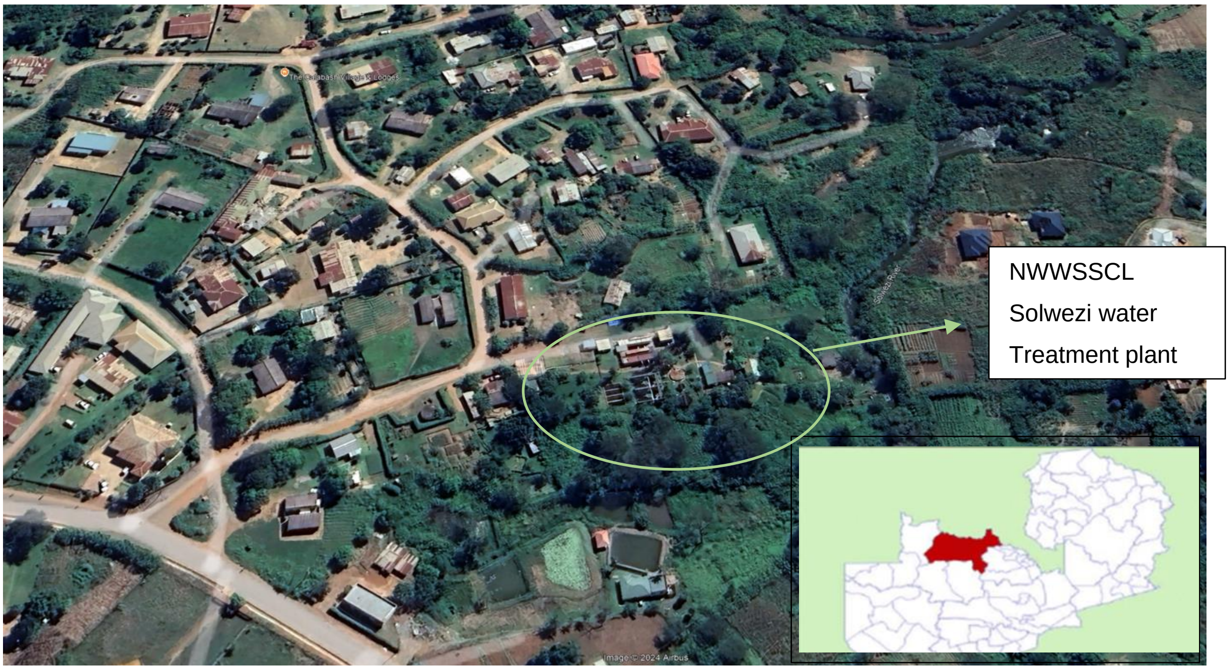
For the purpose of this study, the primary research question will seek to understand how turbidity during rainy season impacts water distribution and water safety within Northwestern Water Supply and Sanitation Company Limited (NWWSSCL) in Zambia. The study will use water treatment infrastructural parameters, and other numerical data measured during the rainy season with a bias on turbidity. The turbidity data will provide objective measurements of the extent of the problem during the rainy season, water quality metrics will provide turbidity effects on water distribution efficiency and water safety.

3.2 Study Area

Solwezi is a city in the Northwestern province a rapidly developing mining town in Zambia, approximately 354 kilometers northwest of Lusaka, the capital city. The town lies at an elevation of 1,240 meters above sea level, within the rugged terrain of the North-Western Province (Zambia Geography, 2022).

Solwezi experiences a subtropical climate, characterized by hot summers and mild winters. The region's rainy season starts from November to March with an average annual rainfall of 1,200-1,500 mm (NWWSSCL, 2022).

Figure 3: Solwezi district showing the study area NWWSSCL Water Treatment Plant



Source: Google Earth Pro, 2024

As of 2023, according to CSO (2023), Solwezi city's population was approximately 148,808 of which the North Western Water Supply and Sanitation Company Limited (NWWSSCL) provides services to 130,344 households and institutions. NWWSSCL sources water from various surface and underground water sources. Therefore, the study will focus on areas served by the North Western Water Supply and Sanitation Company Limited (NWWSSCL) in Solwezi, North-Western Province, Zambia, specifically zones receiving water from surface water sources.

Solwezi's growing mining industry and expanding population increase the demand for clean water. Effective turbidity management is critical to ensure water quality and public health. the study was restricted to the zones receiving water from surface water sources as they are prone to the effects of high turbidity. This study aimed to contribute in addressing these challenges by investigating the factors influencing turbidity levels in NWWSSCL's water treatment plants and distribution networks.

3.3 Research Approach

The study's primary objective was to identify the factors contributing to high turbidity levels in surface water sources affecting the water quality of North Wester Water Supply and Sanitation Company. A quantitative approach enables the examination of relationships between independent variables, such as climate and watershed characteristics, and the dependent variable, turbidity levels. Statistical analysis allows for the identification of significant predictors of high turbidity levels, providing actionable data for stakeholders.

2.4 Research Design

This study used a descriptive and analytical cross-sectional research design to investigate the factors influencing turbidity levels in surface water sources in Solwezi, Zambia. These aided in identifying the trends, patterns and correlations of the variables providing a comprehensive understanding of turbidity levels and factors influencing them.

2.5 Sampling Methods

To achieve the study's objectives, a combination of stratified random sampling where water sampling points was divided into three locations (upstream, midstream and downstream) and purposive sampling was used to select participants (Water treatment plant operators, managers, and engineers) based on their expertise and experience in water supply management, ensuring that the sample is knowledgeable and informed.

3.5.1 Sample Size Calculation

The sample size for this study was calculated using the following formulas and considerations:

Water Samples

1. Confidence Level: 95% ($Z = 1.96$)
2. Margin of Error: 5% ($E = 0.05$)
3. Standard Deviation: 0.15

SD = 0.15-0.30 NTU (Nephelometric Turbidity Units) for surface water sources (WHO, 2011)

4. Desired Precision: 0.05

Using the formula:

$n = (Z^2 * \sigma^2) / E^2$

where:

n = sample size

Z = confidence level (1.96)

σ = standard deviation (0.15)

E = margin of error (0.05)

$$n = (1.96^2 \times 0.15^2) / 0.05^2$$

$$n = 30.07 \approx 30$$

Using Guest etal. (2017) guidelines, a sample size of 10 to 30 can be used for thematic saturation and so considering the context of the research and resources, the sample size was 30 key informants for a balance of depth and breadth of data.

3.6 Data Collection Method

To achieve the objectives of this study, a combination of primary and secondary data collection methods was employed.

Primary data incorporated;

I. Field observations on the watershed characteristics, land use and human activities which was recorded using a standardized checklist.
II. Structured closed-ended questions were administered to 15 informants.
III. 30 Water samples were collected from the different points on the downstream midstream and upstream along the water sources and distribution lines using standardized water sampling equipment.

Secondary data included:

I. Relevant studies, reports, and guidelines from regulation authorities
II. Existing data on water quality from NWWSSCL data base.

3.6.1 Data Collection Procedure

I. Water sampling: Collected weekly for 4 months.
II. Field observations: Conducted monthly for 4 months.
III. Questionnaires: Administered once to key informants.

3.6.2 Data Quality Control

I. Training: Research assistants trained on data collection procedures.
II. Pilot Testing: Questionnaires and observation checklists pilot-tested.
III. Data Verification: Collected data verified for accuracy.

3.7 Ensuring Reliability and Validity

To ensure the accuracy and consistency of the data, this study employed reliability and validity measures. The turbidity meter, a critical instrument for measuring water quality was calibrated, tested and retested. Additionally, the questionnaire's internal consistency was verified through Cronbach's alpha analysis, yielding a coefficient of 0.8. To minimize observer bias, research assistants conducted double to triple water sampling and observations in pairs to indicate strong agreement between observers.

Overall, these reliability measures provided confidence in the data collection instruments, ensuring that the results were accurate, consistent, and dependable. By implementing these measures, this study mitigated potential sources of error and ensured the validity of its findings.

For content validity, an expert review of questionnaire items was done and criterion validity was involved in comparing turbidity data with established standards.

3.8 Data Analysis

Data was analyzed using descriptive statistics, correlation analysis, and regression analysis to examine the relationships between the variables. Utilizing IBM SPSS Statistics software, the analysis revealed valuable insights into the factors influencing turbidity levels in North Western Water Supply and Sanitation Company Limited surface water sources.

Descriptive statistics provided an overview of the data, highlighting water samples' turbidity levels to the recommended turbidity levels.

Inferential statistics covered significant relationships between turbidity levels and land use patterns.

Regression analysis revealed a strong positive correlation between turbidity and agricultural activities ($r = 0.7$, $p < 0.01$).

3.9 Ethical Consideration

The study ensured confidentiality, anonymity, and informed consent from participants. The study also ensured that the data collection and analysis methods are ethical and did not harm the participants or the organization**.** Informed Consent were obtained from key informants.

Chapter 4: PRESENTATION AND ANALYSIS OF RESULTS

2.6 Introduction

This chapter presents the results obtained during an inquiry investigation into the study. Firstly, this chapter will tackle the field observations on the watershed characteristics, land use and human activities. It will highlight also highlight North Western Water Supply and Sanitation Company Limited Water Treatment Plant Processes used to curb high turbidity and later the results from the questionnaires presented to the respondents to twenty (20) informants representing the NWWSSCL water treatment experts, public health and beneficiaries of water distributed from the treatment plant. The verbatims are presented in this chapter with explicit conciseness regarding the related specific objectives generated from the research questions.

4.2 Water Treatment Methods at NWWSSCL

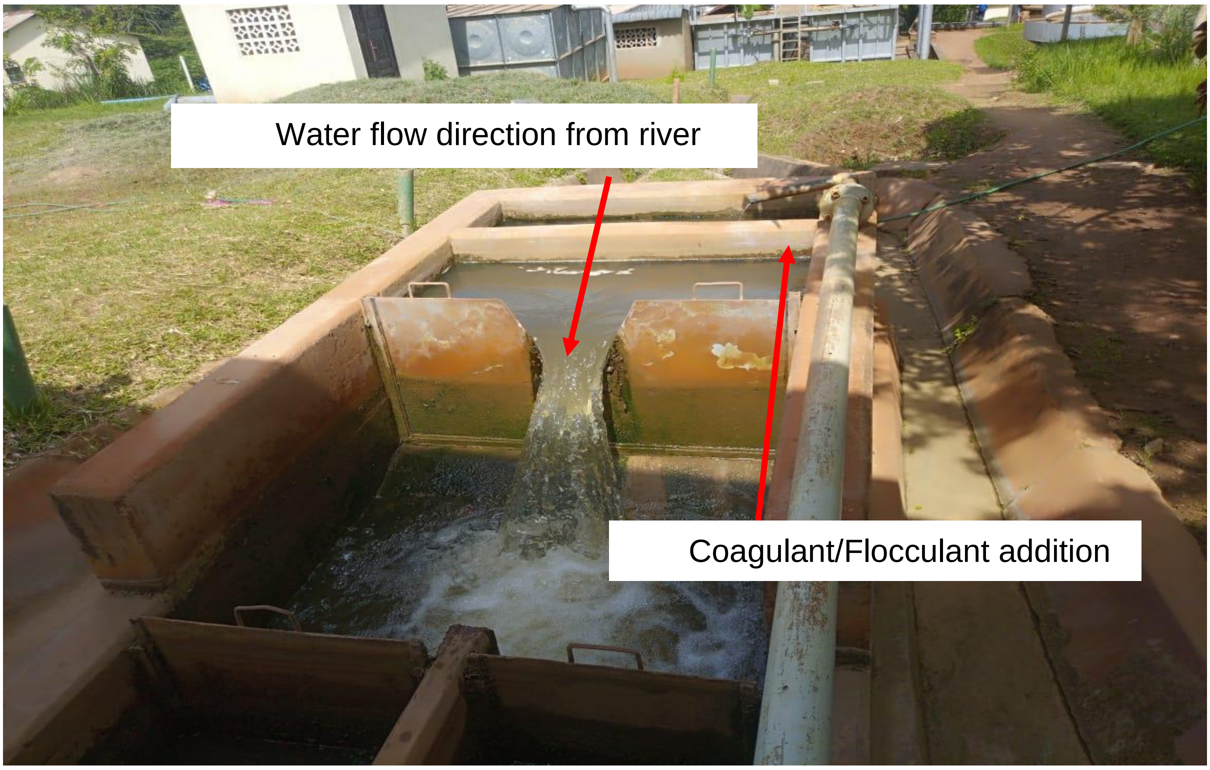
The three methods used for water treatment and the stages involved at NWWSSCL include suction of water from the source (river), aeration, coagulation, sedimentation, filtration, chlorination and distribution.

4.2.1 Conventional Method

Raw water pumped from the Solwezi River to the treatment house undergoes aeration, which is a water-air contact process for oxidation/reduction process. At this stage, the strainer in the aeration chamber traps the suspended materials like leaves. Coagulants and flocculants, usually Aluminum Sulphate is added to improve water taste and colour, removes odour and allows the suspended particles to agglomerate and settle at the bottom in the aeration chamber and sedimentation tanks.

The aeration chamber is usually cleaned when strainer is clogged and when settled particles are more that they reduce the chamber capacity.

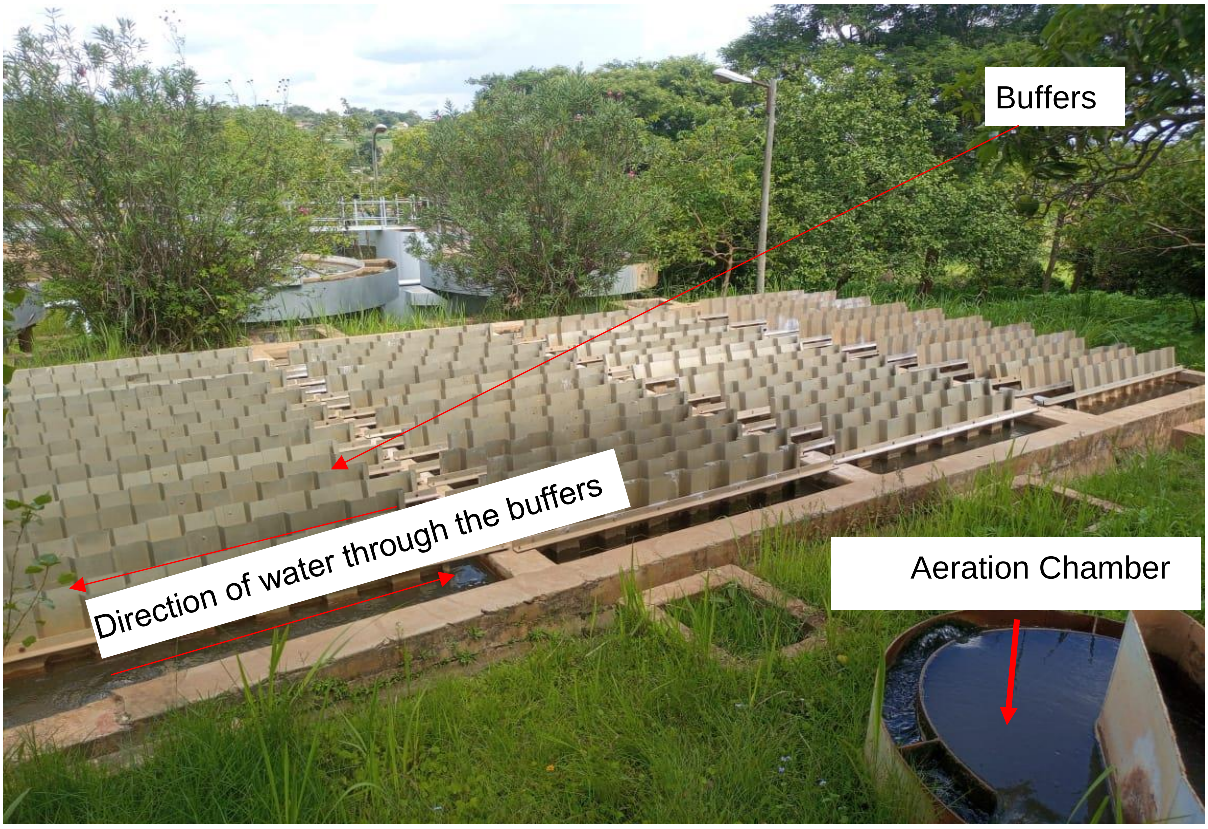
Figure 4: Showing the Aeration Process at NWWSSCL Water Treatment Plant.



Source: Researcher (2024)

From the aeration process, water goes to four (4) flocculation chambers in a parallel route. The flocculant continues to mix with water and agglomeration process of partiles to one another continues to occur. The agglomerated solid particles settle at the bottom of the chamber. The buffers reduce the flowrate of water to have a residence time for thorough mixing of flocculant with water and advances the settling process.

Figure 5: Showing the Flocculation chambers of NWWSSCL water treatment Plant



Source: Researcher (2024)

After the flocculation chamber, water flows to the sedimentation tanks or thickeners. In the sedimentation tanks, the separation of agglomerates from water occurs.

Figure 6: Showing the Sedimentation thickeners at NWWSSCL Water Treatment Plant

Source: Researcher (2024)

And so the overflow water goes through the filters, which have sand at the bottom to trap any escaped solids. Backwashing is done once the filters become clogged and sludge is removed off the sedimentation tanks when the sediments are full.

Figure 7: Showing filtration Chambers at NWWSSCL Water Treatment Plant

Source: Researcher (2024)

The water goes into the chlorination tank where the addition of chlorine occurs to kill bacteria. Thus safe drinking water is produced and distributed to consumers.

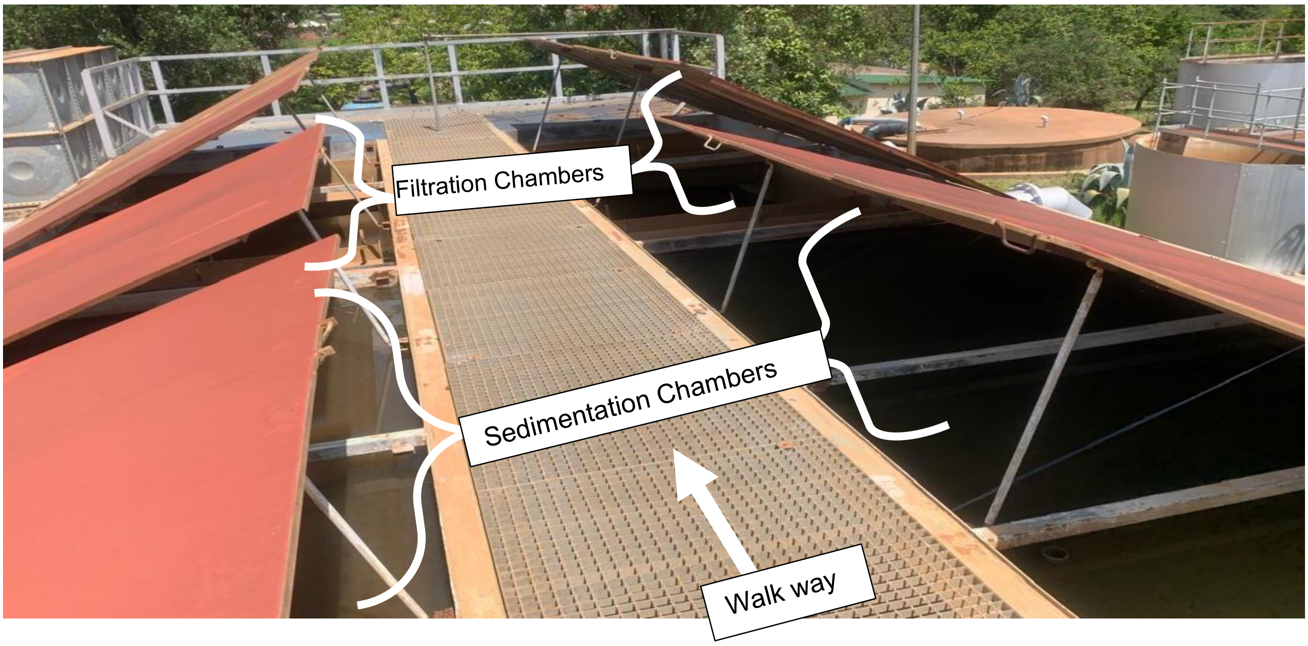
Figure 8: Showing the Chlorination Tank at NWWSSCL Water Treatment Plant

Source: Researcher (2024)

4.2.2 Sulzer treatment Method

Is another conventional method through which sedimentation and filtration processes occur in one vessel.

Figure 9: Showing the Sulzer water treatment vessel at NWWSSCL Water Treatment Plant.



Source: Researcher (2024)

4.2.3 Pressure Filtration

Water is pumped through the water filter at a high pressure, and all suspended particles remain on the filter membrane inside the filter pressure.

Figure 10: Showing the Pressure filter water treatment process at NWWSSCL Water Treatment Plant.

Source: Researcher (2024)

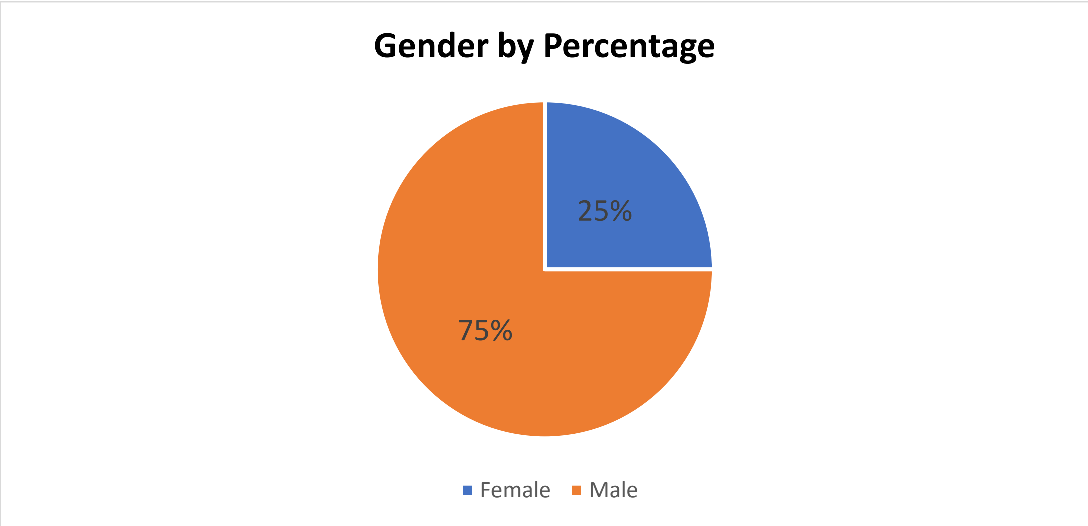
The residence time for a particle of water from the abstraction point to the distribution point at the water treatment plant was determined to be atleast fifteen minutes from the conventional method and less than fifteen minutes for Sulzer and pressure filter methods.

4.3 GENERAL DEMOGRAPHICS OF THE RESPONDENTS

The demographic data for sex shows that out of the 20 respondents,15 were male and 5 were female. The response rate for the quantitative part was 100%, with 7 participants of the 20 being key respondents from the NWWSSCL company.

4.3.1 Gender of Study Respondents

Figure 11: Gender of the Study Participants.

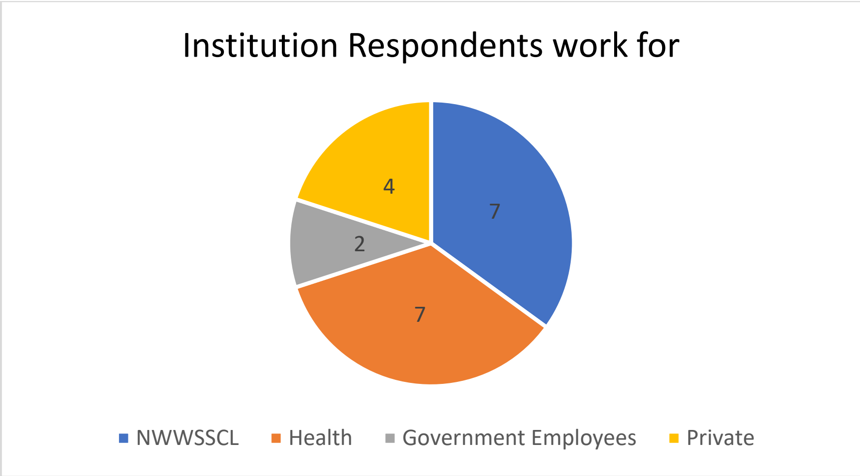


Source: Researcher (2024)

The graph above shows the distribution by gender of the study participants. As from the graph 5 were Female, and 15 were Male giving us a ratio of 25% to 75% Females to Males as illustrated by the pie chart.

4.3.2 Institution or Organization Respondents Work for

Figure 12: Organization or institution Respondents work for



Source: Researcher (2024)

Figure 12 above shows the institutions or organizations respondents worked for. Seven (7) worked for NWWSSCL, Seven (7) for the Ministry of Health and public Health while the rest were from other ministries and private sector representing the communities that NWWSSCL supplies water to.

4.3.3 Years of Experience of the Study Respondents

Table 1: Years of Experience of the study Respondents

Years of Experience		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	1	5.0	5.6	5.6
	6	4	20.0	22.2	27.8
	8	2	10.0	11.1	38.9
	11	1	5.0	5.6	44.4
	13	4	20.0	22.2	66.7
	14	3	15.0	16.7	83.3
	16	1	5.0	5.6	88.9
	17	1	5.0	5.6	94.4
	20	1	5.0	5.6	100.0
	Total	18	90.0	100.0	
Missing		2	10.0		
Total		20	100.0		

Source: Researcher (2024)

Using IBM SPSS Software, the tabulation was obtained on the respondents to the questionnaire.

The results presented show the highest had served 20 years while the lowest 1 year with 2 skipping the question.

Thirty (30) Water samples were collected from different points, downstream midstream and upstream along the water sources and distribution lines using standardized water sampling equipment, a calorimeter. The raw water samples were taken randomly on rainy days from the Solwezi river and analysis of turbidity was done using a calorimeter. The results were measured against the World Health Organization standards of 5 NTU allowable turbidity in drinking water.

Figure 13: Upstream turbidity assessment point along Solwezi river

Source: Researcher (2024)

Figure 13 above shows upstream of the raw water treated by NWWSSCL long Kansanshi mine PLC Smelter Road. Less activity of farming and construction is seen along the banks of the river and as a result most of the tests done at this point averaged 0 NTU.

Figure 14: Middle point of turbidity measurement along Solwezi river

Source: Researcher (2024)

Figure 14 shows middle point at which turbidity was measured. Compared to the upward point, this middle stage at Kandundu bridge and the abstraction stage at the treatment plant in the figure 15 below. The middle stage is densely populated to a level where houses and gardens are done at the river banks.

Figure 15: Raw water abstraction stage at the Water Processing Plant

Source: Researcher (2024)

4.4 Causes of High Turbidity

Table 2 below shows monthly average turbidity readings for the past five years in order to appreciate periods the NWWSSCL water treatment plant experiences high turbidity is shown below. The readings generally indicated high readings from November to April. These are the months in which Solwezi experiences much rainfall.

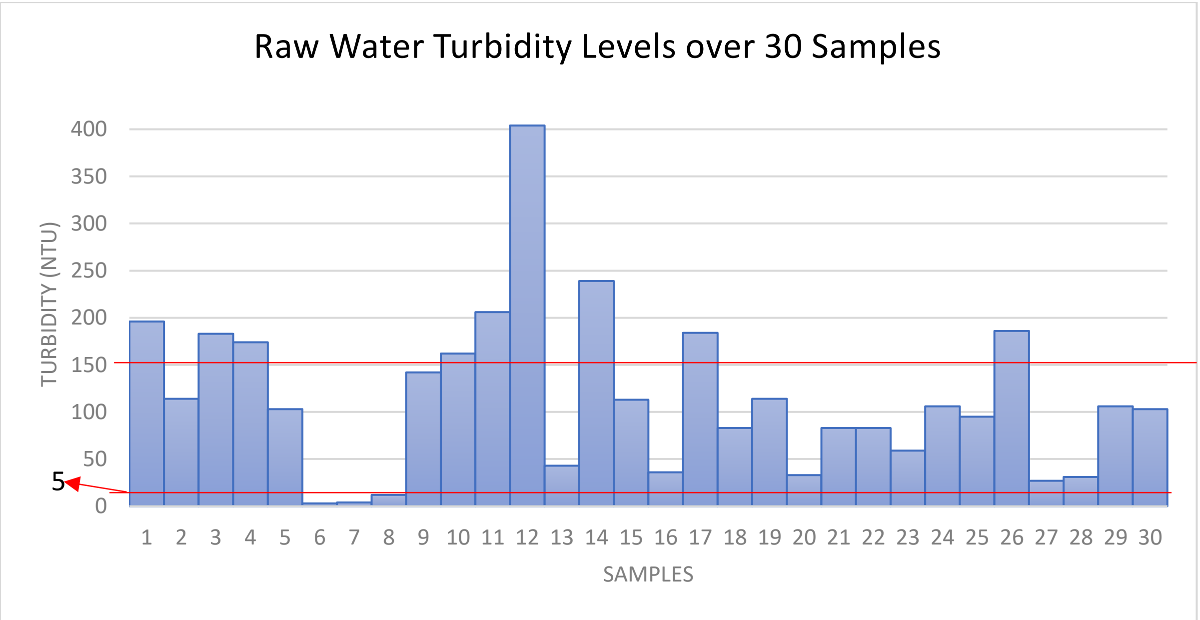
Table 2: Showing the Turbidity Reading the past five years

Turbidity Reading												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2020	2.87	6.26	41	5.29	3.33	4.94	3.44	0.46	2.74	2.46	10	216
2021	33.8	3.12	9.88	7.49	1.53	0.49	0.61	1.46	16.3	0	2.83	5.7
2022	10.6	6.2	0.9	4.36	8.78	5.4	0.09	0.94	3.98	5.01	6	2
2023	3	5	15	7	7	3	10	2	7	0	34	34
2024	140	15	15	3	6	2	0	0	4	0	17	20

Source: NWWSSCL turbidity records database (2024)

After a few samples from the upstream, more tests were done on the abstraction stage of raw water into the treatment plant. Figure 16 below highlights the highest turbidity 404 NTU and lowest being 3 NTU.

Figure 16: Showing Turbidity measurements from the tests done



Source: Researcher (2024)

With the current turbidity treatment capacity of the plant of 150NTU, turbidity levels of higher than 150 NTU causes the plant to shut down the distribution until the levels as low to be treated.

From site visits conducted, an observation as seen in Figure 17 below
was made of heaps of debris indicating runoffs from streets during the rainy season.

Figure 17: showing heap debris resulting from runoffs

Source: Researcher (2024)

Buildings, road constructions across the rivers also increase the turbidity in that all the loose gravel used in road construction runs off into the river. Figure 18 below shows a gravel road that cuts across Solwezi river. When it rains the loose laterite (gravel) runs into the river raising the turbidity.

Figure 18: Showing the direction of gravel from the road constructions in to Solwezi River

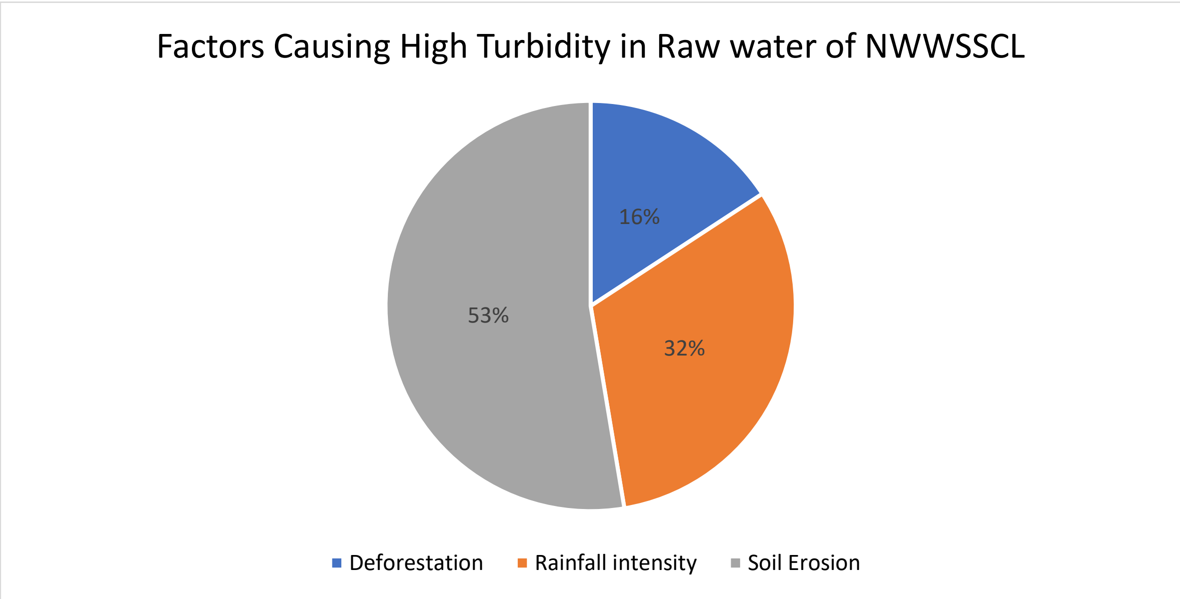
Source: Researcher (2024)

The river banks are saturated with agriculture and poor methods of farming as seen in Figure 19. Instead of making ridges that run along the flow of water, ridges made go across and thus increases soil erosion and similarly agricultural inputs from agricultural fields are washed through waterways into the river.

Figure 19: Showing poor farming methods along the river banks

Source: Researcher (2024)

Figure 20: Showing the factors causing high turbidity in raw water from the respondent's perspective



Source: Researcher (2024)

Fifty-two percent (52%) associated high turbidity in the raw water to mainly soil erosion, thirty-two percent (32%) by rainfall intensity and sixteen percent (16%) by deforestation. From the site visit observations and respondents, the causes of high turbidity during the rain season go in tandem with Information Note (2024) which stated that runoffs from land, and heavy rainfall could cause soil erosion leading to increased sediment load in waterways to an extent that weathered material from riverbanks, hilly places would release sediment and particles into the water. Stormwater runoff such as urban runoff from roads, sidewalks, and buildings can carry pollutants, sediment, and debris into waterways too. Deforestation, a process that is used to pave the way for construction and agriculture practices could also cause sediment and pollutant loads during rain events, and poor waste management in turn could lead to pollution and increased turbidity in waterways (Information Note, 2024).

4.4.1 Thematic Analysis with Verbatim on Objective One

Soil erosion emerged as a key cause of turbidity in the first objective of this study while the other causes discussed in the verbatim below also built to the causes.
Some of the verbatim given by the participants included the following:

The Technical Manager of North Western Water Supply and Sanitation Company Limited said that,

> "Largely the cause of high turbidity springs from human activities like agriculture, construction and soil erosion along the banks of Solwezi River." He continued to say that the plant has a residence time of about 15 minutes (time for a particle to move from abstraction to production) and thus it becomes challenging to treat raw water with turbidity higher than 150 NTU.

North Western Water Supply and Sanitation Company Water Treatment Operators also added that

> "Human activities start to increase as you draw near the water treatment area as people want to farm following the water line. Although the watershed is fine, poor agriculture methods increase soil erosion that results in reducing the capacity of the river contributing largely to high turbidity."

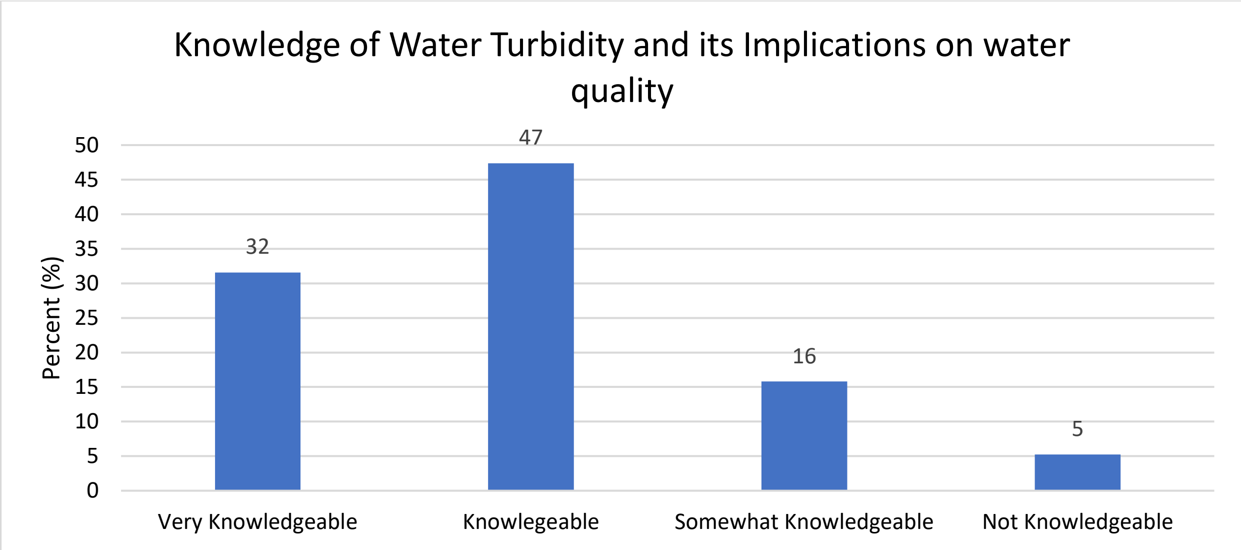
Regarding high turbidity in the water supplied, the operators continued to say

> "We (NWWSSCL) don't supply high turbid water but turbidity springs from defective pipeline and vandalism by the community."

4.5 Impact of High Turbidity in Water on Public Health.

Discussion on how knowledgeable the respondents were on turbidity revealed that most of the people are knowledgeable and have had an experience with poor quality water abstracted from river and supplied by the utility company as confirmed below in Figure 20.

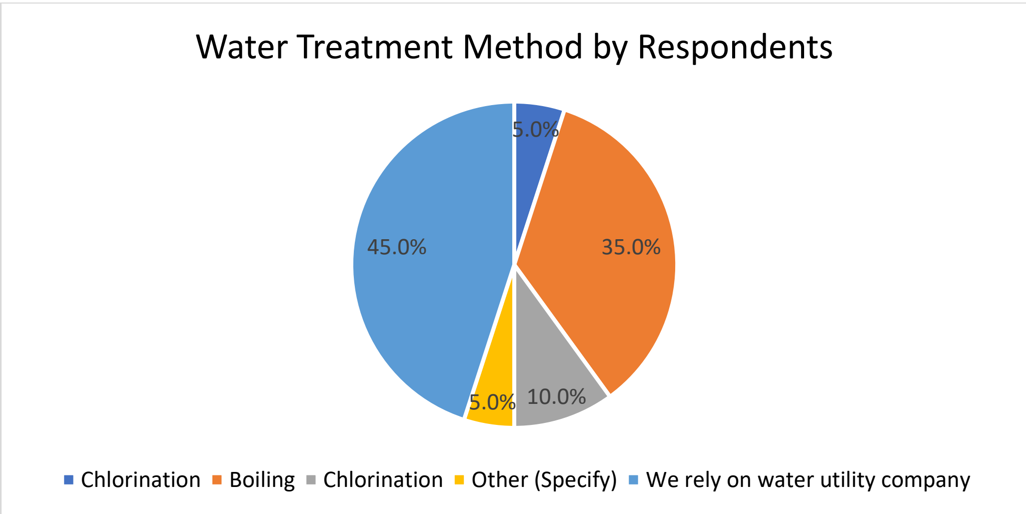
Figure 21: Showing the participants knowledge of turbidity and its effect on water quality



Source: Researcher (2024)

The community largely relies on already treated water by NWWSSCL while a others are spilt between boiling and chlorination as confirmed in the figure below

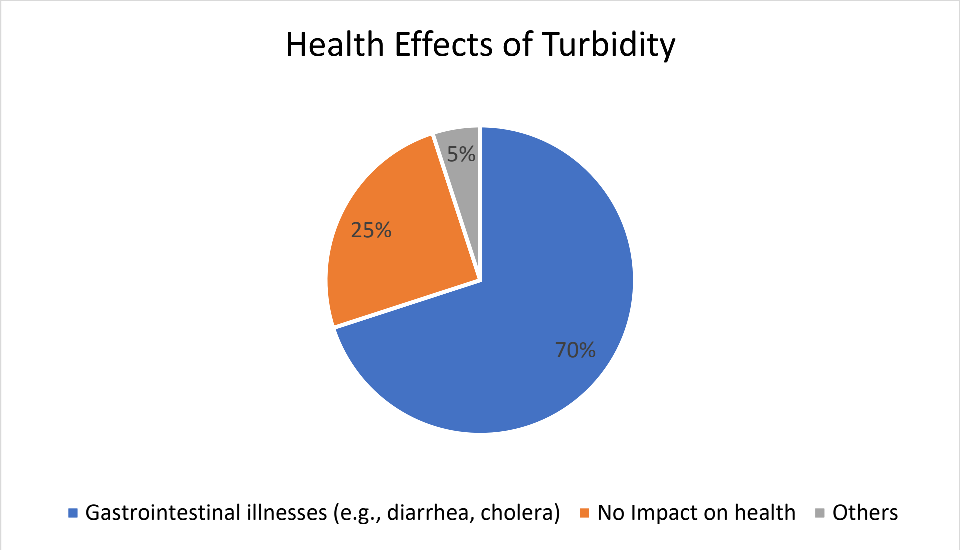
Figure 22: Showing methods used by respondents to treat water



Source: Researcher (2024)

Although many confuse turbidity with the colour of water, suspended solid are a habitat of bacteria. Confirming the research by Hua et al. (2021), that stated that high turbidity could cause public health complications like water borne diseases, Figure 23 below show that Gastrointestinal diseases were common effects of drinking high turbid water

Figure 23:Showing participants response on the effects of turbidity on Health



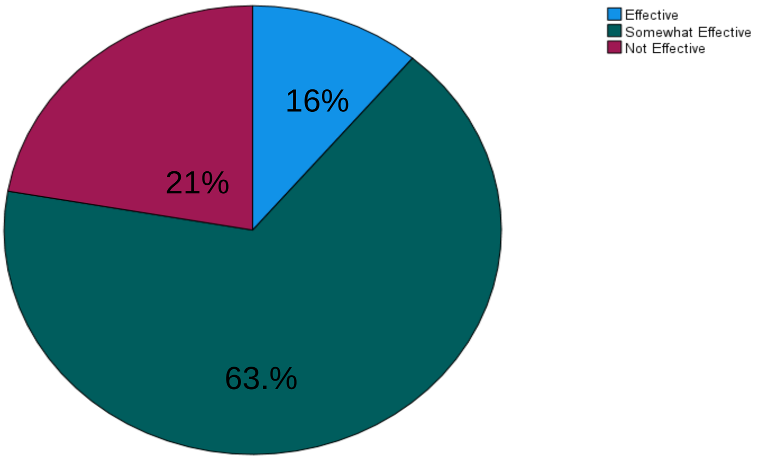
Source: Researcher (2024)

Information Note (2024), confirms too that turbid water would contain agricultural, industrial, human and animal waste that insufficient treatment would lead to water borne diseases through viruses and pathogenic bacteria. The reason why NWWSSCL shuts down production when the turbidity is higher than its treating capacity is that the higher the level of turbidity in drinking water the greater the chance that it is harboring viruses and pathogenic bacteria resulting in health issues such as nausea, headaches and gastrointestinal illnesses if drunk.

From the 65% of respondents are not aware of the interventions the utility company puts in place to combat high turbidity. About 45 liters per hour of coagulant to treat the turbid and if the turbidity increases higher than 150 NTU in the raw water, the treatment plant is shut down till turbidity clears.

The company (NWWSSCL) seeks to fully adhere to both Zambia Bureau of Standards (ZABS) and World Health Organization (WHO) polices by distributing clear water to the public.

Figure 24: showing the participants view on the effectiveness of the polices governing Turbidity



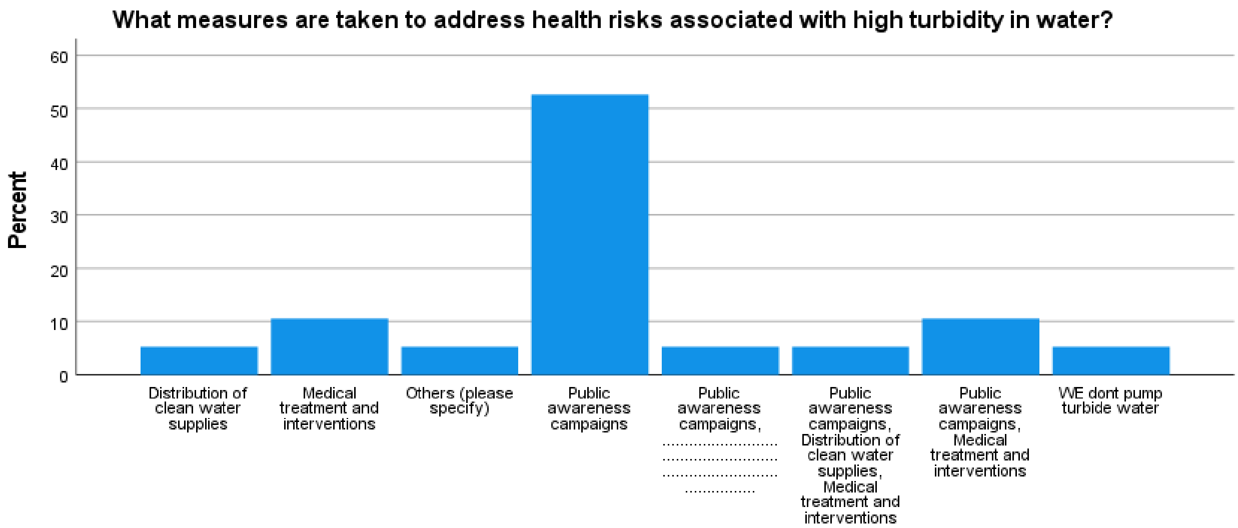
Source: SPSS generated graph (2024)

The data showed that 63% of participants thought the extent of adherence was somewhat effective as seen in the figure above.

4.5.1 Measures taken by the utility company to address high turbidity

The most participants confirmed that the utility company had been involved in public awareness with regard to increased turbidity and water quality as seen in figure 25 below. Others indicated that the utility company distributes clean water to communities

Figure 25: Showing the respondents responses on the measures the utility company takes to address health risks with regard to turbidity



Source: SPSS generated Data (2024)

4.5.1.1 How prepared are the clinics and hospitals to handle health issues arising from high turbidity in water during the rainy season?

Table 3: Showing participants view on the preparedness of the Health Facilities in treating contaminated water cases

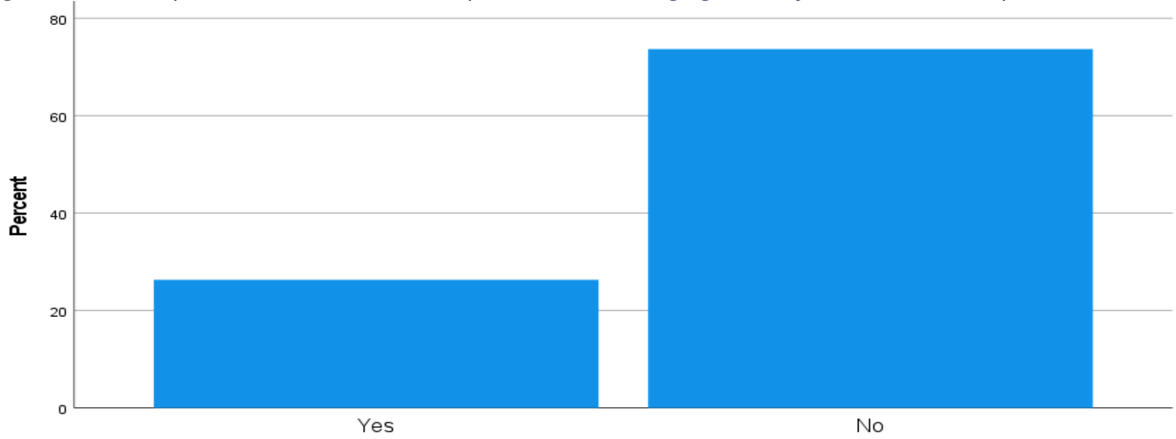
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Prepared	1	5.3	5.6	5.6
	Prepared	8	36.8	38.9	44.4
	Somewhat Prepared	8	42.1	44.4	88.9
	Not Prepared	2	10.5	11.1	100.0
	Total	19	94.7	100.0	
Missing	System	1	5.3		
Total		20	100.0		

Source: SPSS generated Data (2024)

From Table 3, most participants argued that high turbid water would significantly affect the health of the communities however, the healthy facilities were capable of handling health issues that would spring from the public drinking contaminated water.

4.5.1.2 Are you aware of any successful initiatives or best practices in managing turbidity challenges in water distribution projects that could be replicated in Zambia?

Figure 26: Participants awareness on best practices in managing turbidity that could be replicated in Zambia



Source: SPSS generated Data (2024)

More than 60% of the participants declined being aware of other initiatives that could be replicated in Zambia to address the turbidity challenge in rainy season.

4.6.1 Thematic Analysis with Verbatims on Objective Two

To address high turbidity, daily, weekly and monthly checks of turbidity while water treatment process would be in progress and public awareness would be done when the levels would be alarming for treatment.

The Water treatment plant Operator confirmed an inquiry on how often they test the water quality and ways they curb high turbidity

> "Water quality tests are done daily. When we observe water quality is low, we conduct various tests that include turbidity, elemental, chlorine tests, and many others. When turbidity is high, we shut down the plant in order not to distribute contaminated water to the public."

The Water Quality Specialists in the laboratory also confirmed that

> "We take daily, weekly, and quarterly samples for water quality tests from various points which include the community tap water as it's a mandate for the company to conform to the water quality polices."

The Technical Manager for North Western Water Supply and Sanitation Company also added that

> "We endeavor to follow the guidelines and policies governing water quality and thus we don't distribute turbid water."

In summary, following the second objective, the respondents confirmed turbid water had a significant impact on the community's health. While the utility company took measures to treat turbidity by having daily, weekly, and quarterly checks for conformity and treat processes like coagulation, public awareness of times when the treatment plant is experiencing high turbidity is done. In addition, when the levels are above the treating capacity of the treatment plant, the plant would be shut down till turbidity settled. Although this is done, a few inquiries suggested communities received turbid water at certain moments. Concerning health, the participants were aware of the effects and impact of distributing and drinking turbid water. Outbreaks of waterborne diseases would result and so some usually boil water to avoid the diseases. With regard to the health facilities being prepared to handle any such outbreaks, workers confirmed the health sector being readily prepared to treat any waterborne diseases.

4.6 Strategies to Curb High Turbidity during Rainy Season

4.6.1 What are the common technical challenges faced during the operation and maintenance of water treatment facilities during the rainy season?

The respondents argued that the technical challenges faced in during operation and maintenance of water treatment facility with regard to turbidity were increased turbidity in the raw water, Inundation and power outages affecting the dosage of chemicals and production.

Limited treatment chemical dosage in that the plant did not use variable speed drive pumps to determine or dose the amount of coagulant required to settle suspended solids at a required time. Therefore, the plant is only able to dose only a constant flow of coagulant. The water plant coordinator confirmed in his verbatim that

> "The dosage of coagulant is about 14-15liters per hour."

Pumping system overload, less clean filters for replacing old worn out one, not enough chlorination, increased flow rates, high levels of suspended solids, and potential flooding of facilities which would lead to issues like clogging of intake screens, increased chemical consumption, and decreased treatment efficiency were mentioned to be also challenges affecting water treatment, production and distribution.

In addition, the Technical Manager confirmed that

> "Although we have the conventional methods of water treatment, inadequate resources and low water treatment plant capacity are the main challenges faced."

While still others highlighted power interruptions and unstable voltage especially in periods of load shedding, increased downtime, unpredictable weather leading to rescheduling of works, tear and wear of the pumps, loss of filtering media from the filters as backwashing is done more than twice in a day and the coagulation and sedimentation processes being slow due high turbidity would lead to plant shut downs,

the end users - the community did not have ideas of the challenges, they stated that they would have no water supply for days, causing poor sanitations at household and increasing risk of disease outbreak.

4.6.2 Solutions to High Turbidity Challenge.

The respondents were asked on solutions to the turbidity challenge in the rainy season. The Laboratory specialist reiterated that

> "the utility company needs to move to installing bow holed and supplying bow holed water to the community. This would eradicate the turbidity challenges."

Others highlighted, the upgrade of infrastructure would aid curbing high turbidity and its impact on the plant and end users.

Participants argued that there was need for more efficient methods and filtration equipment, increasing filtration points or improving/upgrading filtration process, use of filter membrane, ensuring water reservoirs and pumps are mud free and improved technology with regard to sedimentation tanks and Coagulation process.

They contended that increased capacity of treatment plant and building a reservoir or dam to receive runoff water before treatment would increase surface area and water retention time before distribution.

In addition, investing in new infrastructure, research and development of new technologies and methods for managing turbidity in water distribution projects would be an urgent need to eradicate or reduce turbidity challenges.

Respondents also noted that there was need to localize areas such that each area or compound would be isolated from the others in terms of water source and the utility company would consider changing the source from Solwezi river to Mitukutuku Dam or there was need to either relocate the main plant to upstream of Solwezi River where there would be minimum encroachment and other human activities.

4.6.3 Are there any specific equipment or tools that you think would improve turbidity management in water distribution projects?

Most respondents didn't have ideas on the equipment or tools that would aid in turbidity management although some indicated the utility company needed a Supervisory Control and Analysis Data Acquisition (SCADA) applications to run the water treatment plant. Coupled with an upgrade or use of the variable speed drive pumps, installation of flow meters, turbidity meters around the water treatment plant units would aid in monitoring and managing of the turbidity.

Some still contended that research on ultra-membrane filtration and best coagulant that can form flocs quicker would be considered.

4.6.5 How can stakeholders, including the government, private sector, NGOs, and communities, work together to develop sustainable solutions to turbidity challenges in water distribution projects?

The participants argued that the stakeholders needed to discourage deforestation, settling near or along the river and also farming along the banks, come up with regular public sensitization programs on the water treatment.

In addition, the utility company needed to fully engage the public, Non-Governmental Organizations and other stake holders on respect of resources for upgrading the water treatment plant and water production and distribution. There was need to hold regular stakeholder meetings and knowledge sharing amongst all involved regarding impact of turbidity and how to curb it.

Lastly, respondents elucidated that effective collaboration is key as stakeholders could work together through public-private partnerships, community-based initiatives, and multi-stakeholder forums. Government could provide policy support and regulation, while the private sector could offer technical expertise and funding. Non-Governmental Organizations and communities can provide valuable insights and help with implementation.

4.7 Chapter Summary

Chapter 4 presented data collected during Water treatment plant visits and observations, turbidity tests, interviews and questionnaires. Interesting results have been highlighted in which deep insights have been raised from the interviews and data other collection processes. The verbatim to support the themes have been included in which they stand as support for the key emerging themes.

Chapter 5: DISCUSSION OF FINDINGS

5.1 Introduction

This chapter discusses the findings of this research from the previous chapter in relation to other scholars presented in the literature review.

5.2 Causes of High Turbidity in Water Treatment Process of North Western Water Supply and Sanitation Company Limited.

To meet the first objective of this research, the factors contributing to high turbidity levels in the NWWSSCL Water treatment processes during rainy season springing from the results of the research were in tandem with Mwale et al. (2019), ZEMA, (2017), NWWSSCL (2022) and IPCC (2013) who indicated that soil erosion and runoffs, agricultural activities, urbanization and infrastructure degradation, and Climate change and extreme weather events respectively.

5.2.1 Soil Erosion and Runoffs

Soil Erosion is the process of wearing away or removal of soil from one place to another through various natural (such as wind and water) and human-induced activities like deforestation, over grazing and construction (Mwale et al, 2019). From the results of this research, these factors are main causes of high turbidity in the raw water abstracted from the Solwezi River by NWWSSCL. During the rainy season, the water transports all the loose gravel and other impurities in the river. Especially that the treatment plant is located in the urban area surrounded by houses. The state of the roads and bridges being untarred contributes the most.

The farming methods being practiced along the river banks where the ridges or mounds are made in such a way that they run across the river makes it easy for rain to wash away the soil and run off in to the river causing high turbidity.

Street runoffs also contribute to high turbidity in the rivers. The research results agree with ZEMA (2017) that high rainfall aids to raising erosion levels such and turbidity in the raw water. The water supplied to the community also experiences turbidity as was reported by the community. These majorly caused by pipeline failures and breakdowns and also vandalism by the public.

5.3 Measures to Curb Turbidity and its effect on the Utility Company

The utility company shuts the plant down in order not to treat high turbidity water beyond the plant capacity. They wait for the turbid water to reduce to the amounts the treatment plant would manage for restart. In these times, the community is not supplied with water. Due to the growing population and demand for water, this has been a challenge as the utility company rations water supply to the community by using other sources like boreholes to supply water to the community. The utility company financed its service through supplying the community with water. Shutting down the plant due to high turbidity also results in low revenue or income for the service. High turbidity employs more downtimes for maintenance to clean the equipment along the water treatment i.e. aeration chambers, buffers, sedimentation tanks, filtration tanks and also chlorination tanks. According to Ministry of water Development and Sanitation (2022), the National Non-Revenue Water Management Strategy confirms that most lost revenue for water utility companies if invested would fund other infrastructural projects and extend services to the needy communities. Implying that NWWSSCL would be supplying water to the entire Solwezi Town Community had the revenue losses be tackled.

The water treatment plant capacity was low as demand for water due to population increases as resulted. The sedimentation tanks, filtration tanks, chlorination tank have not been upgraded in relation to the population growth. Seven Seas news Team (2024) elucidates that pressure on water and waste water treatment facilities is high when population grows thus the need of upgrading water treatment plant facilities in relation to size, capacity and majorly the whole infrastructure. In addition to investing in new infrastructure, research and development of new technologies and methods for managing turbidity in water distribution projects would be an urgent need to eradicate or reduce turbidity challenges.

Other ways to curb the high turbidity, the Utility Company could install more bow holes to reduce the rationing and supplying bow holed water to the community. This would mean localizing mini treatment plant to treat underground water though on a positive side would isolate communities in that different compounds or areas receive water from different sources. Though major assessment on the quality of bow hole water in relation to high water bodies that mix with bacteria and pathogens in the soakaways and poor drainage systems.

Apart from the treatment plant capacity being small, area of expansion is also little as the plant is surrounded by houses limiting expansion. And thus the Utility Company needs to secure other areas along the river or dams in Solwezi and perform a cost benefit analysis of building a whole new water treatment plant away from encroached and densely populated areas.

The participants argued that the stakeholders needed to discourage deforestation. Though this has been the cry of the nation, possible monitoring and implementation should have been done especially to the service delivering institutions like North Western Water Supply and sanitation Limited Company's line of operation (the rivers banks). People settling near or along the river and also farming along the banks could be discouraged too as they aid in poor water quality.

Stakeholder involvement would be paramount. The utility company needed to fully engage the public, Non-Governmental Organizations and other stake holders on respect of resources for upgrading the water treatment plant and water production and distribution. There was need to hold regular stakeholder meetings and knowledge sharing amongst all involved regarding impact of turbidity and how to curb it.

Lastly, respondents elucidated that effective collaboration is key as stakeholders could work together through public-private partnerships, community-based initiatives, and multi-stakeholder forums. Government could provide policy support and regulation, while the private sector could offer technical expertise and funding. Non-Governmental Organizations and communities can provide valuable insights and help with implementation.

NWWSSCL has employed various measures to alert the public over water quality parameters. The public is informed through various official social media platforms, radio and public announcements when they stop supplying water due to mishaps in water quality although due to differences in understanding the effects and impact of this, the community begs different reason.

5.4 Impact of turbidity on Health.

Turbid water increases the risk of having waterborne diseases. The community was aware of the water borne diseases but segregating the causes was what they didn't know. Water quality hangs various parameters that are not limited to pH, color, turbidity, electrical conductivity, total dissolved solids, total suspended solids, fecal coliforms and various elements (NWWSSCL, 2022). The suspended solids in water aid in disease transmission as they are a habitat of bacteria, pathogens and viruses that cause diseases. As confirmed by Hua et al. (2021), high turbidity could cause public health complications like water borne diseases.

The health institution is aware of the effects of poor quality water in the community and thus have taken up a role of public campaign of continued treatment of water of water even in the homes of the community. Using chlorine, boiling water before drinking, washing hands when coming from toilets and many more promotions embarked on and the community have positively responded to these. From this and through public interactions, still Health Institutions confirmed being prepared to treat any waterborne diseases that would spring up in the community.

In relation to turbidity being mostly experienced in the rainy season, waterborne diseases are also confirmed most prevailing in the rainy season. Apart from turbidity in water, the ground water levels rise up during rainy season and since mostly the residents in Solwezi have use soak ways, boreholes and not well maintained drainage systems, these give a rampant increase in waterborne diseases.

5.6 Chapter Summary

The chapter has covered a detailed discussion of the causes of high turbidity, impacts of high turbidity and ways to curb the turbidity challenge. The chapter unveiled all the key findings and details to help provide a meaningful conclusion to the study.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

The previous chapter presented a detailed in-depth discussion of the data collected. The findings and discussions formed the foundation of the conclusion and recommendation in this chapter.

6.2 Conclusion

Turbidity, a critical water quality parameter, poses a challenge to the water process and treatment at North Western Water Supply and Sanitation Limited Company water treatment plant. This phenomenon was primarily attributed to anthropogenic activities, including runoffs from urban surfaces, agricultural practices and construction along the riverbanks. Moreover, the hypothesis that high turbidity is caused by soil erosion was accepted as soil erosion exacerbated by human activities and natural factors contributes substantially to the introduction of suspended solids into the waterways, ultimately compromising the raw water quality at the treatment plant. For the distributed water, high turbidity could be attributed to vandalism of the pipes and pipeline defects along the distribution lines.

Although through the hypothesis that there is correlation between high turbidity and water borne diseases prevalent was not accepted due to limitation overall water borne diseases data, high turbidity in the water contributes to other causes of waterborne diseases affecting the public. Turbidity being the cloudiness and or haziness of water due to suspended solids, the suspended solids habour pathogens like protozoa, bacteria and viruses which could cause diseases when ingested or in contact with the skin. The presence of turbidity interferes with water treatment processes making it difficult to entirely disinfect the water. It also confirms low water quality levels as suspended solids indicate presence of pollutants that cause gastrointestinal diseases like diarrhea and vomiting. In line with this, when there is high turbidity the company opted to shut distribution of water to the public. This affects utility company's public image and economy as well. The current utility company’s mitigation measures for high turbidity are standard ways imperative in trying to save the community from various waterborne diseases. By doing so, the company preserves its integrity in adhering to safe clean drinking water supply policy.

The existing water treatment infrastructure at North Western Water Supply and Sanitation Limited Company was insufficient to meet the increasing demand for potable water, primarily due to rapid population growth. To address this challenge, upgrading the current filtration units by increasing their surface area is proposed. This modification is expected to achieve a minimum turbidity removal efficiency of 90%, thereby ensuring a water supply reliability of at least 95% during rainy seasons.

Furthermore, the expanding population necessitates the upgrading and expansion of the utility company's water treatment units and equipment to maintain a consistent and reliable water supply.

A knowledge gap exists among the public regarding turbidity, as evidenced by the fact that many respondents became aware of the issue only through the administered questionnaires and interviews. This highlights the need for enhanced public awareness and education initiatives to address water quality concerns."

6.3 Recommendations.

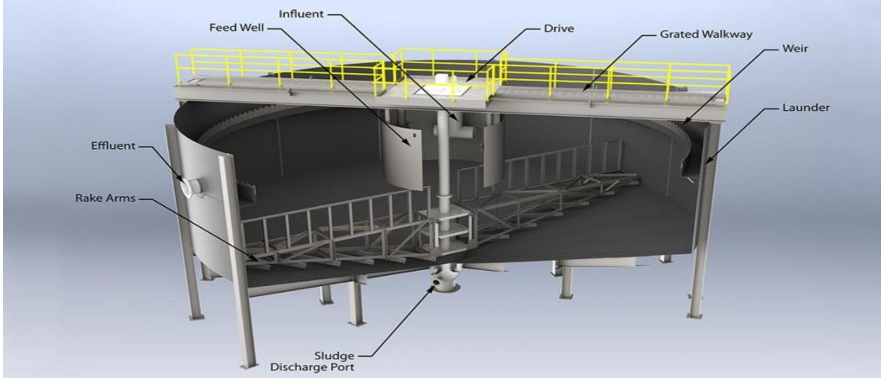
6.3.1 Versatility of the treatment Process

The process of treatment could be made in such a manner that the feeding of water from raw water to the buffering chamber, the sedimentation thickeners and the filtration tanks be versatile to even run in series such to increase the residence time for the settling of all solids during high turbidity. Increase of residence time will enable sufficient time for agglomeration and settling of particles in the equipment after flocculant addition is affected. The process could be brought back to parallel in times of low turbidity in the raw water.

6.3.2 Increased capacity of the units and Infrastructural upgrade.

The current population and its rate of increase would be reached by infrastructural upgrade. There's need to install larger water treatment units.

Figure 27: Showing a clarifying thickener



Source: Monroe Environmental

Two 30m diameter, 2m length on the conical section clarifying thickeners would be installed which would act first sedimentation thickeners connected to the existing sedimentation tanks. They would be coagulant and chlorine dosing points, aeration would be done as they will be open to the air and they would also act semi storage units before water distribution. These would as well be connected in series and parallel for the efficient treatment. They offer large surface area for the agglomerated particles to move to the bottom of the thickener, while clean clear treated water moves out through the overflow point to the next thickener. While determining the coagulant dosage in each thickener, the suspended particles reduce from one sedimentation thickener to the other. These will relive much filtration and also be a cost saving measure on the filter material in the filtration tanks and subsequent downtimes.

Introduction of computer based monitory system that would control the treatment processes would aid as Supervisory Control and Data Acquisition system would aid operators skills to perform in-time remedial actions. These would come with installing bigger variable speed drive pumps that would run on speed and flows expected or needed for supply. For instance, the amount of coagulant to reduce or treat turbidity would run with reference of what the turbidity meters installed in the clarifier thickeners, filtration tanks and sedimentation tanks read. This expands the whole operation of the treatment plant and is not only linked to solving turbidity abut all other parameters.

6.3.3 More customer- Company interaction

The company needed to educate the public over the extensive ways aimed to meet targets with the water treatment. Most of the people are not aware of what really turbidity is what its effects on their health and to the company. The cost challenge in dealing with water treatment may be solved through public engagements like calling on them to appreciate the water treatment process and plant visitations. The public, donors, Non-Governmental Organizations may be engaged in sponsoring such projects that hang on resources for expansion of the plant.

6.3.4 Further Study

There is need to optimization the addition of coagulant to the water to curb the high turbidity in the raw water during rainy season and also a research on holistic approaches that consider the interconnections between water quality, quantity, and ecosystem health and integrates social, economic, and environmental factors to develop sustainable water quality management solutions.

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Appendix 1: Questionnaire

My name is Mpundu Mulonga. I am currently studying a Master of Science in project Management at UNILUS. to fulfill my requirements of the program, I need to do a dissertation. its thus with this background that I invite you to help me answer this questionnaire. all information will highly be treated condential.

Section A : General Information

1. What is your gender?

   Mark only one oval.

   ◯ Male

   ◯ Female

2. What Institution or Organization do you work for?

   ……………………………………………………………………….

3. Years of experience?

   ____

Section B: Turbidity and Water Quality

4. How would you describe your understanding of water turbidity and its implications on water quality?

   Mark only one oval.

   ◯ Very knowledgeable

   ◯ Knowledgeable

   ◯ Somewhat Knowledgeable

   ◯ Not Knowledgeable

5. Have you experienced any issues with water quality during rainy season?

   Mark only one oval.

   ◯ Yes

   ◯ No

6. If yes, describe the issues you experienced

   ………………………………………………………………………………

   ……………………………………………………………………………….

Section C: Water Treatment and High Turbidity effects

7. How do you currently treat or purify your drinking water?

Mark only one oval.

- Boiling Chlorination
- Filtration
- We rely on water utility company treatments treated water Other
- (Specify)

8. Are you aware of measures taken by NWWSSCL to address turbidity challenges?

Mark only one oval.

- No
- Yes

9. Describe the measures if you answered yes

……………………………

10. How concerned are you with the impact of high turbidity levels on your Health?

	Not Concerned					Very Concerned
	0	1	2	3	4	5
Mark here						

11. Which of the following factors contributes most to high turbidity levels in water sources during the rainy season?

Mark only one oval.

- Soil Erosion
- Deforestation
- Rainfall intensity
- Other (Specify

....

12. How effective are the current mitigation strategies employed by the Northwestern Water Supply and Sanitation Company Limited (NWWSSC) in reducing turbidity?

Mark only one oval.

- Not Effective at all
- Very Effective

13. Do you think there's need for upgrading existing infrastructure to curb turbidity challenges?

Mark only one oval.

- Yes
- No
- Somewhat

14. How can the existing infrastructure be upgraded to handle high turbidity levels during the rainy season?

15. What are the common technical challenges faced during the operation and maintenance of water treatment facilities during the rainy season?

………………………………………………………………………………………..

16. How do you currently monitor and measure turbidity levels in the water distribution system?

Mark only one oval.

- Turbidity meters
- ph. Meters
- Conductivity meters
- Others (Specify)

....

17. Are there any specific equipment or tools that you think would improve turbidity Management in water distribution projects?

18. How often do you conduct routine maintenance checks on water treatment infrastructure?

Check all that apply.

- [ ] Daily
- [ ] Weekly
- [ ] Monthly
- [ ] Quarterly
- [ ] Yearly
- [ ] When there's need

Section D: High Turbidity and Its Impact

19. Have you observed any health-related issues or diseases that may be linked to high turbidity levels in drinking water?

Mark only one oval.

( ) Yes No

( ) No sure

( ) Somewhat

20. How does increased water turbidity during the rainy season affect the health of the communities?

Mark only one oval.

( ) Significantly Impacts Health

( ) Moderately Impacts Health

( ) Slightly Impacts Health

( ) No Impact on health

21. What specific health issues have you observed that are directly linked to high turbidity levels in water?

Check all that apply.

- [ ] Gastrointestinal illnesses (e.g., diarrhea, cholera) Skin infections
- [ ] Respiratory problems No Impact on health
- [ ] Others (please specify)…………………………………………………………………

22. How prepared are the clinics and hospitals to handle health issues arising from high turbidity in water during the rainy season?

Mark only one oval.

( ) Very Prepared

( ) Prepared

( ) Somewhat Prepared

( )

Not prepared

27. What measures are taken to address health risks associated with high turbidity in water?

Check all that apply.

- ☐ Public awareness campaigns
- ☐ Distribution of clean water supplies
- ☐ Medical treatment and Interventions
- ☐ Others (please specify)

....

28. Has in your view Health sector and public health collaborated with the Northwestern Water and Sewerage Company (NWWSC) to mitigate the health impacts of high turbidity during the rainy season? If yes, please describe the nature of this collaboration.

29. What strategies would you recommend to improve the management of water turbidity to safeguard public health during the rainy season?

30. What strategies or programs are in place to educate the public about the risks associated with high turbidity levels in drinking water?

31. What are the existing policies or regulations governing water quality standards in Zambia, particularly regarding turbidity?

32. What are the existing policies or regulations governing water quality standards in Zambia, particularly regarding turbidity?

33. How effective do you think the current policies and regulations are in addressing turbidity challenges in water distribution projects

Mark only one oval.

- Effective
- Somewhat effective
- Not Effective

34. Are you aware of any successful initiatives or best practices in managing turbidity challenges in water distribution projects that could be replicated in Zambia

Mark only one oval.

- Yes
- No

35. Are there any specific data or research gaps that need to be filled to better understand and address turbidity challenges in Zambia?

36. How can stakeholders, including the government, private sector, NGOs, and communities, work together to develop sustainable solutions to turbidity challenges in water distribution projects

37. Would you be willing to participate in a follow-up interview to discuss these issues in more detail?

Mark only one oval.

- Yes
- No

If yes, please provide your preferred contact information. *

Thank you for your time and valuable insights. Your responses will greatly contribute to our understanding of the health impacts of water turbidity and help develop effective strategies to mitigate these challenge

Appendix 2 Solwezi Plant Yearly Water Quality Parameter Readings

SOLWEZI PLANT (RAW)2024

PARAMETERS	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
pH	7.87	8.19	8.19	8.19	8.07	8.22	8.36	8.32	8.24	8.18	7.96	7.94
Color	351	67	67	13	20	10	0	0	18	18	29	25
Turbdity	140	15	15	3	6	2	0	0	4	0	17	20
Electrical Conductvity	272	312	312	301	197	245	374	345	532	401	420	371
Total Dissolved Solids	136	156	156	151	98.6	122.5	187	174	266	200.5	210	183
Manganese	0.33	0.044	0.044	0.061	0.096	0.031	0.023		0.017	0.034		0.008
T.S.S						5		7			20	
Sulphate						1		3			7	32
Nitrate						1.4		2.2				3.21
Iron	0.3	0.13	0.05	0.09	0.04	0.05	0.1	0.04			0.35	0.27
Flouride				0.72		0.54		0.34			0	
Copper						0.01		0.05			0.5	0.05
Calcium						0.24		0.16				3.21
Magnesium						0.03		0.6				0.42
Chlorides	2.99	17.49	17.49	20.5	42.9	19.4	14.5	12	22.49	7	16.99	12.49
Fecal Coliforms	TNTC	TNTC	TNTC	50	TNTC	TNTC	13	0	11	84	45	TNTC
Total Coliforms	TNTC	TNTC	TNTC	8	TNTC	TNTC	62	0	121	196	61	TNTC

SOLWEZI PLANT (RAW)2023

PARAMETERS	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
pH	7.81	7.72	7.98	7.4	7.82	7.27	7.6	7.4	7.7	6.9	8.16	8.28
Color	36	16	39	17	19	26	10	14	19	2	10	16
Turbdity	3	5	15	7	7	3	10	2	7	0	34	34
Electrical Conductvity	370	235	297	312	320	376	369	582	410	409	388	362
Total Dissolved Solids	186	119	148	156	160	188	184	291	205	203	174	182
Manganese		0.142					0.045					
zinc												
Iron						0.02		0.04	0.25		0.31	
Copper	0.05		0.03		0.02					0.02		0.07
Calcium												
Magnesium												
Chlorides	123.79	13.61	12.49	7.49	16.99	4.5	13.99	9.5	9.99	4.99	10.9	15.49
Fecal Coliforms	8	0	TNTC	0	0	96	92	TNTC	0	0	TNTC	TNTC
Total Coliforms	0	0	TNTC	0	0	42	71	136	0	0	0	0

SOLWEZI PLANT (RAW)2022

PARAMETERS	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
pH	7.5	8.01	7.82	8.2	7.4	7.99	8.46	7.99	7.3	7.6	7.4	7.6
Color	13	28	8	0	20	14	10	21	10	42	63	51
Turbdity	10.6	6.2	0.9	4.36	8.78	5.4	0.09	0.94	3.98	5.01	6	2
Electrical Conductvity	456	424	342	444	328	314	376	409	185	430	406	409
Total Dissolved Solids	228	211	171	222	165	157	188	205	370	215	204	203
Manganese		0.066										
zinc				0.04								
Iron	0.15		0.46		0.25			0.02	0.03		0.13	0.15
Copper			0.14				0.03			0.1		
Calcium										1.83		
Magnesium										0.64		
Chlorides	15.99	4.17	6.49		10.95	5.77	8.99	6	8.5	10.3	10.3	7.5
Fecal Coliforms	TNTC	215	150	106	121	16	83	511	0	0	TNTC	0
Total Coliforms	16	124	80	52	2	234	1	136	0	0	18	108

SOLWEZI PLANT (RAW) 2021

PARAMETERS	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
pH	7.92	7.62	7.33	7.6	7.6	7.6	7.5	7.4	7.6	7.3	6.85	8.39
Color	38	18	24	15	31	21	24	21	120	20	6	16
Turbdity	33.8	3.12	9.88	7.49	1.53	0.49	0.61	1.46	16.3	0	2.83	5.7
Electrical Conductvity	161.3	325	336	290	298	169.3	295	330	300	404	429	428
Total Dissolved Solids	80.7	163	168	145	149	84.6	175	175	150	202	215	219
Manganese	0.68	0.022	0.073	0.062	0.035	0.35	0.25	0.015	0.063	0.025	0.096	0.034
zinc	0.01	0	0.02	0	0	0.1	0.12	0	0	0.19	0.25	0.18
Copper	0.05	0.02	0.14	0.12	0.01	0	0.08	0.07	0.05	0.14	0.1	0
Calcium	1.54	0.95	1.15	2.32	0.96	1.45	0.87	0.97	0.47	0.85	0.98	1.25
Magnesium	2.06	3.25	2.15	3.15	1.15	2.15	1.56	2.56	1.45	2.15	1.15	2.15
Chlorides	1.5	7.77	6.49	12.46	12.49	9.99	12.49	13	9.99	10	5.99	4.99
Fecal Coliforms	0	2	12	19	33	120	128	21	35	82	81	38
Total Coliforms	121	6	47	62	10	5	13	4	30	112	110	1009

SOLWEZI PLANT (RAW)

PARAMETERS	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Ph	7.8	7.5	7.84	8.09	8.27	8.26	8.12	7.71	8.36	7.92	8.01	7.59
Color	38	37	195	0	14	9	5	4	13	19	0	66
Turbidity	2.87	6.26	41	5.29	3.33	4.94	3.44	0.46	2.74	2.46	10	216
Electrical Conductivity	381	137	259	341	345	360	380	386	422	451	443.9	392
Total Dissolved Solids	190.5	68.5	139.5	171	173	180	190	193	211	226	221.94	196
Magnesium	1.52	2.31	0.54	2.1	1.64	2.02	1.55	1.95	2.3	1	2.2	2.32
Calcium	0	0.96	5.28	1.15	0.87	0.75	0.12	0.75	0.25	0.45	0.89	1.15
cobalt	0	0.01	0	0.01	0	0	0	0	0.01	0.03	0	0.01
Zinc	0	0	0.01	0	0	0	0.02	0.04	0	0.05	0.04	0.04
Iron	0.07	0.04	0.02	0.03	0.2	0	0	0	0.01	0.07	0.05	0.08
Chlorides	17.4	5.7	10	11	8.67	14.97	16.2	12.49	2.5	2.93	11	17.49
Total Coliforms	0	401	181	160	1	TNTC	44	32	6	128	172	TNTC
Fecal Coliforms	0	201	72	50	0	21	6	10	2	68	160	46

Appendix 3: Thickening Clarifier Budget Template

Area	Description		Supply Cost		Installation Hours	Labour Installation Cost		Freight Cost		Total Project Cost	
361	Tails Thickening		$	9,201,792.74	124,464.00	$	2,629,182.05	$	428,911.42	$	12,259,886.20
		BU - BUILDINGS & ARCHITECTURE	$	-	-	$	-	$	-	$	-
		CI - EARTHWORKS	$	222,080.00	480.88	$	10,098.38	$	-	$	232,178.38
		CN - CONSTRUCTION COSTS	$	-	-	$	-	$	-	$	-
		CT - CONTINGENCY	$	-	-	$	-	$	-	$	-
		EL - ELECTRICAL	$	343,197.41	1,255.54	$	26,366.34	$	-	$	369,563.75
		EN - ENGINEERING & COMMISSIONING	$	-	-	$	-	$	-	$	-
		FR - FREIGHT	$	-	-	$	-	$	-	$	-
		LA - CONSTRUCTION LABOUR	$	-	-	$	-	$	-	$	-
		IN - INFRASTRUCTURE	$	-	-	$	-	$	-	$	-
		ME - MECHANICAL EQUIPMENT	$	6,251,262.13	7,635.04	$	160,335.84	$	281,650.00	$	6,693,247.97
		MF - MINING FLEET	$	-	-	$	-	$	-	$	-
		OW - OWNERS COST	$	-	-	$	-	$	-	$	-
		PI - PIPING, SPI's & VALVING	$	1,201,898.70	23,088.97	$	484,868.36	$	82,368.28	$	1,769,135.35
		PL - PLATEWORK	$	207,235.92	46,213.91	$	970,492.10	$	19,077.47	$	1,196,805.50
		SC - STRUCTURAL CONCRETE	$	523,416.68	30,875.90	$	663,831.85	$	-	$	1,187,248.53
		SP - SPARES	$	-	-	$	-	$	-	$	-
		SS - STRUCTURAL STEEL	$	452,701.89	14,913.77	$	313,189.18	$	45,815.67	$	811,706.73
		FO - FOREX	$	-	-	$	-	$	-	$	-