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ENVIROMENTAL IMPACT ASSESSMENT OF CHEMICAL PROCESSES INVOLVED IN WATER PROCESSING IN THE BINDURA MUNICIPALITY

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APPROVAL FORM

The undersigned certify that they have read and recommend to the Zimbabwe Open University for acceptance a research project entitled, "**Environmental impact assessment of chemical processes involved in water processing in Bindura Municipality"** Submitted by Tatenda Hloko to the Faculty of Science Education at Bindura University of Science Education in partial fulfilment of the requirements of the Bachelor of Education Honours in Science Education in Chemistry.

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DEDICATION

I dedicate this project to my husband, Emmanuel Hloko, my mom and children whose unwavering support, encouragement and love have been the driving force behind my success throughout my studies. Your sacrifices, patience and belief in me have meant the world to me, and I share this achievement with you.

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ABSTRACT

The research examined the environmental impacts of chemical processes in water treatment in Bindura municipality which included an interrogation on the effects of chemicals frequently used in water treatment and suggested strategies for reducing the negative effects of these chemicals. The study adopted a mixed method approach characterised by the use of qualitative and quantitative research methods, and ultimately used the exploratory sequential research design which also involved the collection of qualitative data first, followed by quantitative data to validate the research findings. A sample of 40 participants selected through purposive, and simple random sampling techniques was used while data was collected using questionnaire, open ended interview, and observation methods. The data were presented in tables, graphs, pie charts and in verbatim in cases of the data that could not be quantified while the same analysed using thematic analysis which involved coding of data into themes. Research findings suggest that participants were familiar with some of the chemicals used and confirmed that chlorine, alum (aluminium sulphate), lime, and sodium hypochlorite were commonly used for disinfection, coagulation, and pH adjustment. Research also found that the chemical processes are useful for biodiversity conservation on local ecosystems, prevention of contamination, protecting public health and raising awareness about the importance of protecting aquatic ecosystems from harmful chemicals. The study recommended using treated wastewater for irrigation, industrial processes and toilet flashing purposes to help conserve fresh water, and reduce the impact which could be effective if greener alternatives such as ozone or UV treatment chlorine are adopted.

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ACRONYMS

AOPs	-	Advanced Oxidation Processes
APA	-	American Psychological Association
DBPs	-	Disinfectant by-products
EMA	-	Environmental Management Authority
ECT	-	Environmental Chemistry Theory
EEC	-	European Economic Commission
ECF	-	Environmental Chemistry Theoretical Framework
EIT	-	Ecological Impacts Theory
EUC	-	European Union Council
HAAs	-	Haloacetic acids
IEA	-	International Energy Agency
IWRM	-	Integrated Water Resources Management
UV	-	ultraviolet
VOCs	-	volatile organic compounds
WTP	-	Water Treatment Process
WHO	-	World Health Organisation
THMs	-	Trihalomethanes
USEPA	-	United States Environmental Protection Agency
Zinwa	-	Zimbabwe National Water Authority

CHAPTER ONE: INTRODUCTION OF THE STUDY

1.1 Introduction

Environmental sustainability has become a global priority, particularly in sectors such as water treatment where chemical usage is prevalent. This study focuses on Bindura Municipality and examines the environmental impacts of chemical processes used in water treatment. This chapter introduces the study by presenting its background information to the study, statement of the problem, research objectives and questions which would guide the research process. It also outlines the significance, assumptions, delimitations and limitations of the study, as well as definitions of terms and layout of chapters before wrapping up with a chapter summary.

1.2 Background of the study

Water is a fundamental resource that is essential for all forms of life even in urban areas like Bindura Municipality in Zimbabwe which are undergoing rapid industrialisation have seen an escalating demand for clean and safe water. Industrialization has become a focal point of economic growth and development worldwide. The World Bank (2022) noted that global industrialization has been driven by advancements in technology, shifts towards sustainable practices, social and institutional factors and environmental factors such as access to resource water like, which is a major important resource in all forms of life. In this study industrialisation refers to the expansion and modernisation of water treatment processes to meet the demands of growing industries (Rani et al 2025). For instance in Bindura Municipality the rise in mining and agricultural processes led to greater water demand , this situation underscores the importance of industrial water treatment in managing water resource sustainability and protecting environmental and public health. Zimbabwe`s Vision 2030 also aims to transform the country into an upper-middle-income economy by encouraging industrialization and economic productivity (Government of Zimbabwe, 2020).

The increase in demand for clean and safe water for home and industrial use has prompted various chemical processes within water treatment facilities globally. These processes are important for removing contaminants and ensuring water is potable, especially in urban and industrial regions. However, this demand often comes at the expense of the environment, particularly when chemical processes used in the treatment of water introduce harmful substances into local ecosystems. The World Health organisation [WHO] (2019) noted the

potential for chemical pollutants to affect aquatic life, biodiversity, and human health becoming a pressing issue.

Recent studies have highlighted that chemical processes such as chlorination, coagulation, and ozonation are widely used to disinfect and purify water. While these methods can be effective in addressing microbial contamination and improving the quality of the water, they often lead to the unintended production of harmful by-products (Drewes and Graham, 2018). For example, according to Klein (2017), the chlorination of water can produce trihalomethanes (THMs), which are associated with adverse health effects. In addition, chemical treatments can often result in the discharge of residual chemicals into aquatic ecosystems, potentially disrupting local flora and fauna (Zhang et al. 2019).The global perspective on environmental impacts necessitates an examination of diverse practices across different regions.

Emerging economies may employ less regulated chemical processes, which may yield greater environmental degradation compared to those in developed countries where regulations are more stringent (Shah et al, 2018). The need for comprehensive assessments across varying socio-economic contexts becomes imperative to foster a standardised approach that prioritises both human health and environmental integrity. Baker et al. (2020) reiterated that previous studies had highlighted the importance of risk assessment in identifying potential hazards associated with chemical treatments in water processing. On the other hand Sakson et al (2021) understand that the integration of alternative approaches, such as biological filtration and advanced oxidation processes, has been proposed as sustainable methods to reduce chemical dependencies. Also these alternatives often require systematic evaluations to determine their efficacy and environmental impact relative to traditional chemical methods.

According to Osei et al (2020), indicated that chemical contaminants from water treatment processes can lead to significant ecological disruptions, including the degradation of aquatic habitats and reduced biodiversity. For example, the discharge of residual chemicals into natural water bodies can introduce heavy metals and other pollutants thereby posing risks not only to water quality but also to human health through bioaccumulation in the food chain (Kansanga et al, 2023). In Bindura, where water quality issues have been exacerbated by historical mining activities, it becomes very critical to assess the effectiveness of current water processing methods and their environmental ramifications (Mukanga and Chikozho, 2022).The interplay of socio-economic factors also complicates the environmental assessment process. Zinyandu et al., (2022), the implications of chemical usage in the treatment of water have direct

consequences for agricultural productivity and overall public health, further emphasising the need for sustainable practices that minimize ecological footprints. Studies have shown that the water processing facilities in Bindura municipality often utilize a range of chemicals to treat water for human consumption and the chemical treatments usually result in the generation of chemical residues. The environmental consequences of these processes are not well documented in the region thereby necessitating comprehensive assessments to understand their impacts. Furthermore, studies by Zhang et al. (2020) showed that such chemical residues can contaminate groundwater and surface water which affect not only water quality but also aquatic ecosystems.

The regulation and management of chemical discharges in water processing plants may not be adequately enforced in many developing regions and towns, including Bindura. Munyati (2022) understands that the lack of enforcement could also lead to significant ecological disruption which negatively impact local communities that depend on these water sources for their livelihoods. A similar study by the U.S Environmental Protection Agency [EPA] (2020) revealed that the unmonitored release of chemicals into water bodies could lead to bioaccumulation in fish and other aquatic organisms thereby posing health risks to both wildlife and humans. It is important to understand that chemical processes in municipal water treatment facilities is critical to ensure safe drinking water as various chemicals used can adversely affect local ecosystems (.Jotre et al (2022). Also should be understood that the processes involved in water treatment in Bindura to meet public health standards warrant thorough evaluation, especially given the increased demand for clean water due to population growth (Chikozho, 2021). Considering these and other factors, this study seeks to assess the environmental impact of chemical processes at Bindura municipality water works or Bindura municipality water treatment plant close to Mazowe River along Matepatepa Road to promote environmental sustainability in the municipality.

1.3 Statement of the problem

The escalation of industrial activities in urban areas has often led to significant environmental challenges, particularly concerning water quality and public health (Kumar et al, 2020). Thus, the environmental impact of chemical processes involved in the processing of water has also become an issue of concern, particularly within the context of urban municipalities such as Bindura. With increasing industrial activities and population growth, the demand for clean

water has arisen, prompting municipalities to adopt various chemical treatment methods in water process facilities. However, the application of chemicals, such as chlorine, flocculants, and coagulants, can lead to unintended ecological consequences, including the contamination of local water bodies, disruption of aquatic ecosystems, and potential risks to human health. Previous studies have shown that chemical residues can persist in the environment, leading to bioaccumulation in aquatic organisms and subsequently entering the human food chain (Sinha et al, 2020). In Bindura, the challenges associated with waste management and treatment efficiency in water processing plants raise significant questions about the long-term sustainability of the current practices employed by the municipality to ensure water safety (Moyo et al, 2021). According to Masiyandima and Rukuni (2018) the implementation of chemical processes in water treatment facilities raises concerns about the potential negative impacts on the local aquatic ecosystem and the surrounding communities. Moreover, the lack of comprehensive data on chemical usage and its environmental ramifications in Bindura Municipality highlights the urgent need for targeted investigations. It is anticipated that findings from this study could provide critical insights into the necessity for policy reforms and the implementation of more sustainable water treatment methods. Therefore, this research sought to explore and analyse the specific environmental impacts of chemical processes used in water treatment in Bindura municipality

1.4 Research questions

The main research question is: What are the environmental impacts of chemical processes in the processing of water at Bindura municipality?

The sub research questions are

- What are the prevalent chemical processes in modern water processing?
- What is the effect of these chemical processes on local ecosystems, particularly aquatic life?
- What can be done to reduce further negative effects of chemical processes in water processing at Bindura municipality?

1.5 Aim and objectives

The study aimed to determine the environmental impacts of chemical processes in the processing of water in Bindura municipality. To accomplish this, the study dwelt on the following objectives;

- To establish the prevalent chemical processes in modern water processing.
- To determine the effect of chemical processes on local ecosystems, particularly aquatic life.
- To suggest solutions or strategies towards reducing further negative effects of chemical processes in water processing at Bindura municipality.

1.6 Significance of the study

The assessment of the environmental impacts of chemical processes in water treatment is essential for developing sustainable practices that can mitigate negative effects while assuring good water quality. The findings of this study will benefit different stakeholders such as policymakers and regulatory authorities, environmental organizations, local authorities, industry professionals, and the general public. Environmental impacts of chemical processes in water treatment are significant in understanding how these processes affect ecosystems, human health, and the overall environment. The study can inform strategies for more sustainable and effective water treatment methods by identifying potential problems, like chemical runoff which harms aquatic life or create harmful byproducts along the way. Understanding these impacts usually leads to more sustainable practices and better regulatory frameworks. However, the major beneficiary from the research findings would be the residents of Bindura municipality who drink the water supplied by the municipality.

1.6.1 Policy makers

The findings can provide essential empirical data and scientific analysis on the environmental consequences of chemicals used in water treatment. This helps policymakers to understand which processes are most harmful and also to make evidence based decisions on which technologies, chemicals to promote, regulate and phase out which can minimise harm and promote safer alternatives to the environment. The policymakers can also use the data to justify regulatory actions to stakeholders and educate the public on the need for environmental safeguards in water treatment.

1.6.2 Environmental organisations

Environmental organisations also benefit from the findings as they rely on scientific studies to advocate for sustainable practices and raise awareness about the potential hazards associated with certain chemical treatments. The findings from this study can help such organisations push for changes in legislation and policies or promote community initiatives aimed at reducing

chemical usage in water treatment processes. Environmental organisations can also use information from the study to educate the public about the importance of protecting water resources.

1.6.3 Industry professionals

Professionals from different stakeholders involved in water treatment such as engineers, chemists, and operators, can also benefit by understanding the environmental impacts of the chemical processes in water treatment which is critical for improving operational efficiency and compliance with regulations. The knowledge that is gained from the study can lead to innovations in technology that has the potential to reduce waste and enhance the effectiveness of treatments while minimizing ecological footprints.

1.6.4 The general public

The general public which includes the residents of Bindura municipality`s suburbs will benefit from the study through improved water quality and safety. As communities become more informed about the implications of chemical treatments on their local environments they may advocate for better practices within the municipality or support initiatives aimed at enhancing water quality while public awareness can drive demand for greener technologies in water treatment processes.

1.7 Delimitation of the study

The study was confined to the boundaries and population of Bindura municipality in Bindura. Bindura municipality locates itself in Bindura, the provincial capital of Mashonaland Central, the northern province of Zimbabwe about 87km North of Harare. Bindura is located in gold mining infested area which is host to Freda Rebecca Gold Mine. Residents of the municipality are located within Chipadze, Chiwaridzo, Garikai, and Wood Brook high density suburb including Chipindura Park medium density area, Green Hill, Clever Hill low density areas among others. However, Bindura municipality water works are located along Matepatepa road in the Northern west adjacent Mazowe River. The study is limited to the environmental impacts of chemical processes in the water treatment or processing. Refer to map below.

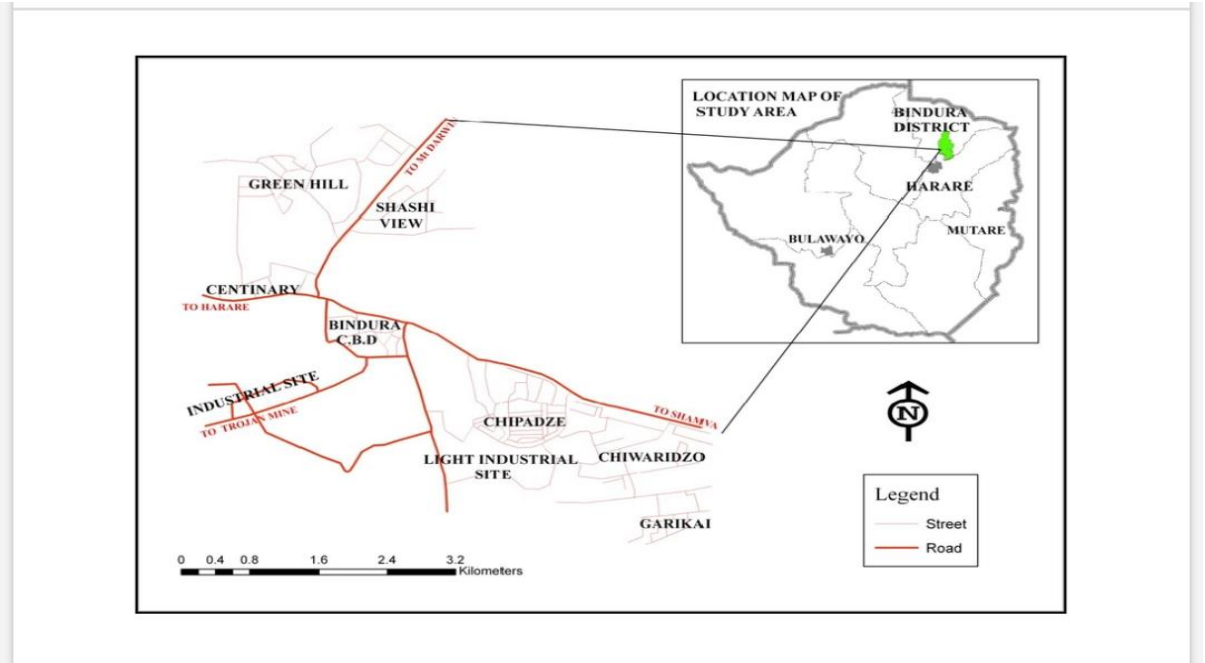

Figure 1.1 Map of Bindura Urban, Zimbabwe (Source: Majoni et al 2018)

1.8 Limitations of the study

One of the limitations encountered during the study was on the environmental impacts that vary significantly over time due to seasonal changes, weather patterns, and operational practices at treatment facilities. Higher temperatures in hot season can accelerate chemical reactions, such as chlorine reacting more rapidly and forming more disinfection by products. The study was conducted over a short period of time which led to the failure of capturing these time-based variations which was not conducted across dry and rainy seasons, leading to incomplete conclusions about long-term environmental impacts of chemical processes in water treatment.

Another limitation has to do with the complexity of chemical interactions in water treatment processes. The use of different chemicals in the treatment processes can interact in unpredictable ways which will lead to byproducts that may have their own environmental impacts. This complexity makes it challenging to isolate specific effects attributable to individual chemicals. Public perception of chemical processes in water treatment also influence the findings as well. Low levels of public understanding about water treatment processes also affected the accuracy of qualitative data collected through interviews.

1.9 Organisation of the study

The research work is composed of five chapters. With Chapter 1 introducing the first stage of the research which covers the background of the study, statement of the problem, research objectives, research questions which would guide the research process, hypothesis or assumptions. The section also covers the importance of the study, the delimitations, limitations and definition of the key terms including a dissertation layout.

Chapter 2 addressed the review of the related literature where different sources with related information are consulted. The theoretical and conceptual frameworks on the topic were applied to build up the basis of the study.

Chapter 3 focused on the methodology used to gather data, sample selection from a given population, instruments used for data collection, and their characteristics,

Chapter 4 dealt with data collection, presentation, interpretation and analysis of the data.

Chapter 5 gave the summary overview of the whole study, conclusions, recommendations and areas of further study.

1.10 Chapter summary

The main purpose of the study was to assess and evaluate the environmental impacts resulting from chemical processes in the processing or treatment of water in Bindura, and more specifically at Bindura Water works. The chapter set the stage for the research by presenting background information on the study, statement of the problem, research objectives and questions which would guide the research process as well as significance of the study. The chapter also presented research hypothesis and assumptions, delimitations and limitations to the study, definition of terms and a layout of chapters. The next chapter focuses on the review of related literature.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter provides a comprehensive review of existing literature on environmental impacts of chemical processes in the processing or treatment of water for home and industrial use at Bindura municipality. The review aims to provide a theoretical framework and examine key studies and concepts related to the subject under study. In addition, the literature review will be guided by the research questions and objectives. Several journals, books, documents and related scholarly work would be perused in order to get a glimpse of the findings from previous related studies.

2.2 Theoretical framework

A theoretical framework is the lens through which researchers analyse and interpret data which guide their investigations and helping them understand the relationship between variables. Creswell and Creswell (2018) agree that a theoretical framework is a conceptual structure that provides a foundation for understanding and interpreting phenomena. A theoretical framework consists of interrelated concepts, theories and assumption that guide research, analysis and data interpretation. A framework should demonstrate an understanding of theories and concepts relevant to the research topic thereby connecting the study to existing knowledge and facilitating the evaluation of theoretical assumptions. In the study of environmental impacts of chemical processes in water treatment, the choice of theoretical framework can significantly influence various aspects of the study including the formulation of research questions, the selection of the methodologies and the interpretation of results.

2.2.1 Environmental Chemistry

Ghosh and Bhaduri (2022) define environmental chemistry as the exploration of chemical and biochemical phenomena that transpire within the environment. This study employs the principles of environmental chemistry to gain insights into the chemical reactions and processes associated with water treatment, specifically focusing on the behavior and movement of chemicals during treatment, as well as their impact on aquatic life (Schwarzenbach et al., 2017). In contrast, the US EPA (2020) emphasized that the framework of environmental chemistry allows researchers to evaluate the potential environmental repercussions of chemical processes, including

their influence on water quality, aquatic ecosystems, and human health. Additionally, this framework aids in predicting how chemicals behave in water treatment systems, assessing their reactivity, persistence, and bioaccumulation potential (Hemond and Fechner, 2019). According to WHO (2019), applying the principles of environmental chemistry enables researchers to devise more sustainable and eco-friendly water treatment solutions that mitigate the adverse effects of chemical processes on the environment. Wang et al. (2023) further highlighted that environmental chemistry provides valuable insights into how specific chemical treatments, such as chlorination or ozonation, effectively eliminate pathogens in water, while also potentially generating harmful by-products like trihalomethanes.

Environmental chemistry investigates the chemical processes occurring in the environment and their modulation by various environmental factors. In the context of water treatment, this field specifically examines the impact of these factors on ecosystems, particularly aquatic life in the Mazowe River, where a water processing facility is situated. Research by Zhang et al. (2022) has demonstrated that environmental conditions can modify the behavior of contaminants as well as the effectiveness of treatment methods.

2.3 Conceptual Framework

Water treatment is a vital process for ensuring safe drinking water and the sustainable management of water resources. However, the chemical processes involved can significantly impact the environment, making it essential to understand these effects in order to develop sustainable water treatment approaches. The conceptual framework delineates the primary components, relationships, and factors involved in examining the environmental impacts of chemical processes within water treatment.

2.4 Prevalent Chemical Processes in Water Treatment

Water purification entails the elimination of undesirable chemicals, biological contaminants, suspended solids, and gases from water to render it suitable for specific uses. According to WHO (2022) and USEPA (2022), water purification encompasses a range of physical, chemical, and biological processes aimed at removing contaminants, including suspended solids, bacteria, viruses, and chemicals. While the majority of water is purified and disinfected for human consumption (drinking water), purification processes are also applicable in medical, pharmacological, chemical, and industrial

contexts. Regulatory bodies typically establish standards for drinking water quality, which include specified minimum and maximum contaminant concentrations based on the intended use of the water. This discussion focuses on modern water processing techniques, specifically coagulation and flocculation.

2.4.1 Modern Water Processing

Modern water treatment incorporates various chemical processes to eliminate contaminants, pollutants, and pathogens from water. Treatment facilities employ a range of chemical methods to ensure water safety for consumption and its suitability for environmental discharge. The primary processes include coagulation and flocculation, followed by sedimentation, filtration, disinfection, and other advanced treatment techniques (WaterOperator.org, 2019). Each stage in the water treatment process is crucial for effectively removing contaminants, pathogens, and impurities, ultimately resulting in safe and clean drinking water. The combination and types of processes used can vary based on the size of the plant and the quality of the source water. These methods are commonly implemented in municipalities, including regions like Bindura, due to their cost-effectiveness, scalability, and proven capacity to ensure water safety.

The chemicals employed in water treatment depend on the specific processes utilized. For instance, treatments for boiler water and cooling water are designed to prevent equipment deterioration and minimize fresh water consumption, thereby conserving water resources. Water purification and wastewater treatment effectively remove contaminants before returning water to the cycle. By employing a combination of physical and chemical methods, each of these treatments eliminates suspended solids, viruses, fungi, bacteria, algae, and harmful minerals, ensuring the water is safe for human use, equipment, and the environment.

2.4.1.1 **Coagulation and Flocculation**

Coagulation and flocculation represent the initial steps in the water treatment process. During this phase, a coagulant, such as alum, is introduced, and the mixture is stirred rapidly to aggregate small suspended particles into larger clumps that can be removed more easily. Kan (2019) supports that coagulation is the preliminary step, wherein coagulants (aluminum sulfate or ferric chloride) are added to raw water to facilitate the clumping of suspended particles. The purpose of introducing coagulants into the water treatment process is to help bind suspended particles, mud, and contaminants into larger

entities called flocs, which can be more readily removed (USEPA, 2022). Yargeau (2012) noted that the chemical processes of coagulation and flocculation enhance the removal of finely divided solids by forming flocs that settle more easily prior to filtration or sedimentation. This process improves the efficiency of subsequent sedimentation and filtration stages. The underlying chemical reaction involves neutralizing the charges on suspended particles, enabling them to adhere to one another more effectively.

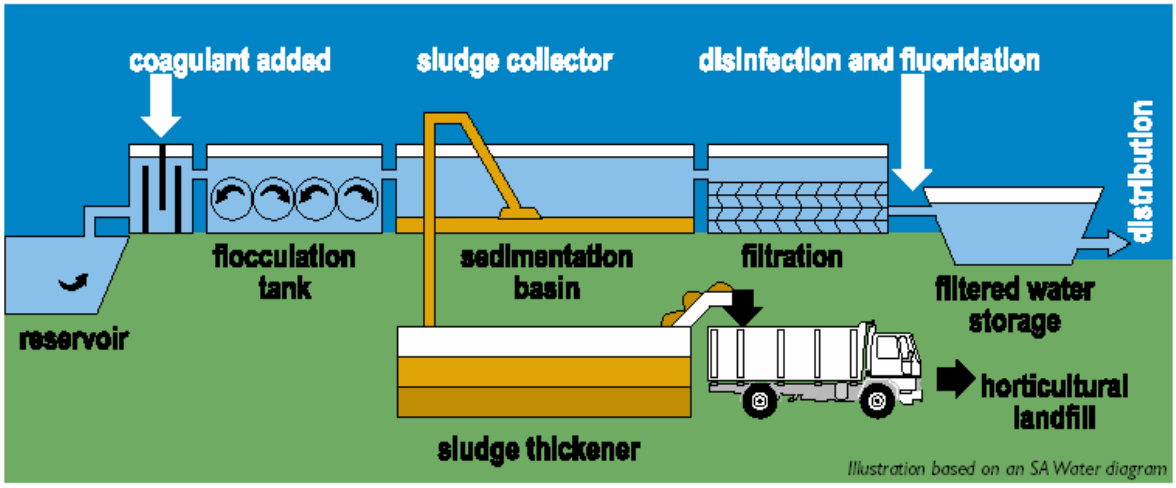

Figure 2.1 Water Treatment Process (Source: The Cooperative Research Centre for Water Quality and Treatment, 2004)

According to AWWA (2011), the coagulation process enhances the removal of impurities, resulting in clear water while effective flocculation can also lead to significant reduction in suspended solids, thus improving water aesthetic and quality. Mohamed and Ngadi (2024) noted that before coagulation and flocculation, raw water is run through a screen to separate visible solids from the liquid. The next step involves the addition of aluminium sulphate$Al_2(SO_4)_3$ and Calcium hydroxide $Ca(OH)_2$ to the liquid. The aluminium based compound is often called alum and induces clumping of suspended particles. This process is called flocculation. Calcium hydroxide (also known as lime) raises the pH of the mixture and produces more charged species (electrolytes) on the suspended particles. These charges are extracted and increase the size of the solid (coagulate) which simplify the filtration process. Coagulation is a major application of lime in the treatment of wastewater.

2.4.1.2 Sedimentation

After coagulation, the water is allowed to sit in a sedimentation basin. The larger flocs formed during coagulation will settle to the bottom due to gravity, creating a layer of sludge. This process removes a significant portion of the sediment and particulate matter from the water. The clarified water is then withdrawn from the top of the basin, leaving the sludge behind for further disposal or treatment (Smith and Jones, 2021).

2.4.1.3 Filtration

Filtration is the process of removing solids from a fluid by passing it through a porous medium. Studies by Faust and Ally (2010) indicated that filtration is widely used in water treatment to remove solids, including bacteria present in surface waters, precipitated hardness from lime-softened waters, and precipitated iron and manganese. Filtration is employed in wastewater treatment as a finishing process beyond secondary biological treatment or to remove solids remaining after precipitation or chemical coagulation in physicochemical processing.

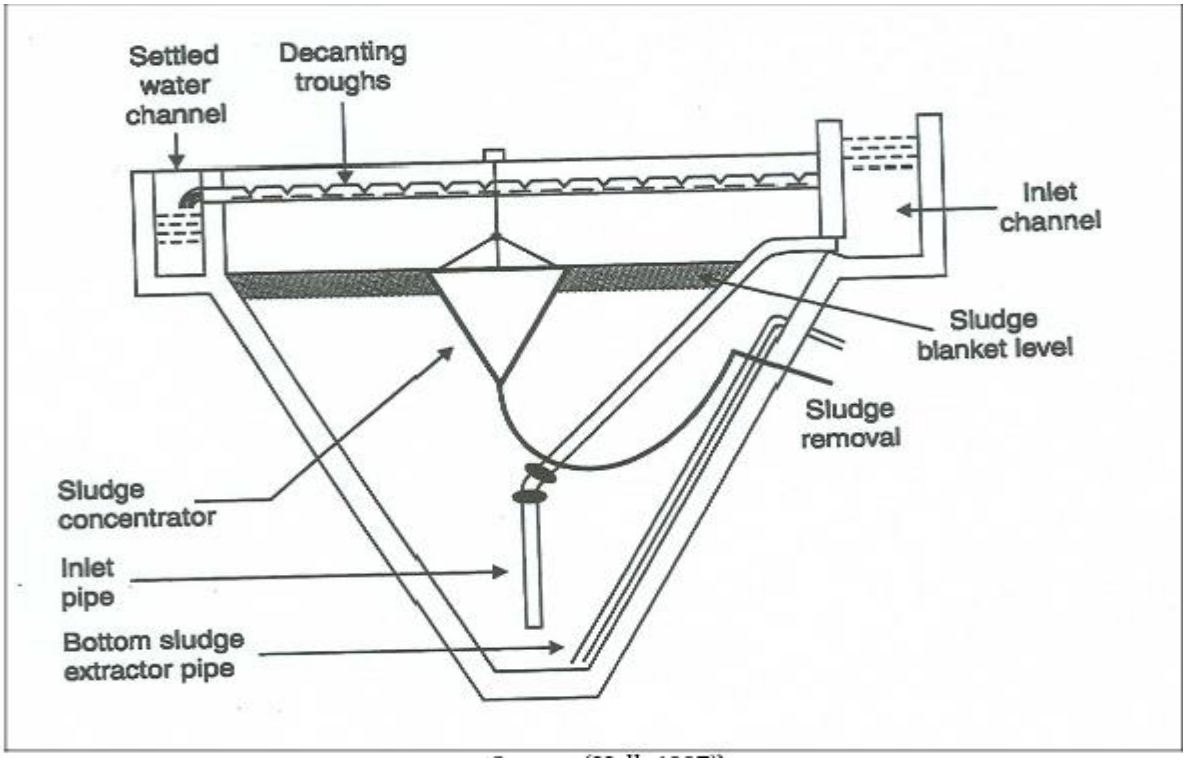

Figure 2.2 Up-flow Sludge Blanket Type with Hoper (Source: UNESCO-IHE Institute for Water Education, 2008)

The clarified water undergoes filtration, where it passes through various media such as sand, gravel, or activated carbon. This stage is critical for removing any remaining suspended solids

and contaminants that would have not been captured during coagulation and sedimentation. In addition, the America Water Works Association (2018) states that this step can also involve chemical processes where granular activated carbon removes organic materials and chlorine, as well as additional contaminants through absorption. If sludge is improperly disposed for example dumped into rivers, it could pollute local water bodies. Therefore proper drying and composting are required to prevent contamination.

2.4.1.4 Disinfection

According to Rani et al (2025) disinfection of water refers to the process of deactivating pathogenic microorganisms to ensure the safety of drinking water. Disinfection is a critical phase in water processing aimed at eliminating pathogenic microorganisms such as bacteria, viruses and protozoa. Common disinfectants include chlorine, ozone, and ultraviolet (UV) light (World Health Organisation, 2017). Chlorination involves the addition of chlorine gas or hypochlorite, which reacts with the pathogens, thereby inactivating them. However, ozone is infusion in another method that relies on the strong oxidizing potential of ozone to destroy microbes, while UV light disrupts the DNA of microorganisms, thereby effectively sterilizing the water. This process is performed in order to control the outbreak of diseases while disinfection of wastewater would allow the partial destruction of disease-causing organisms before discharge in receiving water bodies. This is done in order to reduce the risk of disease for recreational users of surface water, to protect aquatic ecosystems and to mitigate the risks of contamination of downstream sources of drinking water.

2.4.1.5 Advanced Oxidation Processes (AOPs)

With the advancements in technology and increasing awareness in emerging contaminants which include pharmaceuticals and personal care products, many water treatment facilities now employ Advanced Oxidation Processes (OAPs). These OAPs typically involve generation of hydroxyl radicals (**.**OH) through reactions which involve ozone, hydrogen peroxide, or UV light. Studies by Liu et al. (2020) confirmed that these radicals are extremely reactive and can degrade a wide variety of organic contaminants that may not be efficiently removed through conventional treatment methods.

2.4.1.6 Energy Consumption

Water treatment processes typically require significant energy. Coagulation and flocculation processes usually require mechanical agitators to mix chemicals with water and these motors consume energy continuously during operations, leading to increased greenhouse gas

emissions if fossil fuels are the primary energy sources. A study by Fuchs et al (2022) revealed that energy-efficient technologies, such as micro-generated treatments, can reduce energy consumption and contribute to sustainable water management and in areas like Bindura where power supply may be inconsistent as they demand can raise operational costs which increase reliance on other forms of energy which have their own environmental impact.

2.4.1.7 Waste Production

Chemical water treatment processes, while essential for ensuring safe and potable water, generate various forms of waste that pose challenges to environmental sustainability. The waste from water treatment includes both solid and liquid forms, slug and other wastes that need to be managed appropriately. Slug as one of the primary waste contains high concentrations of suspended solids, organic matter and chemical residue such as aluminium, iron and lime (Mokaya et al., 2020).According to Guibaud et al. (2022), the chemical nature of sludge varies depending on the coagulants used and the source water quality but it generally poses disposal and leachate risks if deposited in unlined landfills or discharged into natural water bodies. Also residual chemicals from processes such as chlorination, pH adjustment and flocculation can persist in both treated and waste streams. These residues are a concern for both aquatic ecosystems and downstream users particularly when discharged without further treatment or neutralisation (Alwi et al., 2023). Lee et al (2023) discuss innovative methods for sludge management that can mitigate environmental impacts while recovering valuable resources. These include sludge dewatering, chemical recovery and reuse and the use of eco-friendly coagulants derived from plant materials (Al-Mamun et al., 2022).

2.4.2 Environmental challenges in water treatment

The impact of chemicals on the environment is a complex issue that involves a range of environmental concerns, including air and water pollution, greenhouse gas emissions, soil contamination, and the depletion of natural resources. Water treatment is a critical process that ensures the availability of clean and safe water for various purposes. The process is critical in maintaining public health, protecting the environment and promoting sustainable water management. One of the primary objectives of water treatment is to remove impurities, contaminants and pollutants from water sources. This includes the removal of bacteria, viruses, chemicals, heavy metals, and other harmful substances that can pose risks to human health.

While water treatment is critical for human consumption and industrial use there are numerous challenges in the treatment processes. Some of these challenges include inefficient or outdated water treatment control systems which can have significant negative environmental impacts in the process. In addition, outdated systems may result in overuse of chemicals which would lead to water pollution and harm to aquatic ecosystems. For example, a study by Kummerer (2022) highlights that wastewater treatment plants frequently discharge effluents containing pollutants which can persist in the environment and accumulate in aquatic organisms, leading to ecological and health risks.

Climate change also poses a profound threat to water treatment processes as changes in precipitation patterns and increased frequency of extreme weather events can overwhelm treatment facilities. A study by Gleick et al (2020) discusses how heavy rainfall can lead to combined sewer overflows, resulting in untreated sewerage contaminating water bodies, and underscores the need for adaptive infrastructure that can withstand such fluctuations. Another challenge is the energy-intensive nature of current water treatment technologies, which contributes to greenhouse gas emissions. According to a report by the International Energy Agency (IEA, 2021), the water sector consumes a significant amount of energy, which can exacerbate climate change impacts. Therefore, transitioning to energy-efficient treatment methods and integrating renewable energy sources are critical steps toward sustainable water management.

According to IEA (2021) it is essential to upgrade these water treatment control systems to modern in order to reduce the environmental impact and ensure sustainable water management practices. Additionally, socio-economic factors also play a role in water treatment challenges. Communities in low-income areas often face significant barriers to accessing advanced water treatment technologies, leading to disparities in water quality. A survey conducted by the World Health Organisation (WHO, 2022) indicates that marginalised populations are disproportionally affected by inadequate water treatment, emphasising the need for equitable solutions. It is also important to understand that inadequate industrial water purification can create significant risks and consequences to ecosystems and human health. This usually, results in the discharge of pollutants and contaminants into water bodies, leading to the degradation of aquatic ecosystems and the loss of biodiversity. Untreated industrial wastewater can also contain hazardous

substances that can contaminate drinking water sources, posing serious health risks to humans and wildlife.

Chemicals released into the environment can have profound and detrimental effects on ecosystems, human health, and the overall biosphere. Contaminants such as pesticides, heavy metals, pharmaceuticals, and industrial chemicals are among the most studied with each contributing uniquely to environmental degradation. One of the primary environmental concerns has to do with the impact of agricultural chemicals, particularly pesticides and herbicides. According to Carpenter et al (2022) these substances can run off into water bodies which would lead to eutrophication which is characterised by excessive nutrient loading that depletes oxygen in aquatic environments thereby harming marine life. In addition, Gillion et al (2021) also noted that the decline of biodiversity in aquatic systems can be attributed to these compounds, as they disrupt food chains and habitat structures.

A study by Jarup and Akesson (2022) noted that heavy metals such as lead, mercury, and cadmium are also significant environmental pollutants which need to be removed from water for it to be safe for domestic use among other uses. The study further revealed that these metals accumulate in organisms through bioaccumulation, which leads to toxic effects in higher trophic levels, including humans. For example, mercury is predominantly harmful as it can influence neurological development in humans and wildlife (Snyder et al, 2023).

Furthermore, Boxall et al (2021) noted that the presence of pharmaceuticals in the environment resulting from improper disposal and pharmaceutical manufacturing processes can disrupt endocrine systems in wildlife thereby contributing to development of antibiotic resistant bacteria. Dianati et al (2023) also postulated that this phenomenon possesses risks not only to human populations, and hence the suggestion for urgent need for improved regulatory measures and waste management practices. Overall, the impact of chemicals on the environment underscores the importance of sustainable practices and stringent regulations to mitigate the effects of chemicals on the environment.

2.5 Effects of chemical processes on aquatic life

The use of chemical agents in water treatment, such as chlorine for disinfection and aluminum sulfate for coagulation, is critical for producing safe drinking water. However, when these

substances are not properly managed, they cause serious threats to the environment. In many municipalities, including Bindura, effluents and sludge containing residual chemicals are often released into nearby rivers and wetlands, leading to environmental degradation. For instance, chlorine and its disinfection by-products (DBPs) like trihalomethanes have been found to be toxic to aquatic organisms, reducing fish populations and altering reproductive patterns (Rani et al., 2025). Similarly, excessive aluminum from alum sludge can accumulate in soils, impairing plant growth and microbial activity. Furthermore, the disposal of chemically laden sludge into landfills or open environments increases the risk of groundwater contamination, particularly during the rainy season when leaching intensifies. These impacts underline the urgent need for improved chemical management and environmentally conscious treatment practices in water utilities.

Water treatment also protects the environment and preserves natural ecosystems. For example, the treatment of wastewater helps to remove pollutants and harmful substances from wastewater before it is released back into rivers, lakes and oceans. Besides preventing the contamination of water bodies this also helps maintain the balance of aquatic ecosystems, and safeguards the health of plants, animals and marine life. In addition, environmental sustainability in water treatment is crucial for protecting water quality, ecosystems, and ensuring long-term access to clean water. While this involves the use of efficient resources, sustainable practices minimize the environmental impact, conserve water resources and promote the preservation of the ecosystem.

It is therefore, imperative to always note that water treatment processes are essential for ensuring safe drinking water and managing wastewater. According to Fabian et al (2016), water treatment processes are an important component of society where people live globally. Like many other water treatments in Zimbabwe, the Bindura WTP is of convectional type. The water supply system starts with intake of surface water directly from a pick up weir in the Mazowe River. The WTP is a convectional type consisting mainly of a coagulation unit, sedimentation combined with flocculation unit, filtration unit and the disinfection unit and sludge ponds (Crittenden; Trussell; Hand; Howe and Tchobanoglous, 2012). The settled solids (sludge) from the sedimentation tanks and backwashed sand filters are directed there. Ideally, sludge is left to dry and is removed safely but in some cases some of it end up in the Mazowe which becomes a problem by introducing heavy metals (aluminium), excess nutrients and toxic

residues from treatment chemicals which end up posing a serious threat to the environment particularly the aquatic life.

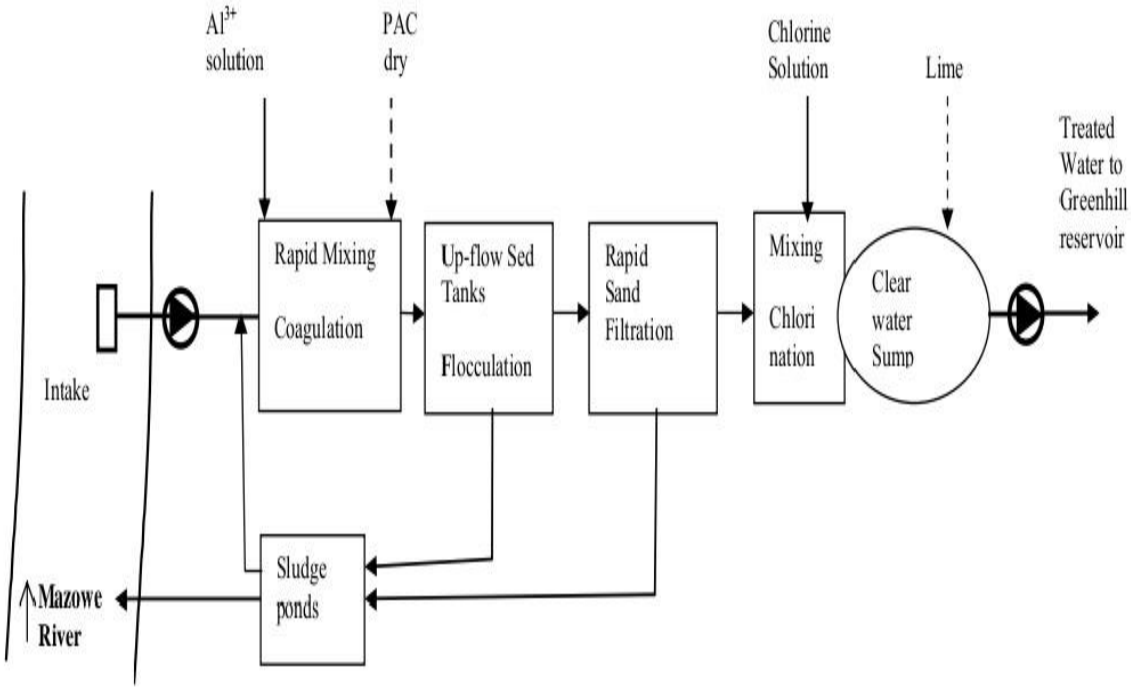

Figure 2.3 Bindura WTP Process Scheme (Source: UNESCO-IHE Institute for Water Education, 2008)

The Environmental impacts of chemical processes on the processing of water can be significant and varied, and some of the potential impacts include air pollution, water pollution, climate change, human health impacts, ecosystem impacts, and soil pollution among others. While chemical processes such as coagulation, chlorination and pH adjustment ensure safe drinking water, growing evidence suggests that their by-products and residues may have adverse effects on ecosystems particularly aquatic environments. These include chemical residues and contaminants, Eutrophication and nutrient pollution. However, the chemical processes involved can have significant environmental impacts that must be considered. Chemical processes have significant influence on aquatic ecosystems and impact both the physical and biological components.

2.5.1 Chemical residues and contaminants

Chlorine is widely used as a disinfectant due to its effectiveness against pathogens. Gomez. Rodi and Lopez de Alda (2021) understood that chemical processes involve the use of chlorine,

chloramines, and other disinfectants to kill pathogens in water while being effective can react with natural organic matter to form disinfectant by-products (DBPs), such as trihalomethanes (THMs) and haloacetic acids (HAAs), which are harmful to both human health and aquatic ecosystems. These DBPs can persist in the environment, accumulating in water bodies and affecting biodiversity. When discharged into rivers, these chemicals may disrupt aquatic food chains, cause cellular damage, oxidative stress and reproductive dysfunction in fish and amphibians.

2.5.2 Nutrient Runoff and Eutrophication

Chemical processes in water treatment often inadvertently release excess nutrients, particularly nitrogen and phosphorus, into nearby water bodies a process known as eutrophication. Moss et al. (2018) confirms that these nutrients can lead to eutrophication where nutrient overload causes algal blooms that deplete oxygen in the water thereby leading to hyponix conditions and mass fish mortality harming aquatic life and disrupting ecosystems. Usually, eutrophication is caused by lower levels of nutrient contamination in waterways, most of which is due to the inorganic nutrients nitrate and phosphate that induce the growth of algae. For example, the purification or treatment of wastewater should be managed carefully to prevent nutrient-loaded effluents from compromising water quality in surrounding environments. The chemical processes used in water treatment have the potential to lead to environmental impacts like increased turbidity, decreased water clarity, and potential contamination of water sources with chemicals and heavy metals, affecting aquatic life and potentially human health.

2.5.3 Pollution

Pollution refers to the introduction of contaminants into the environment that causes adverse changes. These contaminants can be in the form of chemical substances, excessive noise or even light, which can harm human health, ecosystems and the overall quality of life. The United States Environmental Protection Agency (EPA, 2023), posited that pollution can be classified into different types, such as air pollution, water pollution, soil pollution, noise pollution and light pollution. In addition to other effects of chemical processes it is also important to note that chemicals released into the air can contribute to air pollution, negatively impacting human health and the environment (WHO, 2021).

Particulate matter, nitrogen oxides, and volatile organic compounds can cause respiratory problems and other health challenges. Besides polluting the air, the same chemicals can contaminate water sources and harm aquatic life and human health (USEPA, 2022). For

example, pesticides, heavy metals and industrial chemicals can accumulate in water bodies and affect aquatic ecosystems and human consumption. Furthermore, these chemicals have the potential to pollute soil, affecting plant growth, microbial communities, and ecosystems health (EEA, 2020). For example, according to IPBES (2019) pesticides, heavy metals, and industrial chemicals can persist in soil, impacting soil fertility and biodiversity. In addition, chemical pollution can contribute to biodiversity loss by harming species and disrupting ecosystems. For example, pesticides can affect pollinators such as bees, and other wildlife among others in the environment.

The same processes also release particulate matter, which has the potential to aggravate respiratory issues and other health problems including damaging the environment. Chemical processes can leave behind residuals that can contaminate water sources, posing risks to both human health and the environment, and also the processes often produce toxic by-products that can harm aquatic life and ecosystems. Furthermore, EEA (2020) also noted that these chemical processes also pollute the soil which causes chemical leaching into soil, contaminating groundwater and posing risks to human health and also degrade soil quality and reduce its fertility and ability to support plant growth. These chemical processes negatively affect aquatic life as chemicals harm aquatic life, including fish and other organisms, as well as leads to disruption of the ecosystems which leads to changes in species composition and ecosystem function.

2.6 Reduction of negative effects of chemical processes in water treatment

To effectively reduce the effects of chemical processes in water treatment, several strategies can be employed, focusing on alternative technologies, regulatory measures, and community engagement. These strategies can be achieved through technological innovation, adoption of friendly alternatives, effective government policies for regulation purposes and active community participation.

2.6.1 Adoption of Advanced Oxidation Processes (AOPs)

Adoption of Advanced Oxidation Processes including the use of ozone, hydrogen peroxide, and UV light can significantly minimize the use of harmful chemicals in the treatment or purification of water. Huang et al, (2023) indicated that the advanced oxidation processes generate hydroxyl radicals that can efficiently degrade organic pollutants without introducing additional harmful substances into the water. The studies further revealed that AOPs are

effective in breaking down complex contaminants that traditional chemical methods struggled to or could not remove. For example, studies by Miklos, et al (2019) showed that AOPs have been shown to effectively remove pesticide residues from wastewater, making the water safe for discharge.

2.6.2 Implementation of Green Chemistry Principles

Green chemistry focuses on designing chemical processes that minimize the use and generation of hazardous substances which include the use of less toxic reagents, solvents, and catalysts that are environmentally friendly. For example, employing biodegradable and nontoxic surfactants in the treatment of water reduces environmental toxicity. As put by Khan et al (2022), the use of biodegradable coagulants and flocculants such as plant-based materials can drastically reduce the chemical load in water treatment facilities. In addition, these alternatives have shown promising results in removing turbidity and other pollutants while being more environmentally friendly.

2.6.3 Integrated Water Resources Management (IWRM)

Smith et al (2023) noted that the implementation of integrated water resources management practices aids in the holistic management of water resources and ensures the appropriate utilisation of chemical processes thereby promoting the use of sustainable practices that minimise pollution and enhance the quality of water as well as reduce the dependency on chemical treatments.

2.6.4 Regulatory Frameworks

Strengthening regulatory frameworks helps monitor and limit the use of chemicals in water treatment processes (Jones and Miller, 2023). In addition, establishment of stricter regulations on chemical discharges and encouraging environmental impact assessments can help minimize harmful practices. The commendable policies would promote the adoption of safer technologies and require regular assessments of chemical impacts which can lead to substantial improvements in water quality. For example, policies that promote sustainable chemical management practices inform operators about best practices in waste minimization and safety. Villanueva et al (2014) noted that the U.S Environmental Protection Agency (USEPA), World Health Organization (WHO), and European Union Council (EUC) together currently regulate more than 120 drinking water contaminants. Research shows that even regulated chemicals carry some uncertainty because new information requires questioning and possibly revising

limits while emerging chemical contaminants also generate concern because little to nothing is known about their potential health effects, much less the levels at which they would occur.

2.6.5 Public Education and Community Involvement

The need to educate communities about the effects of chemical pollution and involving them in decision-making processes is critical and can foster more responsible water usage and wastewater management. Study by Brown and Taylor (2023) noted that community-based programs usually promote sustainable practices that lessen reliance on harmful chemical treatments.

2.7 Chapter summary

The study examined the environmental impact of chemical processes in the treatment or processing of water at Bindura Municipality. The chapter presented a review of literature related to the current study being guided by the research questions and or objectives. The chapter also identified and presented the theoretical framework and conceptual framework that influenced the course of the study. Researcher perused and interrogated several journals, books, documents and related scholarly work in order to get a glimpse of what other scholars found in previous related studies. The chapter also looked interrogated strategies that would be used in an effort to reduce the negative of chemical processes in water treatment. The next chapter looks into the research methodology.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

The chapter focuses on the research methodology which incorporates the research approach and research design, target population, sampling methods and techniques including sample size on environmental impacts of chemical processes in the processing or treatment of water for home and industrial use at Bindura Municipality. The chapter also presents data collection methods or research instruments, reliability and validity measures, including data presentation and analysis procedure and ethical standards or principles.

3.2 Research methodology

The study adopted a mixed methods research approach with both qualitative and quantitative method and analysis to provide a comprehensive understanding of both the scientific and social dimensions of the research. The method involves the integration of quantitative and qualitative data, and provides an opportunity for triangulation of data which also involves the use of multiple methods to validate findings and increase the reliability and validity of the study. By triangulation of data researchers can confirm or disconfirm results, which will provide a more accurate understanding of the study (Denzin, 2019). In addition, the mixed methods research allows researchers to explore the “what” and “why” of a phenomenon which would provide a richer understanding of the research context (Teddlie and Tashakkori, 2019).

3.3 Research design

There are numerous research designs that can be used in mixed method research, and depending on the nature of the study the design can either be qualitative or quantitative. The study adopted the exploratory research design to validate findings. According to Creswell and Poth (2022), a research design refers to the overall strategy that researchers adopt to integrate the different components of the study in a cohesive and logical way, thereby ensuring that the research problem is effectively addressed. For this study researcher adopted an exploratory research design to investigate the environmental impacts of chemical processes in the treatment of water at Bindura Municipality. The exploratory research design was appropriate because of the topic

which is relatively under-researched within the local context and limited existing literature specific to Bindura water treatment operations and their ecological effects. By using this design, the researcher aimed to gain an in-depth insight into the types of chemicals used, their disposal methods and perceptions of local stakeholders regarding environmental outcomes. The qualitative phase of the study helped to identify key variables and themes related to environmental impacts which could inform the development of a quantitative survey instrument (Creswell and Plano Clark, 2018). The design also allowed flexibility in data collection, enabling the use of interviews, observations and document analysis to uncover patterns and relationships, and hypothesis for further testing.

The integration of exploratory research design also had its own limitations. Findings derived from the study might lack generalization, as the sample used context-specific to Bindura Municipality and did not represent other regions or water treatment systems (Saunders et al., 2019). Secondly, the reliance on qualitative data such as interviews and observations introduced the risk of subjectivity and researcher bias, which might have influenced data interpretation. Additionally, as noted by Swedberg (2020) the design did not permit rigorous statistical analysis or the testing of hypotheses, limiting the ability to establish causal relationships between chemical processes and environmental impacts. The open-ended nature of an exploratory research, while advantageous for discovery, also resulted in findings that were broad or inconclusive. As such, the outcomes of the study intended to provide foundational insights that may guide future, more structured research efforts (Yin, 2023).

3.4 Population and sampling

In the study the population comprises council employees at the water, Zinwa employees, and management from Bindura municipality, villagers downstream and officials from Environment Management Agency (EMA). According to Webster (2025), population is defined as the total number of individuals or entities sharing common characteristics from which information may be required. A sample size for the study consisted of 40 participants, among them, 15 workers at the water works, 7 from Zinwa and 13 villagers from the nearby village downstream, 3 Bindura Municipality management staff and 2 officials from EMA. A sample is the actual subset of individuals or cases selected from the sampling frame to participate in the research study. Purposive sampling technique was used to select participants for interviews while those to participate on questionnaires will be selected through random sampling.

3.4.1 Purposive Sampling technique

Purposive sampling technique was adopted to select participants from the target population to participate in the study. EMA and Bindura Municipality Management staff were intentionally identified and selected to provide key information or technical information on the subject while workers at the water works and villagers downstream were selected through random sampling. Purposive sampling refers to a sampling technique where researchers intentionally select participants based on certain characteristics, knowledge or experience (Adeoye, 2023). Similarly, purposive sampling is a non-probability sampling technique where the researcher deliberately selects participants based on specific criteria that would align with the research objectives (Creswell & Plano Clark, 2018).

3.4.1 Random sampling

To ensure the reliability and representativeness of the data collected, the study employed a random sampling technique to select participants from the communities surrounding Bindura Municipality water treatment area. The approach was chosen because it gives each member of the population an equal chance of being selected, thereby reducing the risk of selection bias. Through random sampling, a diverse cross-section of residents including those living near water bodies such as the Mazowe River was included in the study. The method was particularly useful in capturing a wide range of views and observations regarding the environmental impacts of chemical processes used in local water treatment. The resulting data provided a sound basis for generalizing the study findings to the broader community. 15 participants out of the close to 40 employees were selected. Same method also applied to the villagers in the nearby village downstream which also resulted in the selection of 13 participants from the village.

3.5 Research Instruments

Questionnaires, interviews, observations and document analysis were used to collect data. In-depth interviews were used to collect data from Bindura municipality management, Zinwa and EMA officials. Questionnaires were used to solicit data from the villagers downstream and the workers at the water works while the observation method was used to collect data changing patterns or developments resulting from the use of chemicals as they often spill into the river.

3.5.1 The survey questionnaire

A survey was employed in the study as a primary method of data collection to gather quantitative information from community members residing near Bindura Municipality water plant. Structured questionnaires containing both open and closed ended questions was used to assess the participant's awareness of water treatment practices, perceptions of water quality and observed environmental impacts such as changes in aquatic life. The method allowed efficient data collection from a large sample. Survey questionnaire were distributed to participants through online and paper-based surveys. Surveys are a cost-effective, and an efficient way to collect data from a huge number of participants. The use of survey questionnaires allows for the collection of more objective and quantifiable data than from other data collection methods tools. A survey is a method of collecting data from group of people through standardised questions and recording their responses (Taherdoost, 2016).

3.5.2 Interviews

Interviews were used to collect data from Zinwa and EMA officials to allow an in-depth exploration of participants` thoughts, feelings and experiences, and also provide rich detailed data that could be used to develop a nuanced understanding of a research phenomenon. However, these interviews are subjective and biased, with limited generalizability, and time consuming as well as resource-intensive. Time constraints and scheduling difficulties also limited the number of interviewees who could be included. Despite these face-to-face interviews were carried out at their most convenient time and was valuable for collecting critical data for the study. Interviews are probably the most common tool used in planning, monitoring and evaluation. Interviews are a qualitative data collection method that involves direct interaction between the researcher and the participant (Bansal and Corley, 2020). In addition, Dearnley (2020) defines interviews as a form of qualitative data collection that involves a conversation between the researcher and the participant, with the aim of gathering rich, detailed and contextualized data.

3.5.3 Observation

Observation method was adopted as a complementary research instrument to gain first-hand insight into the chemical processes applied during water treatment at Bindura Municipality. A structured observation checklist was employed to monitor daily operations at the treatment plant, focusing on chemical dosing, waste handling, and effluent discharge practices. The method enabled the researcher to directly witness activities that might affect the environment,

such as improper storage of chemicals or overflow of treated water into nearby streams. Observation also helped validate data obtained from interviews and questionnaires, enhancing the credibility of the findings through triangulation. Observation method is a qualitative research technique that involves observing participants in their natural environment and collecting data on their behaviours and interactions (Babe, 2020). However the method is often time-consuming and difficult to ensure that the observations are accurate and unbiased. Observations were limited to specific times and could not capture routine practises outside of scheduled visits. As a result some practices or environmental effects may have gone undocumented. However, being difficult to control confounding variables, time-consuming and labour-intensive, Patton (2019) still claims that the observation method is still a valuable tool for collecting rich and detailed data.

3.6 Data collection procedures

Researcher sought authority and permission from Bindura Municipality, EMA and Zinwa, and consent from individual respondents including the villagers in order to participate in the study. To collect data from interviews, the researcher arranged meetings with individual respondents in a face-to-face mode and interviewed them to extract the data one after the other at their most convenient times. Interviewed included the managers from Bindura municipality, officials from EMA and Zinwa and answers were recorded as the interview meetings progressed. With respect to the survey questionnaire researcher prepared the questionnaire with both open-ended questions which were distributed to individual respondents including the villagers and workers at the works. For the villagers the questionnaire was translated to their mother language which written in Shona for better understanding. The study used an observation guide or developmental checklist. During the observation the researcher could ask some questions about the situation to some randomly selected respondents.

3.7 Data presentation and analysis procedure

The data was coded, and analysed using thematic analysis, a widely used qualitative data analysis method that involve identifying, analysing, and interpreting recurring patterns or themes within the data. Data collected through questionnaires, interviews, and observations were analysed using both qualitative and quantitative methods. Quantitative data from the questionnaires were entered into Microsoft Excel and analysed using descriptive statistics such as frequencies, percentages, and graphical representations including bar charts and pie charts.

This allowed for a clear visual interpretation of community responses regarding water treatment and its environmental impacts. Qualitative data from interviews and field notes were analysed thematically, where recurring patterns, opinions, and concerns were identified, coded, and grouped into themes relevant to the research objectives. The data from interviews, observations and survey questionnaires was triangulated to validate findings and to present a holistic view of the phenomenon. These complementary analysis methods provided a comprehensive understanding of the environmental effects of chemical processes used in water treatment at Bindura Municipality.

3.8 Ethical considerations

Ethical standards were strictly observed throughout the study to ensure the protection of participants and the integrity of the research. The following ethics were considered;

3.8.1 Informed consent

The researcher also ensured that participants had given their consent to participate in the research process, which means that they understood the nature and purpose of the research before giving their consent to participate. Participants were given the freedom to choose if they wanted to participate and also to withdraw from participating any time they so felt without any challenges.

3.8.2 Confidentiality and privacy

The researcher ensured confidentiality of participant and their privacy was observed by ensuring data any related information was not shared. According to the APA (2020) researchers must protect the participant`s confidentiality and maintain anonymity of data.

3.8.3 Anonymity

Pseudo names were used instead to ensure anonymity of participants for them to participate in the research freely. The researcher would ensure that the identities of participants remain anonymous. There is also need for researcher to ensure respect for other persons during the research process.

3.8.4 Responsibility

The researcher ensured that the research is conducted in an ethic and responsible manner.

3.8.5 Objectivity

Researcher ensured that the study remained objective by avoiding biases and ensuring accuracy of data collected.

3.9 Chapter summary

The chapter provided an overview of the research methodology or focused on developing a methodology that would be used to collect data on the environmental impact of chemical processes in the treatment or processing of water at Bindura municipality. The chapter outlined or looked into and presented the research methodology and design, the research population, sampling methods and sample size including data collection methods and tools, data analysis procedures as well as ethical considerations. The next chapter will dwell on data presentation, interpretation and analysis.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The study seeks to determine environmental impacts of chemical processes in the processing of water in Bindura municipality. To achieve this, the study would establish the prevalent chemical processes in modern water processing, determine the effects of chemical processes on local ecosystems, particularly aquatic life and suggest solutions or strategies in order to reduce further negative effects of chemical processes in water processing at Bindura municipality. This chapter presents, interprets and analyze data that was collected from the field. Through the investigation of these findings, it would be possible to identify areas for improvement and suggest strategies for reducing or preventing further negative environmental impacts of chemical processes involved in water treatment. Data was collected through questionnaires, interviews and observations and would be presented qualitatively and quantitatively.

4.2 Response rate

The study achieved a 100% response rate from all administered questionnaires and conducted interviews. However, it is important to note that some challenges were encountered, particularly with a few questionnaires that contained incomplete responses and unanswered questions. These gaps may have been due to a lack of clarity in some items, respondent fatigue, or reluctance to disclose certain information. Despite these limitations, the data collected were sufficient to draw meaningful conclusions and support the overall objectives of the study.

4.3 Demographic profiles

Demographic profiling of the participants was essential in providing a clear understanding of the characteristics of the study. This section presents key demographics variables such as age, gender, educational background, employment status and other relevant attributes. These variables were analysed to identify trends, patterns and relationships that may influence the study.by understanding the demographic makeup of respondents helps to contextualize the data and ensure that the findings are interpreted within the social and cultural framework.

Additionally demographic profiles aid in assessing the representativeness of the sample and contribute to the generalizability of the research findings to a broader population.

4.3.1 Gender profiles of participants

One of the attributes significant to the study was the respondents` gender profiles and hence, it was critical to capture. Gender influences people's experiences, opportunities, and challenges in a variety of contexts. The gender of participants was important as this helped researcher to understand behavioural patterns, decision making processes and social interactions which may be relevant to the research topic, and gender representation enhances the generalizability of the findings to the broader populations. In addition, this also allowed for a more comprehensive analysis of the research topic, and also could inform the development of targeted interventions or policies. Table 4.1 shows the distribution of participants according to their gender profiles.

Table 4.1 Gender profiles of participants (n=40)

Participant Gender	Frequency	Percentage
Male	23	57.5%
Female	17	42.5%

Table 4.1 profiled the gender for research participants as this would help to understand the gender disparities in among the research participants and shows that 57.5% of the participants were males while their female counterparts constituted 42.5%. It can be noted that female are increasingly participating in fields that were once dominated by males although males were slightly more than females, the observation conquers with Williams (2023). Although there was no equal representation it can be noted that it was fair considering previous disparities between male and female representation especially before independence when women were often considered seconded class citizens in their own countries.

4.3.2 Age profiles for respondents

The study sought to profile participant ages which are illustrated on figure 4.3 bellow,

Table 4.2 Age profiles of participants (n=40)

Age Ranges	Frequency	Percentage
20-35 years	7	17.5%
36-40 years	15	37.5%
41-45 years	11	27.5%

46-50years	5	12.5%
51 years +	2	5%

Table 4.2 shows that the age profiles of the learners and teacher participants in Bindura Municipality as regards this study. It can be noted that the majority, 37.5% of the participants were between 36 and 40, while 27.5% of them were between 41and 45 years old. Findings also suggest that 17.5% of respondents were between 20 and 35 years old, while 12.5% of them were participant teachers between 46 and 50 years respectively. It can be further noted that the least, 5% of the participants were 51 years and above. Age profiles of respondents are an essential demographic variable that helped researcher to analyze the characteristics of the sample while age related differences also impacted on the various factors such as aptitudes, behaviours, preferences and experiences.

4.3.3 Education profiles for participants

The study also profiled the educational levels for the participants in the study. Figure 4.1 shows the levels in education profiles of research participants.

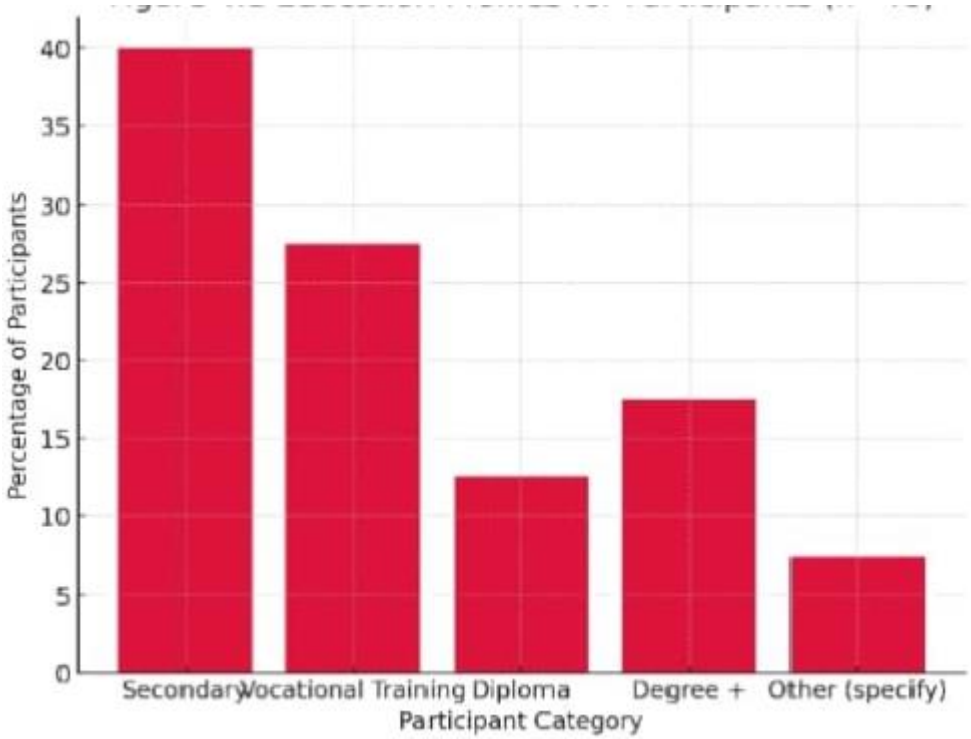

Figure 4.1 Education profiles for Participants (n=40)

Figure 4.1 profiled the levels of education of each research participant which helped to ascertain the levels of participation of the respondents in the study. From figure 4.1 it can be noted that the majority, 40% of the participants had attained Secondary level education while 27.5% of them had vocational qualifications. In addition, the findings indicated that the least 17.5% of the participants had at least degree while 12.5% of the respondents had diplomas. Findings further also noted that the least 7.5% of participants had other qualifications not specified above. Educational profiles helped researcher to understand the category in which each participant would be put during the data collection process.

4.3.4 Profiles of participant employment status

The study also profiled the employment status for the participants in the study. Figure 4.2 shows the employment status profile of each research participants.

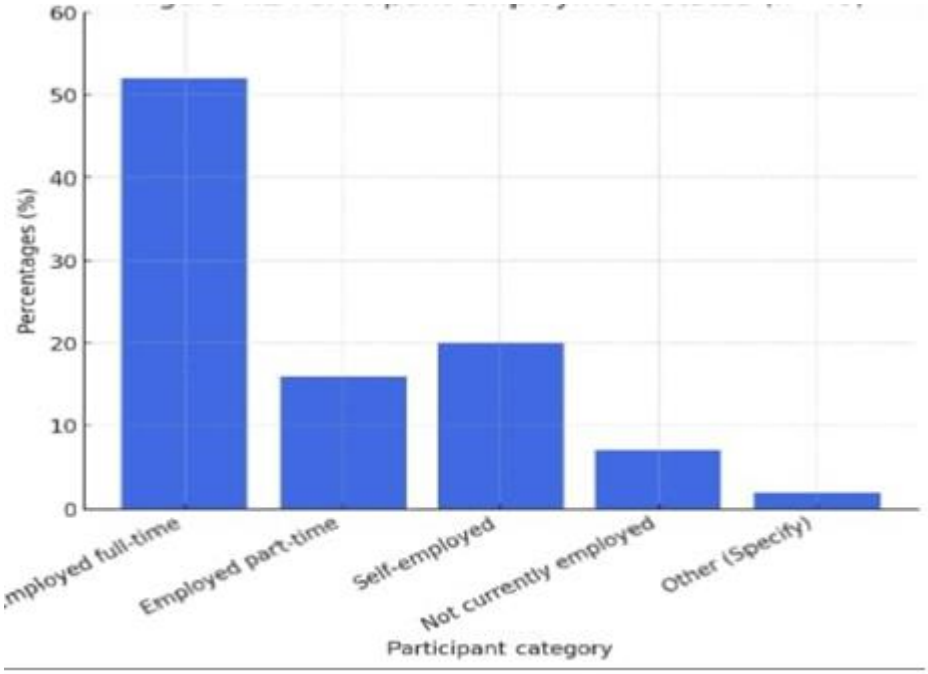

Figure 4.2 Participant employment status (n=40)

Figure 4.2 shows that the majority, 52.5% of participants were on full-time employment while 20% were on part-time employment. Findings indicated that 17.5% of these participants were self-employed while 7.5% of the participants were not currently employed or between employment. It can also be further noted that the least 2.5% of respondents could not confirm whether in employment or not instead they had other occupations. Profiling the levels of

education of each research participant helped to ascertain the levels and capabilities of participation of the respondents in the study.

4.4 Prevalent chemical processes at municipal water works

The study evaluated chemical processes that are used at Bindura Municipality water works against the numerous chemical processes often used in water treatment whether in municipalities or at Zinwa controlled water treatment plants. The study also gathered knowledge of chemical processes that are commonly used in treating water at Bindura water works. Research suggested that the majority, 100% of participants knew one or two or more methods or processes used in water treatment processes. Findings revealed that the majority, 42% of participants revealed that they were familiar with chlorination while some of them, 29% indicated that they knew coagulation/flocculation among other methods used in the water treatment processes. Findings also indicated that 18% of participants confirmed were familiar with sedimentation and filtration as some of the prevalent water treatment processes in municipalities while another 11% suggested they were familiar with disinfection as one of the processes used in water treatment in Bindura Municipality. Knowledge of the methods water treatment processes would help understand the chemical processes used at Bindura municipal water works. Interviewee 1 interrogated made the following remarks;

> *"Common chemicals used in water treatment at Bindura Water Works typically include chlorine, alum (aluminium sulphate), lime, and sodium hypochlorite. These chemicals are used for disinfection, coagulation, and pH adjustment."*

This is a clear and informative response listing specific chemicals used in a real-life context, which adds practical value. It shows an understanding of the roles these chemicals play in the treatment process (disinfection, coagulation, pH adjustment).

4.5 Effects of chemical water treatment processes on aquatic life

The study also profiled the effects of chemical processes used in water treatment of local ecosystems. This would help understand if ever there are any benefits or challenges associated with chemical processes on aquatic life especially the death of fish and frogs among other living organisms.

4.5.1 Challenges to aquatic life due to chemical processes

The study further examined challenges faced by aquatic life due to chemical processes. Table 4.4 profiles and illustrates the challenges associated with aquatic life due to chemical processes.

Table 4.3 Challenges to aquatic life due to chemical processes (n=40)

Challenges to aquatic life	Frequency	Percentage
Nutrient pollution	3	7.5%
Heavy metal contamination	6	15%
Pesticides and herbicides	7	17.5%
Plastic pollution	10	25%
Acidification and altered pH levels	2	5%
Pharmaceutical contamination	12	30%

Table 4.3 displayed that the majority, 30% of respondents revealed that pharmaceutical contamination was one of the major challenges while 25% pointed out that plastic pollution was a major problem. It can also be noted that 17.5% of participants pointed out that pesticides and herbicides were a major challenge to aquatic life while 15% revealed that heavy metal contamination was one of the challenges to aquatic life. Research findings also indicated that 7.5% of participants pointed to nutrient pollution as one of the challenges to aquatic life while the least 5% of the respondents cited acidification and altered pH levels as some of the challenges faced by aquatic life.

4.5.2 Contributions of chemical processes to ecological pollution

The study also examined the contributions of chemical processes to ecological pollution and table 4.4 profiled these contributions as indicated below.

Table 4.4 Contributions of chemical processes to ecological pollution (n=40)

Contributions	Frequency	Percentages
Volatile organic emissions & industrial discharges	4	10%
Toxic emissions and greenhouse gasses	2	5%
Chemical runoff	5	12.5%
Pharmaceuticals and personal care products	9	22.5%
Pesticides and herbicides	13	32.5%
Oil spills and hazardous material leaks	7	17.5%

It can be noted that findings on table 4.4 unveiled that the majority, 32.5% of participants revealed that agricultural pesticides and herbicides often end up affecting the soil health and biodiversity while 22.5% also felt that pharmaceuticals and personal care products often enter water bodies through wastewater treatment plants thereby affecting or damaging aquatic life. It can further be noted that 17.5% of respondents were of the view that oil spills in extraction and transportation and hazardous material leaks from storage tanks have often led to localised pollution of air, water and soil thereby impacting marine ecosystems while 12.5% also revealed that chemical runoff resulting from fertilisers and pesticides often leach into waterways thereby causing eutrophication and harm aquatic ecosystems. Findings further revealed that 10% of respondents confirmed that emissions from industrial processes (industrial discharges) solvents and plants lead to the formation of ground-level ozone which pollute the air. It can be noted that the least, 5% of research participants indicated that greenhouses also release CO2, methane (CH4), and nitrous oxide (N20) and toxic emissions contaminate the air thereby causing climate change.

4.5.3 Most concerning environmental issues

The study intended to ascertain most concerning environmental issues. Table 4.5 illustrates those environmental issues that are concerning.

Table 4.5 Most concerning environmental issues (n=40)

Environmental issue	Frequency	Percentage
Death of fish	2	5%
Water discoloration	9	22.5%
Algal blooms	3	7.5%
Sludge disposal	21	52.5%
No concerns raised	5	12.5%

Table 4.5 shows that table 4.5 shows that the majority, 52.5% of participants revealed that sludge disposal was the major environmental issue of concern while 22.5% of them cited water discoloration as an issue of concern. Form the table it can also be noted that 12.5% of the participants did not raise any concerning environmental issues while 7.5% of the same participants were concerned with algal blooms as concerning environmental issue. However, it can also be noted that the least 5% of the participants revealed that the death of fish was an

environmental issue of concern. It was critical for the researcher to look into concerning environmental issues as the knowledge gathered would help stakeholders and those concerned device better ways of handling the issues during water treatment processes.

4.5.4. Damages caused by chemical processes to fauna and flora in Bindura

Table 4.7 profiles the damages and provides illustrations.

Table 4.6 Damages caused by chemical processes to flora and fauna (n=40)

Damages	Response	Percentage
Toxicity and poisoning to both flora and fauna	10	25%
Soil degradation and water contamination	13	32.5%
Bioaccumulation and Biomagnification	2	5%
Disruption of photosynthesis	3	7.5%
Altered growth patterns	5	12.5%
Destruction of habitat	7	17.5%

The study looked at the damages cause by chemical processes to flora and fauna. It can be noted that table 4.6 shows that the majority, 32.5% of participants revealed that chemical processes resulted in soil degradation and water contamination while 25% of the respondents indicated that chemical processes caused toxicity and poisoning to both flora and fauna. From the findings 17.5% of participants reflected that chemical processes caused the destruction of the habitat which leads to loss of biodiversity and suitable living conditions for various species while 12.5% of them revealed that the chemical processes altered growth patterns as they can disrupt hormonal balances in plants. Research findings also suggest that 7.5% of participants revealed that chemical processes disrupted photosynthesis as pollutants like sulphur and nitrogen can interfere with the photosynthetic process thereby reducing plant growth and productivity while the least 5% of them confirmed that these chemicals causes bioaccumulation and bio magnifications in animals and plants.

4.6Minimizing chemical impacts in water treatment

The study also suggested solutions and strategies, as well as improvements that could be adopted to reduce the environmental impacts of chemical processes in water treatment, and measures that could reduce the negative environmental impacts of these processes. It also

focussed on the role of regulatory authorities in promoting sustainable chemical use in water treatment.

4.6.1 Improving water treatment sustainability

Findings revealed that the majority, 37% suggested that the use of treated wastewater for non-potable purposes, for example in irrigation, industrial processes and toilet flashing will help conserve fresh water resources thereby reducing the impact while another 25% recommended the adoption of greener alternatives such as ozone or UV treatment instead of chlorine as well as chemical optimization to minimize chemical dosage and side streams. Findings further indicated that 19% of interviewees suggested the incorporation of natural treatment systems such as constructed wetlands and bioremediation would reduce the need for chemical treatments while 12% of them cited the implementation of energy-efficient technologies and equipment in treatment plants to reduce energy consumption. Findings noted that 7% of the participants recommended the utilization of membrane filtration technologies such as reverse osmosis and nanofiltration which could be more effective while generating less waste than traditional methods. During an interview session one of the participants, Interviewee 2 responded as indicated below;

> *"I think for municipalities to be able to minimize the environmental impact of water treatment improvements can focus on optimising resource use, reducing energy consumption, minimising wastewater and adopting sustainable design and construction practices. But this should include upgrading wastewater treatment, minimising pollution, conservation of water ways, implementing measures and exploring sludge recycling and energy production from waste water."*

This response clearly outlines practical strategies municipalities can adopt to reduce the environmental impact of water treatment. The mention of resource use, energy consumption, and sustainable design shows good awareness of key environmental concerns.

4.6.2 Reduction of negative environmental impacts of chemicals in water treatment

The study intended to measures what could be adopted and implemented in reducing the negative environmental impact of chemical processes in water treatment at Bindura Water Works. Table 4.7 illustrates the measures to be adopted.

Table 4.7 Reduction of Negative Impact of Chemicals in Water Treatment (n=40)

Strategy	Frequency	percentage
Optimization of Chemical dosage	12	30%
Lime stabilization	3	7.5%
Research and development	1	2.5%
Water Minimization Strategies	10	25%
Alternative water treatment technologies	7	17.5%
Natural Water treatment Systems	2	5%
Regulatory Compliance Guidelines	5	12.5%

Findings from table 4.7 displayed that the majority, 30% of participants supported the optimization of chemical dosage involving advanced monitoring and control technologies to minimize the amount of chemicals used such as chlorine and alum, also minimizes excess usage and reduces chemical residuals in treated water while 25% of them cited water minimization strategies to help reduce the negative environmental impact. It can also be noted that 17.5% of the respondents suggested that the need for alternative water treatment technologies such as biological treatment, membrane filtration and activated carbon can also help reduce the negative impact while 12.5% of them suggested that adoption of regulatory compliance guidelines to ensure strict adherence to environmental regulations concerning chemical discharges and promote best practices for handling and disposing of chemicals would be ideal in reducing the negative impact. Table 4.7 further suggests that 7.5% of respondents felt the optimization of lime for sludge stabilization to ensure the necessary amount is used will limit entering the environment while the least 2.5% of these participants confirmed that ongoing research into the impacts of these chemicals on ecosystem is driving the development for safer alternatives and more sustainable practices in water treatment. Several views points were raised by interviewees regarding reduction of negative environmental impacts on chemicals used in water treatment. Interviewee 3 had this to say;

> *"While there are numerous strategies that can be implemented in order to reduce the negative environmental impacts of chemicals used in water treatment the optimization and reduction of chemical dosages as well as adoption of alternative water treatment technologies saves the purpose in greater deal."*

This response identifies the core issue chemical use in water treatment and suggests viable solutions like optimizing dosage and adopting alternative technologies. The focus on both reduction and innovation is commendable.

4.6.3 Roles of regulatory agencies in promoting sustainable chemical water treatment

The study also profiled the roles of regulatory agencies or authorities in promoting sustainable use of chemicals in water treatment processes. Figure 4.3 illustrates these roles as highlighted below.

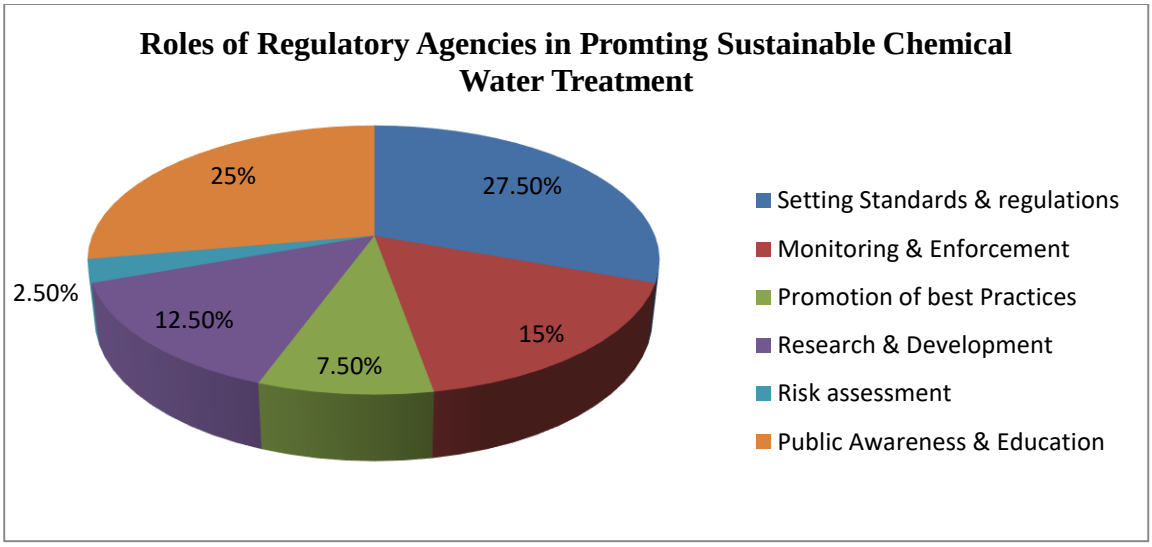

Figure 4.3 Roles of regulatory agencies in promoting sustainable chemical water treatment

Figure 4.3 interrogated the roles of regulatory authorities in promoting sustainable use of chemicals in water treatment. Figure 4.3 shows that the majority, 27.5% of participants suggested that one of the roles of these agencies is to set standards and regulations to be followed while 25% of them revealed noted that agencies provide public awareness and education. Findings further shows that 15% of participants suggested the role of agencies as monitoring and enforcement while 12.5% cite research and development as one the roles of the regulatory authorities. It can be further noted that 7.5% of participants cited promotion of best practices as one of the major roles of regulatory agencies. However, the least 2.5% of them noted that these roles also include risk assessment.

4.7 Findings from observations

The study was meant to conduct some observations at the water works to assess whether all was well with regards to laid down protocols. Accordingly, the observation checklist provided the areas that researcher needed to observe. Observations revealed that chemicals were stored in designated areas with proper labelling and signage while the chemical containers were sealed and protected from environmental exposure. Researcher also noted that water and sludge generated from chemical processes are properly managed and disposed of while water spill

plans and equipment were readily available. Observations also revealed that there were no leakages at the time of the visit while at the same time there were no signs of environmental degradation or contamination. Findings further suggest that observations indicated that safety protocols and emergency procedures were in place and communicated to staff while it was also noted that chemical processes and waste management practices complied with relevant regulations. In addition, findings also suggested that permits and licences were up to date and displayed strategically while no notable observations or concerns related to environmental impacts of chemical processes in water treatment had been observed.

4.8 DISCUSSION AND ANALYSIS

4.8.1 Environmental impacts of water treatment chemicals

The study aimed to examine environmental impacts of chemical processes in water treatment in Bindura Municipality. To achieve this major objective the study was guided by several research questions which converted into themes and would subsequently generated sub themes from the major themes thereof. Research findings were compared with previous scholarly work from available literature contained in the second chapter of the study.

4.8.2 The prevalent chemical processes in modern water treatment

Research findings provide light on the knowledge of participants about prevalent chemical processes used in water treatment at Bindura municipality water works. According to the research this part of the study sought to find out whether participants had knowledge of any chemical processes that are prevalent in water treatment at Bindura municipality water works. Thus, the research found out that the majority of the participants were familiar with one or two chemical processes involved in water treatment. In addition, findings further suggested that these chemicals typically include chlorine, alum (aluminium sulphate), lime, and sodium hypochlorite which are used for disinfection, coagulation, and pH adjustment. While the research noted the different chemical processes involved, WHO (2022); USEPA (2022) all contend that the methods used in the treatment of water included physical processes such as filtration, sedimentation and distillation, and biological processes such as biologically active carbon. They also included chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light.

4.8.3 The effects of chemical processes on local ecosystems

The study also examined the effects of chemical processes on local ecosystems, particularly aquatic life. The study noted that examining and understanding the effects of chemical processes on local ecosystems especially, aquatic organisms would help conserve biodiversity, balance ecology, would also help prevent contamination and protect public health and raise awareness among the public and policy makers about the importance of protecting aquatic ecosystems from harmful chemical processes.

Research findings show that pharmaceutical contamination and plastic pollution were major effects of chemical processes on local ecosystems. Research findings concur with studies by Moses et al (2018) who noted that chemical processes in water treatment often release excess nitrogen and phosphorus into nearby water bodies which lead to eutrophication where nutrient overload causes algal blooms that deplete oxygen in the water resulting in hyponix conditions and mass fish mortality which harm aquatic life and disrupt ecosystems. The study further found that agricultural pesticides and herbicides also affect soil health and biodiversity with pharmaceuticals and personal care products presenting major challenges to aquatic life. In addition, research found that sludge disposal and water discoloration were among major environmental issue of concern. This is in agreement with an example by IPBES (2019) which noted that pesticides, heavy metals, and industrial chemicals can persist in soil, impacting soil fertility and biodiversity.

Furthermore, the research found out that soil degradation and water contamination including chemical processes caused toxicity and poisoning of both flora and fauna. Research findings are in agree with Rani et al (2025) who noted that chlorine and its disinfection by-products (DBPs) like trihalomethanes have been found toxic to aquatic organisms which reduces fish populations and alter reproductive patterns. This was further corroborated by the EEA (2020) which noted that chemical processes also pollute the soil causing chemical leaching into the soil, contaminate groundwater and pose risks to human health as well as degrade soil quality thereby reducing its fertility and ability to support plant growth.

4.8.4 Reducing harmful effects in water treatment

The study also proffered strategies necessary for reducing further negative effects of chemical processes in water treatment at Bindura municipal water works. According to the research the use of treated wastewater for non-potable purposes in irrigation, industrial processes and toilet

flashing will help conserve fresh water resources, and reduce the impact. Research found that this could be effective if coupled with the adoption of greener alternatives such as ozone or UV treatment instead of chlorine including minimizing chemical dosage and side streams. This was corroborated by Khan et al (2022) who stated that the use of biodegradable coagulants and flocculants such as plant-based materials could drastically reduce the chemical load in water treatment facilities.

According to this study focus on optimising resource use, energy consumption reduction, minimisation of wastewater and adoption of sustainable design and construction practices including upgrading wastewater treatment and minimising pollution water conservation will help further reduce environmental impact of water treatment. The research further found that optimization of chemical dosage involving advanced monitoring and control technologies also minimizes excess usage and reduces chemical residuals in treated water. In addition, research found that the roles of regulatory agencies or authorities include setting standards and regulations to be followed and providing public awareness and education to clients to promote sustainable chemical use in water treatment. This was corroborated by Brown and Taylor (2023) who noted that community-based programs usually promote sustainable practices that lessen reliance on harmful chemical treatments.

4.8.5 Findings from observations

Observations conducted by the researcher revealed that much of the stipulated standards were being adhered by the local authority. The research found that chemicals were being stored in designated areas with proper labelling and signage while their containers were sealed and protected from any environmental exposure. Observations also noted that water and sludge generated from chemical processes were properly managed and disposed of. In addition, observations further revealed that there were no leakages at the time observations were conducted as there were no signs of environmental degradation or contamination.

4.9 Chapter summary

This chapter presented data, analysed and interpreted data that was collected through questionnaires, interviews and observations. The chapter profiled and presented demographic data and the collected data was coded into themes with guidance from the research questions. The data was analysed qualitatively and quantitatively. The next chapter presents a summary

of findings, conclusions and recommendations to municipal authorities, policy makers (government), residents, scholars, and other stakeholders.

CHAPTER FIVE: CONCLUSSIONS AND RECOMMENDATIONS

5.1 Introduction

The study examined environmental impacts of chemical processes in water treatment at Bindura municipality water works. While the previous chapter focused on the presentation, analysis and discussion of findings, this chapter focuses on the summary of research findings, conclusions and recommendations based on the objectives and key findings. The chapter may provide recommendations for further research. This chapter is critical to the study in explaining the extent to which the objectives of the study were addressed.

5.2 Summary of findings

The study examined environmental impacts of chemical processes in water treatment in Bindura municipality of Mashonaland Central Province. Based on qualitative interviews and observations including data from questionnaires, key findings demonstrate that the majority of the participants were familiar with one or two chemical processes involved in water treatment. In addition, the study further found that the chemicals such as chlorine, alum (aluminium sulphate), lime, and sodium hypochlorite are usually used for disinfection, coagulation, and pH adjustment during water treatment processes. The research also found that physical chemical water treatment processes include filtration, sedimentation and distillation, while biological processes include biologically active carbon. Research also noted that the chemical processes also included chemical flocculation and chlorination, and electromagnetic radiation such as ultraviolet light. In addition, the study further found that examining the effects of chemical processes on local ecosystems can help conserve biodiversity, balance ecology, and prevent contamination as well as protection of public health raising awareness among the public and policy makers about the importance of protecting aquatic ecosystems from harmful chemical processes. Furthermore, research found that pharmaceutical contamination and plastic pollution were noted major effects of chemical processes on local ecosystems. In addition, further findings suggest that the chemical processes used in water treatment often release excess nitrogen and phosphorus into nearby water bodies which lead to eutrophication where nutrient overload would cause algal blooms that deplete oxygen in the water resulting in hyponix conditions which harm aquatic life and disrupt the ecosystem. Also it was found that agricultural pesticides and herbicides also affect the health of the soil health and biodiversity with pharmaceuticals and personal care products presenting major challenges to aquatic life.

Furthermore, the research found out that soil degradation and water contamination including chemical processes caused toxicity and poisoning of both flora and fauna. According to the research the use of treated wastewater for non-potable purposes in irrigation, industrial processes and toilet flashing will help conserve fresh water resources, and reduce the impact. According to this study focus on optimising resource use, energy consumption reduction, minimisation of wastewater and adoption of sustainable design and construction practices including upgrading wastewater treatment and minimising pollution water conservation will help further reduce environmental impact of water treatment. Researcher observations revealed that much of the stipulated standards were being adhered by the local authority and that chemicals were being stored in designated areas with proper labelling and signage while their containers were sealed and protected from any environmental exposure. The researcher further observed that water and sludge generated from chemical processes were properly managed and disposed of. In addition, observations further revealed that there were no leakages at the time observations were conducted as there were no signs of environmental degradation or contamination. The study also contributed in part to the available literature in that not much was available on the environmental impacts of chemical processes in municipality water treatment processes.

5.3 Implications of the study

The research sought to examine environmental impacts of chemical processes in water treatment in Bindura Municipality. Several common chemical processes used in modern municipal water treatment facilities were identified. These chemical processes included chlorination, coagulation and flocculation as well as aluminium or iron salts, ozonation and advanced oxidation processes such as the use of hydrogen peroxide.

According to the research chemical processes used often lead to discharge of residual chemicals and by-products into local water bodies. For example, chlorination produces disinfection by-products (DBPs) such as trihalomethanes that can be toxic to aquatic life. In addition, coagulants such as aluminium can cause increase turbidity and negative effects to the health of aquatic organisms. Furthermore, the introduction of ozonation has the potential to disrupt local microbial communities by altering the chemical composition of the water, which might have cascading effects on the ecosystem. Additionally, compounds generated through chemical

processes can result in reduced biodiversity in aquatic ecosystems while sensitive species may be particularly vulnerable to pollutants which often lead to shifts in species composition and potential loss of native biodiversity. As a result this often disturbs the ecological balance and service delivery of these ecosystems. According to comprehensive findings presented, the research provides compelling evidence that researcher is extremely optimistic about how chemicals affect the environment during water treatment processes at Bindura municipality water works and hence the need for solutions.

Based on the research findings, several strategies can be adopted to mitigate the negative impacts of chemical water treatment. It is therefore imperative for municipalities to adopt the use of less harmful chemicals and environmentally friendly alternatives such as utilizing biocides which are derived from natural sources instead of traditional chlorine compounds. Adoption and implementation of robust monitoring systems to regularly assess the concentration of chemicals and their by-products in both treated water and effluent discharges can help identify potential ecological harm early. In addition, combining chemical processes with physical and biological water treatment methods such as wetlands or bioremediation can decrease reliance on harsh chemicals and rehabilitate local ecosystems. Overall, while chemicals processes are essential for effective water treatment, their environmental implications necessitate careful management and innovative approaches to minimize adverse effects on local ecosystems. Furthermore, prioritising sustainable practices in municipal water treatment processes can foster healthier environments and more resilient communities.

5.4 Contributions to the literature

The study is critical in that it evaluated the chemicals commonly used in water treatment processes, highlighting their potential environmental risks and how they interact with ecosystems. By analysing the effects of the chemicals on aquatic ecosystems, the study also enhances understanding of how chemical treatments can disrupt local biodiversity and water quality. In addition, the study also connects environmental health and public health by discussing how the by-products of chemical water treatment can affect human in communities that depend on treated water. The study also offers insights that can inform policymakers and stakeholders about sustainable practices and the need for regulatory frameworks that encourage the use of less harmful alternatives in water treatment. Overall, research findings promote

awareness of alternative water treatment methods such as biological or natural treatment systems which could mitigate negative impacts of the environment.

5.5 Limitations of the study

There are several factors that can limit the reliability and applicability of the conclusions drawn from the study on environmental impacts of chemical water treatment processes. For example, the results of the study may be generalised across different regions due to variations in water resources, local regulations and environmental conditions. In addition, the study account for seasonal variations or long-term ecological changes while in some situations the study may accurately represent real-world conditions which lead to discrepancies in how chemical processes perform in full scale operations. Furthermore, the limited scope as some studies focus only one specific chemical neglecting other chemicals potentially harmful, and lack of standardized metrics for evaluating environmental impact can lead to inconsistent conclusions. Limited access to comprehensive data on chemical usage and emissions from treatment facilities and the complexity of interactions between chemicals and the ecosystems including potential synergies may not be understood and hence a limitation. Additionally, overlooking the economic implications of implementing environmentally sound practices which can influence decision-making in water treatment can also be limitation posed.

5.6 Recommendations

5.6.1 Practical recommendations

To address the environmental impacts of chemical processes in water treatment in Zimbabwe, a comprehensive set of recommendations can be tailored for local authorities, residents, regulatory bodies, and the academia including policy makers.

- In light of the studies local authorities are recommended to adopt eco-friendly water treatment methods including the use of environmentally friendly alternatives to chemical processes, such as using biofiltration or natural coagulants.
- Local authorities should conduct regular environmental impact assessments (EIAs) for water treatment facilities to the effects of chemical discharge on local ecosystems.
- Local authorities should regularly conduct awareness education programmes to residents about the potential environmental impacts of chemical use and the importance of water conservation.

- The study also recommends and encourages community participation in monitoring local water quality and reporting cases of water pollution.
- The study recommends the promotion of water harvesting, greywater recycling, and other conservation practices to reduce dependence on chemically treated water.
- The study also recommends the Zimbabwe National Water Authority (ZINWA) to create and implement comprehensive management plans that prioritize sustainable practices and minimize chemical use in water treatment.
- Recommends investing in research and development for alternative water treatment technologies that minimize chemical use and reduce environmental footprints.
- There is need to develop training programmes for personnel in best practices in chemical handling and waste disposal.
- Government makers should allocate adequate financial resources to support research on eco-friendly water treatment technologies and their comparative impacts.
- There is need to develop and enforce regulations that limit harmful chemical discharges from water treatment plants/facilities into the environment, and ensure compliance with laid down environmental standards.
- There should be created partnerships between government agencies, the academia, and industry to share knowledge, data and best practices in water treatment and environmental protection.
- Involve communities in discussions about water and their environmental impacts to foster transparency and trust.
- The study recommends prioritizing policies that can enhance the health of aquatic ecosystems and local biodiversity when evaluating water treatment processes.
- Policy makers should also develop strategies that enhance the resilience of water treatment facilities to environmental changes while minimizing negative impacts.
- There should be collaboration across disciplines such as chemistry, environmental science and engineering to address the complex challenges associated with chemical processes in water treatment.
- Integrate emerging technologies, such as remote sensing and big data analytics to enhance the effectiveness and precision of environmental impact assessments.
- The academia should mentor students through hands-on research opportunities related to the environmental impacts of water treatment, fostering the next generation of environmental scientists.

5.6.2 Future research directions

Future researches would include investing in alternative chemical methods of water are less harmful to the environment which would include the development of biodegradable flocculants and disinfectants, as well as optimization of existing chemical process to reduce harmful by-products. In addition, future studies can focus on exploring the effectiveness and environmental impact of chemical treatments on emerging contaminants such as pharmaceuticals, microplastics, and personal care products that traditional treatments may not adequately address. Furthermore, future researches can focus on assessing the toxicity of chemical by-products produced during water treatment processes on aquatic life and ecosystems which includes understanding how different chemicals interact in the environment and their long-term effects on biodiversity.

5.6.4 Future recommendations

While chemical treatments are essential for ensuring drinking water and effective wastewater management, it is crucial to weigh the environmental benefits against potential negative impacts such as chemical residues and by-product formation. Furthermore, engaging communities and raising awareness about the importance of water treatment processes can foster greater support for sustainable practices and encourage responsible consumption of water resources. Overall, the study highlights the need for ongoing research to better understand the long-term environmental impacts of chemical treatments and explore novel, less harmful approaches to water treatment.

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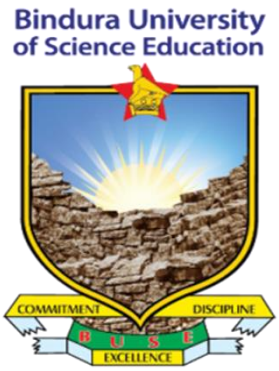
APPENDICES

Appendix 1: The Questionnaire



BINDURA UNIVERSITY OF SCIENCE EDUCATION

"Where Great Minds Meet"

My name is Tatenda Hloko, a student at Bindura University of Science Education pursuing a Bachelor of Science Education Degree in Chemistry (HBScEd CH). I am carrying out a research on the environmental impact of chemical processes in water treatment at Bindura municipality in partial fulfillment of the requirements of the BScEd CH. The study is carried out in Bindura, Mashonaland Central Province. Could you please help solicit information by completing this questionnaire? Be informed that all the information collected shall be kept confidential while all sources of information shall remain anonymous and the information will be used only for academic purposes. Also be advised that your participation in this study is voluntary and you can withdraw from the study at any stage if you so wish without any prejudice.

Your contribution will be greatly appreciated.

Thank you

Section A: Questionnaire (for General Public or Plant Workers)

Instructions: Tick the most appropriate option or fill in the space provided.

Section A: Demographic Information

1. Gender: Male [ ] Female [ ]

2. Age

20-35 years	36-40 years	41-45 years	46-50 years	51 years +

3. What is your highest educational / professional qualification?

Educational level	**Response**
Primary	
Secondary	
Vocational	
College diploma	
Degree	

4. What is your employment level?

Employment Level/Grade	**Response**
General Hand	
Technical Hand	
Technician/Artisan	
Supervisory	
Administrative	

Section B: Prevalent Chemical Processes at Bindura Municipality Water works

5. Are you aware of how water is treated in Bindura Municipality?
Yes [ ] No [ ] Not Sure [ ]

6. Which of the following water treatment processes can you have been used at Bindura Water works? (Tick all that apply)

Chemical process	**Response**
Chlorination	

Coagulation/Flocculation	
Sedimentation	
Filtration	
Disinfection	
Other (specify)	

Section C: Effects of chemical processes on local ecosystems (aquatic life)

7. What challenges to aquatic life have you observed due to chemical processes in recent years?

……
……
……

8. Do you think chemical water treatment processes can contribute to environmental pollution?

Yes [ ] No [ ] Not Sure [ ]

9. In your opinion, which of the following environmental issues is most concerning?

Environmental issue	**Response**
Death of fish	
Water discoloration	
Algal blooms	
Sludge disposal	
Other	

10. Can you say the effects of these chemical processes have extremely damaged fauna and flora in the area?

Yes [ ] No [ ] (If yes, briefly explain:……...

……
……

Section D: Suggestions towards reduce further negative effects of chemical process in water treatment at Bindura Municipality

11. What improvements would you suggest to reduce the environmental impact of water treatment?

……
……
……

12. What measures do you think could be implemented to reduce the negative environmental impacts of chemical processes in water treatment?

……
……
……

13. What role do you think regulatory authorities or agencies should play in promoting sustainable chemical use in water treatment?

……
……
……....

THE END

Appendix 2: **Interview Questions (for Technical Staff, Environmental Officers, or Municipal Leaders)**

Good afternoon

My name is Tatenda Hloko. I am a student at Bindura University of Science Education and am pursuing a Bachelor of Science Education Honours Degree in Chemistry. As part of the requirements of the degree programme I am required to conduct a research on a topic of interest related to the subject in partial fulfillment of the requirements of the programme. Please note that all the information you shall give will remain confidential and your identity will also remain anonymous. Also note that the information shall be used for academic purposes only. I have a few questions to ask you.

The Interview Questions

1. Describe the chemical processes being used in treating water at Bindura Municipality?

2. Which chemicals are used most frequently and why?

3. How are these chemicals stored, handled, and monitored?

4. Are you aware of any emerging technologies or innovations that could help reduce the environmental impacts of chemical processes in water treatment? (Yes/No).

5. Have there been any recorded environmental effects of the processes linked to water treatment at Bindura Muicipality (e.g., death of fish, changes in river ecology etc.)?

6. How is chemical waste, especially sludge, managed and disposed of?

7. Have there been concerns raised by local communities or experts regarding the impact of treated water on aquatic life?

8. What strategies are currently in place to minimize negative environmental effects of chemical treatment?

9. What measures do you think can be implemented to reduce or prevent further negative environmental impacts of chemical processes in water treatment at Bindura Municiplaity?

10. Are there any plans to adopt greener or alternative treatment methods?

11. What sort of support (financial, technical, policy) is needed to improve sustainability?

12. Is there anything else you would like to share about reducing or preventing the negative environmental impact of chemical processes in water treatment?

THE END

Appendix 3: Observation Checklist

Parameters	**Response**
Are the chemicals stored in designated areas with proper labeling and signage?	
Are the chemical containers sealed and protected from environmental exposure?	
Are spill response plans and equipment readily available?	
Re chemical dosing systems calibrated and functioning correctly?	
Are the chemicals applied according to recommended guidelines and regulations?	
Are water and sludge generated from chemical processes properly managed and disposed of?	
Are there any signs of spills or leakages?	
Are there any signs of environmental degradation of contamination?	
Are safety protocols and emergency procedures in place and communicated to staff?	

Are chemical processes and waste management practices compliant with relevant regulations?	
Are permits and licenses up-to-date and displayed?	
Are there any notable observations or concerns related to environmental impacts of chemical processes in water treatment?	

THE END