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Worker's knowledge and perception on occupational exposure related to emissions at wastewater treatment plants, in the City of Tshwane, South Africa

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A thesis submitted in partial fulfilment of the requirements for the

MPH: Occupational Hygiene

20 August 2025

Affidavit

To whom it may concern

This serves to confirm that I, Jeannette Baleseng Msimanga, 8704051139086, student no: 1499799, enrolled for the qualification MPH (Occupational Hygiene) in the Faculty of Health Science, herewith declare that my academic work is in line with the Plagiarism Policy of the University of Witwatersrand, with which I am familiar.

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_ _____

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This affidavit conforms with the requirements of the JUSTICES OF THE PEACE AND COMMISSIONERS OF OATHS ACT 16 OF 1963, and the applicable Regulations published in the GG GNR 1258 of 21 July 1972; GN 903 of 10 July 1998; GN 109 of 2 February 2001 as amended.

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Dedication

This study is dedicated firstly to my maker, for his provision, sustenance and opening doors throughout this study. This research is also dedicated to Water Research Council (WRC) for allowing me to contribute to the body of knowledge and all the wastewater treatment plants management for hosting me on your premises. I also dedicate this study to my immediate family and my in-laws who have been more than supportive throughout this journey. Importantly, the study is dedicated to all the wastewater treatment plant workers that contributed immensely to the study, without your contribution the study could not have happened.

Abstract

Background

Workers at WWTPs are responsible for ensuring there is daily operations and maintenance. Workers are exposed to a variety of biological, chemical and physical hazards that emanate from wastewater and treatment activities.

Aim

The study aimed at evaluating the knowledge and perception of WWTP workers occupational exposure to bioaerosols, volatile organic compounds (VOCs) and odours, including their self-reported health symptoms associated with these emissions, from three WWTPs in the City of Tshwane, Gauteng.

Methods

A cross-sectional quantitative study design was conducted among workers at three wastewater treatment plants (WWTPs), in the city of Tshwane. A total of 32 participants were recruited via convenience sampling: 12 from WWTP A, 10 from WWTP B and 10 from WWTP. All the eligible workers at each study site were invited to participate in the study. Participation was voluntary, and written informed consent was obtained prior to data collection.

Data was collected using a self-administered questionnaire (n=32), which assessed knowledge, perception, and self-reported symptoms related to exposure to bioaerosols, VOCs, and odours (BVOs). Descriptive statistical analysis and correlation analysis were used to explore associations between demographic variables and both knowledge and perception. Self-reported symptoms were recorded for all participants. Data analysis was performed using SPSS software (version 29.0.0).

Ethics clearance was obtained from the University of the Witwatersrand Human Research Ethics committee (Medical): Certificate No. M240107 M240517-B-0001.

Results

The findings indicated that workers demonstrated limited knowledge regarding bioaerosols, VOCs, and combined BVO emissions, including their associated health effects. Fewer than

63% of responses were accurately identified the sources of BVOs and associated health outcomes. Despite this knowledge gap, workers showed strong awareness of key safety practices: 97% recognized the importance of showering and changing clothes after a shift, and 84% correctly identifying the aeration process as the highest-risk activity for exposure to airborne droplets.

Over 44% of the participants reported experiencing flu-like, respiratory, irritant-related, or gastrointestinal symptoms, one to three times within the past six months. Correlation analyses showed generally weak or no associations, between demographic variables and workers' knowledge or perception of BVO occupational exposure. However, a statistically significant negative correlation was observed between education level and knowledge of WWTP emissions ($r = -0.037$, $p = 0.038$), indicating that higher education was modestly associated with lower knowledge scores possibly reflecting overconfidence or information gaps. Additionally, a significant correlation analysis found between educational level and the perception that eating anywhere in the plant is acceptable ($r=-0.410$, $p=0.020$), suggesting greater adherence to safety protocols among more educated workers. A moderate positive correlation was also found between the type of employment and the perception that air quality affects health ($r = 0.365$, $p = 0.040$), suggesting that certain job tasks may be linked to increased awareness of air-related health risks.

Conclusion

The findings highlight the need for comprehensive occupational health strategies and programs within wastewater treatment facilities, particularly those that bridge the gap between knowledge and practical risk perception related to bioaerosols, VOCs, and odours (BVOs). There is limited understanding of BVO-related health risks among workers, despite high compliance with certain safety practices, this suggest that current training programs may be insufficient in addressing invisible or long-term chemical and biological hazards. Tailored educational interventions that incorporate both biological and chemical exposure risks are essential to enhance hazard recognition and promote preventative behaviours across all employment levels.

Future research should focus on longitudinal studies to evaluate the long-term health effects of chronic BVO exposure among WWTP workers, particularly using objective clinical or biomonitoring data alongside self-reported symptoms. Additionally, there is a need to explore organizational and psychosocial factors such as management practices, safety

culture, and risk communication efficacy that may influence workers' engagement with occupational health protocols. Investigating the effectiveness of targeted training modules and behavioural interventions could provide actionable insights for policy development and risk mitigation in similar high-exposure occupational settings.

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I would like to express my profound and immense gratitude to the following people for their dedicated efforts and unwavering support during my research journey:

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LIST OF ABBREVIATIONS

WWTP:	Wastewater Treatment Plant
VOCs:	Volatile Organic Compounds
BVOs:	Bioaerosols, VOCs and odours
W2RAP:	Wastewater Risk Abatement Plan
PPE:	Personal Protective Equipment
LMICs:	Low to Middle Income Countries
HICs:	High Income Countries

DFINITION OF TERMS

Emissions

Emissions are substances that are produced and discharged out into ambient air, which can be harmful to the environment and human health.

Bioaerosol*s*

Bioaerosols are small suspended airborne particles that have biological origin. These particles include pathogenic and or non-pathogen, including alive or dead microorganisms. Due to their small particle size and light weight, they are easily dispersed from one environment to the other. They play a vital role in the transmission route for infectious and sensitization agents. (Kim et al., 2018)

Volatile Organic Compounds (VOCs)

Volatile Organic compounds are organic chemicals which vaporise easily and enter the environment under normal conditions. They are emitted as gases from certain liquids and solid matter. Have strong mobility and resistance to degradation allowing them to travel long distance in the environment once emitted. (Pandey and Yadav, 2018)

Odour

Odour is a sensation resulting from stimulation of the olfactory system in the nose, due to stimulation by particular agents in gaseous form. (Ranveer et al., 2015)

Wastewater treatment plant

A sanitation system consisting of pipelines, pumping stations, pressure mains and other facilities used to collect and convey the wastewater from residential, industrial or commercial sources to a facility that will undertake water through a serious of treatments. For the ultimate purpose to improve the quality of water making it appropriate for a specific end-use (Van Dijk and van Vuuren, 2011).

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CHAPTER ONE

This chapter begins with an overview of wastewater treatment plants (WWTPs) and the ambient air pollutants they emit, with a specific focus on bioaerosols, volatile organic compounds (VOCs), and odours released during various treatment stages. It further explores the adverse health effects associated with these emissions. The chapter also outlines the problem statement and the justification for the study. It concludes by presenting the research question, along with the aim and objectives of the study.

1. BACKGROUND

South Africa has made it mandatory under the South African Water Act (Act 54 of 1956) to treat wastewater to acceptable standards and restore it to natural courses (Mema, 2010). WWTPs are industrial facilities that utilize mechanical, physical, chemical, and biological processes to remove various pollutants from wastewater, either for reuse or discharge into receiving bodies (Hreiz et al., 2015).

The fundamental functionality of WWTPs is to remove pollutants, inactivate microorganisms in the wastewater and to protect human and environmental health (Abu-Orf et al., 2013). The WWTP process produces ambient air pollutants such as bioaerosols, volatile organic compounds (VOCs), and odours (Byliński et al., 2019). Different treatment stages of wastewater produces different chemical compositions. Initially, mechanical treatment stages produce numerous odorous volatile organic compounds, while separation of sludge releases less odorous volatile organic compounds (Byliński et al., 2019). In addition, different stages of wastewater treatment contribute to varying levels of bioaerosol emissions. Pathogenic microorganisms are known to be aerosolized during wastewater mechanical agitation and aeration related process (Jabeen et al., 2023).

Exposure to emissions from wastewater treatment can cause various health effects, including discomfort due to unpleasant odour, even at low concentrations, headaches, dizziness, loss of consciousness, nausea and anxiety (Byliński et al., 2019). Bioaerosols can cause irritation of lower and upper respiratory tract, gastrointestinal lining irritation and contact dermatitis. These compounds can also cause respiratory system inflammation, and (Kim et al., 2018).

1.1. Problem Statement

Globally, over 3.1 billion workers are exposed to various occupational stressors, including physical, biological, chemical, ergonomic, and psychosocial hazards. These exposures lead to occupational diseases, musculoskeletal disorders, mental health issues, and injuries (International Labour Organization, 2013). Africa, with a workforce of approximately 397 million, has the highest occupational fatality rate at 17 deaths per 100,000 workers, surpassing Asia and America. This highlights the urgent need to strengthen occupational health and safety (OHS) systems in Africa (United Nations Global Compact, 2021).

Globally, OHS issues are critical for safe work and economic growth. High-performing economies invest significantly in OHS, while low-performing ones struggle, resulting in approximately 4% of global GDP lost to workplace injuries, deaths, and diseases (International Labour Organization, 2013). Occupational fatalities increased by 14% from 2014 to 2017, with 2.7 million annual deaths, 74% due to diseases (International Labour Organization, 2019). Weak disease surveillance and underreporting exacerbate challenges, particularly in developing regions. While occupational injuries decline in developed countries, work-related diseases remain difficult to monitor and measure, with no comprehensive global statistics available (Takala et al., 2013).

Biological hazards, including bacteria, viruses, fungi, and their toxins, pose significant health risks to workers across various industries, such as mining and manufacturing. These hazards can cause mild allergic reactions, chronic diseases, or death. Globally, approximately 320,471 workers die annually from communicable diseases linked to occupational exposure to biological agents, with Sub-Saharan Africa being the most affected, accounting for 44% (around 139,890 deaths) of global fatalities (International Labour Organization, 2021).

Despite the recognized severity of occupational health risks posed by biological agents, there remains a significant lack of empirical data on exposure patterns, health outcomes, and effective prevention strategies within African contexts (Hamalainen et al., 2017). This data gap is particularly pronounced in low- and middle-income countries (LMICs) such as South Africa, where systematic exposure monitoring and reporting practices are often underdeveloped (International Labour Organization, 2021 , Mohammed et al., 2022). Moreover, no formal occupational exposure limits (OELs) have been established for biological agents at the international level, including by the International Labour

Organization (International Labour Organization, 2021), further complicating risk assessment and regulatory enforcement in these settings. The absence of standardized benchmarks and locally relevant data impedes the development of evidence-based occupational health policies tailored to the unique exposure scenarios encountered in LMICs (Jabeen et al., 2023).

Wastewater treatment plant despite their environmental benefits, are recognised as source of atmospheric pollutants (Byliński et al., 2019). These plants face significant challenges in implementing control measures to reduce the effects of these pollutants (González et al., 2022). In the City of Tshwane, WWTPs operate continuously to serve the sanitation needs of hundreds of thousands of residents, resulting in prolonged occupational exposure of workers to potentially hazardous emissions. These workers play an essential role in ensuring uninterrupted plant operations. However, they frequently face inadequate access to routine health and safety training, reliable provision of personal protective equipment (PPE), and structured medical surveillance programs. This combination of high exposure potential and insufficient protective measures elevates their vulnerability to adverse health outcomes.

Limited studies have explored WWTP workers' knowledge and perception of occupational exposure, particularly in relation to emissions such as VOCs, bioaerosols and odours (Tian et al., 2022). While extensive body of literature addresses the environmental impact of WWTPs emissions (Ravina et al., 2021), risk assessments have predominantly relied on quantitative microbial risk assessment (QMRA) models that tend to isolate individual exposure pathways. This limited focus contributes to insufficient characterization of the complex, cumulative exposure risks encountered by WWTP workers.

Moreover, occupational health and safety enforcement within WWTPs often remains limited, with inadequate prioritization of regulatory requirements and protective measures for workers. This highlights a critical need for the development and implementation of a more robust and comprehensive regulatory framework to safeguard the health and safety of workers in this high-risk occupational setting (Hansen, 2015).

This study aims to assess the knowledge, perceptions, and self-reported health symptoms of wastewater treatment plant (WWTP) workers in the City of Tshwane regarding occupational exposure to bioaerosols, volatile organic compounds (VOCs), and odours (collectively referred to as BVOs). It seeks to identify gaps in awareness and safety practices, evaluate

the extent of symptom reporting potentially linked to exposure, and explore associations between demographic factors and worker perceptions.

Ultimately, the study intends to generate empirical evidence that can inform occupational health interventions, exposure mitigation strategies, and policy recommendations, with the goal of improving health outcomes and regulatory protections for WWTP workers in South Africa and other low- and middle-income country (LMIC) settings.

1.2. Justification of the study

Air pollution is a global issue that significantly impacts public health and the environment (Kelly and Fussell, 2015). In 2019, air pollution caused 4.2 million premature deaths worldwide (WHO, 2022).

Among the various contributors to air pollution, WWTPs are recognised sources of bioaerosols, volatile organic compounds and odours. Which can negatively affect the environment and human health.(Ghorani-Azam et al., 2016). While the environmental implications of WWTP emissions are well documented, there remains a significant research gap on the occupational health risks faced by WWTP workers, particularly in low- and middle-income countries like South Africa.

In the City of Tshwane, WWTPs operate on a continuous 24-hour basis to serve large populations and operate continuously, thereby subjecting workers to prolonged exposure to airborne contaminants, particularly high-risk operational zones. Workers engage in tasks such as manual screening, desludging, routine maintenance, and other close-proximity activities, which significantly elevates the risk of inhalation and dermal exposure to hazardous emissions, including bioaerosols, volatile organic compounds (VOCs), and odorous compounds.

Exposure to these emissions can lead to unhealthy signs of respiratory effects and digestive system problems (Vantarakis et al., 2016). Acute effects from exposure to some VOC may not be evident, but exposure can lead to chronic health risks (Kim et al., 2018). In addition, bioaerosols contain microorganisms that can cause disorders of the respiratory system, digestive system, and skin (Khalid, 2021). Despite the documented health risks associate with exposure to bioaerosols, VOCs and odorous emissions, there is paucity of research exploring these hazards, their perceptions, and the symptoms they associate with such exposures.

More research, robust regulatory frameworks, and safer design considerations are needed to reduce occupational exposure incidents (Khalid, 2021). Gaining insight on the knowledge and perception of the exposed individuals towards the hazards and related risks is critical for effective controls (Bye and Lamvik, 2007).

The current regulatory framework focuses on WWTP emissions to meet ambient air quality standards, but more is needed in the South African context on health emissions standards to mitigate occupational exposure for WWTP workers (Byliński et al., 2019).

The study aims to collect and assess information on knowledge and perception of occupational exposure from WWTP workers relating to emissions from the plants, contributing to the body of knowledge in formulating recommendations for improving health and safety in wastewater treatment facilities. The insights generated from this study are essential for informing comprehensive risk assessments that encompass appropriate control measures and targeted interventions. These findings will support the design of worker-focused awareness programmes, enhance compliance monitoring mechanisms, and inform the development of occupational health policy within South African WWTPs. By focusing on WWTPs in the City of Tshwane, this study contributes to the local evidence base necessary to strengthen worker protection and advance occupational hygiene practices, particularly with respect to exposures to bioaerosols, VOCs and odorous emissions.

1.3. Research Question

What is the knowledge and perception of WWTP worker's occupational exposure to bioaerosols, VOCs & odours, and their self-reported health symptoms associated with these emissions from WWTPs in the City of Tshwane, Gauteng?

1.4. Aim of the Research

To evaluate knowledge and perception of WWTP workers occupational exposure to bioaerosols, VOCs & odours and their self-reported health symptoms associated with these emissions from WWTPs in the City of Tshwane, Gauteng.

1.5. Objectives

I. To assess knowledge of employee’s occupational exposure to bioaerosols, VOCs and odours (BVO) emitted from WWTP;

II. To assess the perception of employee's occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP;
III. To describe self-reported symptoms associated with exposure to bioaerosols, VOCs and odours (BVO) emitted from WWTP.

1.6. Chapter overview

Chapter 1: Introduces overview of wastewater treatment plants (WWTPs), the ambient air pollutants, with the focus on volatile organic compounds (VOCs), odour and bioaerosols emitted during treatment stages. The chapter further describes the adverse health effects associated with the emissions that arise from the various wastewater treatment A problem statement was formulated and justification for the study is presented. The domain of the study specified, aim and objectives are set out.

Chapter 2:

This chapter focuses on reviewing the current state of knowledge and perception surrounding the occupational health risks associated with emissions from WWTPs, with a focus on bioaerosols, volatile organic compounds and odours. The chapter begins with looking at the functionality of WWTPs, Occupational Health and Safety at WWTPs, Emissions from WWTP, associated health outcomes from exposure to these emissions and the concept of knowledge and perception. Ending with the discussion of studies that looked at workers knowledge regarding exposure to various hazards at WWTPs

Chapter 3:

This chapter provides details on the research methodology of the study. The study design, the study sites, study population, the sampling techniques, data collection methods, and the data analysis framework are included in this chapter.

Chapter 4:

This chapter presents the results found from the evaluation of knowledge and perception of WWTP workers occupational exposure to bioaerosols, VOCs & odours and their self-reported health symptoms associated with these emissions from WWTPs in the City of Tshwane, Gauteng. This chapter further presents results on the participants' demographic characteristics, self-reporting of associated symptoms, knowledge and perception of to

bioaerosols, VOCs & odours emissions arising from WWTP, and practises employed, linked towards occupational Health and safety to minimise exposure.

Chapter 5:

This chapter discusses key findings as presented according to the objectives of the study. Furthermore, the strengths and limitations of the study design, methodology and results are thoroughly discussed and compared with others from published studies. Additionally, practical recommendations are provided to improve health and safety practices at WWTPs and to improve occupational health monitoring strategies. Lastly, the chapter closes with a conclusion that highlights the scholarly contribution and policy impacts of this study.

CHAPTER TWO

This chapter focuses on reviewing the current state of knowledge and perception surrounding the occupational health risks associated with emissions from WWTP, with a focus on bioaerosols, volatile organic compounds and odours. The chapter begins with looking at the functionality of WWTPs, treatment technologies employed, emissions arising from the plants, workers exposure, associated health outcomes from exposure to these emissions and the concept of knowledge and perception. Ending with the discussion of studies that looked at workers' knowledge regarding exposure to various hazards at WWTPs.

2. LITERATURE RIVIEW

2.1. Wastewater treatment plant

Industrial and domestic activities, produce waste in all forms containing undesirable contaminants. One of the outputs of these activities is polluted water, referred to as wastewater. Before this water can be returned to natural sources, it requires treatment and purification (Silva, 2023). For several years, environmental challenges concerning chemical and biological water contamination have become a significant concern. According to World Vision, over 770 million people worldwide lack access to safe and clean drinking and household water. Both natural and manmade factors contribute to water scarcity (Villarín and Merel, 2020).

Wastewater Treatment Plants (WWTPs) play a critical role in protecting water resources. In addition is vital in increasing the amount of usable water. These treatment plants make use of physical, biological, and chemical operations to remove contaminants from the wastewater (Singh et al., 2023).

Approximately 144 local municipalities across the 9 provinces in South Africa, are responsible to deliver wastewater services. Through a network comprising of 850 WWTPs with a total installed treatment capacity of 6,971 Ml/d. With the Gauteng province representing the highest volume of wastewater treated in South Africa at 2,460.2 Ml/d. Activated sludge, biological nutrient removal (for effluent treatment), and anaerobic digestion (for sludge treatment) are the predominant treatment technologies employed at Gauteng WWTPs (Department of Water and Sanitation, 2023).

2.2. Treatment technologies

When wastewater arrives at the WWTP, the first cleaning process is preliminary treatment which prepares water for next purification stages by screening and removing grit. During manual or automated screening, gross solids that include various floatable such as sanitary products, diapers, tones, bricks, broken glass and metal items are removed from incoming wastewater. Grit channels serve to remove sand, silt, glass, and other large sized organic and inorganic substances from wastewater by lowering the velocity of water, so the grit settles out (Hansen, 2015).

Preliminary treated effluent will then undergo primary treatment. This process assists in removing suspended solids consisting of organic materials from the wastewater by making use of primary clarifiers. Heavy solids will settle to the bottom to allow for sedimentation.

To further remove organic matter and ammonia, the wastewater undergoes secondary treatment. Various secondary treatment technologies can be used, and they include activated sludge process-(aeration chambers), bio-filters, variants of pond and constructed wetland systems. The goal of the secondary treatment technologies is to biologically break down organic matter and ammonia by mixing wastewater with microorganisms that digest organic matter for their own growth.

All impurities can be removed from sewerage during this final stage; however, this is the most expensive treatment stage. Following the treatment process the effluent that will be of a certain quality, can be discharged into various water courses (Hansen, 2015).

2.3. Emissions

WWTP removes contaminants from wastewater however the treatment stages may be associated with air pollutants that adversely affects air quality (Hamoda, 2006). For this specific study the focus is on bioaerosols, VOCs and odours that are released, compromising the occupational health and safety environment for WWTP workers (Grégorio and Lichtfouse, 2018).

The operation of WWTPs is associated with the emission of various air pollutants that expose workers to potential health risks. These emissions originate from wastewater movement and from both anaerobic and aerobic treatment processes (Kumar et al., 2021).

Volatile organic compounds are a large group of chemical compounds that are characterized by high vapor pressure and low water solubility. These properties allow VOCs to easily leave solid and liquid phases as gases emitted into the atmosphere (Pandey and Yadav, 2018). Volatile organic compounds (VOCs) were found to be one of the most prevalent malodorous substance in wastewater treatment plants, after a thorough investigation into the issue of odour nuisance at treatment plants (Czarnota et al., 2023). As early as the preliminary stage of wastewater treatment, Volatile organic compounds are released.

According to (Lewkowska et al., 2016), the mechanical aspect of the treatment process is the greatest contributor of VOC emission and subsequent associated odours.

Numerous pathogenic microorganisms, including bacteria, viruses, and fungus, are present in raw wastewater. These microorganisms can aerosolize from wastewater into the air during various treatment stages, forming bioaerosols (Tian et al., 2022). Studies focusing of detecting bioaerosols in the air at WWTP, revealed that the highest concentration of bioaerosol emitted in the treatment stages, is during preliminary treatment, process where there is mechanical agitation of wastewater and the aeration tanks section. In addition, the aeration process accelerates dispersion of bioaerosols. Furthermore, apart from the mechanical agitation of wastewater during treatment, the timing, intensity and dispersion of bioaerosols is also influenced but meteorological variables (season and wind conditions) (Michałkiewicz et al., 2011).

Numerous studies have indicated that free air at WWTP is polluted by various components arising from the treatment of wastewater. Identifying the correlation between the direct work environment at WWTP and adverse health status, including mortality of exposed population (Genowska et al., 2023).

2.4. Exposure

WWTPs operate round the clock, 24 hours a day and 7 days and 365 days a year. The failure of WWTP can lead to detrimental public health and environmental consequences. WWTP are considered one of the most dangerous sectors in the industrial field. Poor awareness of workers occupational exposure has led to fatalities (Dannoun and Nouban, 2021).

Occupational Health and Safety in the workplace is a multidisciplinary approach focused on ensuring that the work environment does not cause harm to the health of workers in any form (Jaiswal, 2022). In South Africa, the health and safety requirements of all employees at work

are covered by the Occupational Health and Safety Act, No 85 of 1993. (Occupational Health and Safety Act 85, 1993). Section 8(d) of the Act requires the employer to establish workplace hazards and, in addition, provide the required mitigation measures to protect employees' health and safety.

WWTPs are sources of exposure to various physical, chemical, and biological contaminants. Hazardous agents, including fungi, viruses, and bacteria, are natural constituents of domestic wastewater. Besides physical risks (slips, exposure to UV, moving plant parts, and poorly maintained plants), workers are increasingly exposed to waterborne diseases through different exposure routes (Inhalation, absorption, and ingestion). Arising from daily operational activities of the plant, from manual screening, desludging, plant maintenance, and repairs (Poopedi et al., 2023).

Various personnel are physically involved in the actual operations of the plant. Including maintenance of plant equipment and facilities. During these activities WWTP workers are exposed to a series of hazards and associated risks (Vasovic et al., 2018).

Previous studies relating to WWTPs have focused on effluent quality, protection of the environment and public health. Consequently, research on occupational exposure and potential health risk that arise from such occupational settings remains unclear, particularly in low to middle income countries (Poopedi et al., 2023).

The department of Water Affairs and Water Research council recognising, that the failure of the WWTP can lead to detrimental public health and environmental consequences, developed the Wastewater Risk Abatement Plan (W_2RAP). W_2RAP encompasses all steps in the wastewater value chain, from receiving treatment through to discharge or reuse in a particular water resource. The purpose of W_2RAP was to provide a risk-based approach in operations of the WWTP, to protect public health and natural resources by assessing hazards and associated risk, including required controls along the wastewater treatment chain. Even though the W_2RAP guidelines focus on wastewater value chain and protection of public health, the guidelines make no provision for assessing workers risk that form part of the value chain (Merwe-Botha and Manus, 2011). The risk management of WWTPs is a complex system and requires holistic analysis from several aspects if we are to promote public health.

Annually an estimated 120 million workplace accidents and 200,000 fatalities are reported globally. Recent data on occupational health, indicates that between 40% -50% of working population, worldwide are exposed to high risk working conditions. Several work-related hazards and associated risk are reported to be linked to over 68 million incidents of occupational illnesses annually (Oluoch et al., 2017).

2.5. Health effects

According to (Byliński et al., 2019), VOCs emitted during treatment of wastewater, may be carcinogenic and may cause impairment to the central nervous system, liver and kidneys. In addition, some of the compounds may cause a number of psychometric symptoms such as anxiety, stress, dizziness, headaches and worst-case scenario loss of consciousness.

Furthermore, long term exposure to odours emitted, can cause adverse health effects ranging from psychometric symptoms mentioned above to physical symptoms such as irritation of the mucous membranes of the eyes, nose and throat ,lower respiratory related problems and lethargy (Czarnota et al., 2023).The composition, concentration, and particle size distribution are closely related to the toxicity of bioaerosols. After bioaerosol enters the body via inhalation, proliferation occurs. The respirable particles (PM 10 and PM 2.5) can reach the deep alveoli regions in the lungs and subsequently the bloodstream, causing respiratory tract symptoms and severe lung disease. In addition, it is said that bioaerosols contain carcinogenic substances such as cobalt, cadmium, and arsenic (Lou et al., 2021). Sewerage worker syndrome is characterised by symptoms such as fever, rhinitis, headaches, fatigue, and malaise and has been strongly associated with bioaerosol emissions (Rylander et al., 1976).

2.6. Knowledge

The concept of knowledge has no clear definition. It is the practical and the theoretical understanding of a subject matter (Bolisani and Bratianu, 2018). Knowledge of risk is an implicit and explicit measure of the probability and severity of adverse effects arising from exposure experienced. It Incorporates objective interpretation based on practical skills, past experiences, and theoretical understanding (Durst and Zieba, 2020). (Jaremków et al., 2018) in a study assessing knowledge and awareness of WWTPs workers about exposure to harmful health factors during performance of professional duties in Poland. Determined that the workers' knowledge regarding their occupational exposure correlated to the level of education the worker had. The study concluded that the training material and frequency of

professional training is necessary for high-risk work areas. This was supported by (Mohammed et al., 2022) indicating that sewerage workers in Egypt had poor knowledge and attributed this to the lack of training programme in their current work environment. Whilst (Gebregiorgis Ambaye, 2016) who studied Occupational risk hazards, knowledge of occupational health, safety practice & safety measures among workers, in high risk work environments, in Ethiopia were formal training plans were in place, found that the majority of workers had good level of knowledge regarding occupational hazards in the work place. In this study, knowledge refers to the theoretical and practical understanding of occupational exposure arising from emissions at WWTPs.

2.7. Perception

Perception is our brain's conscious reception, selection, processing, and interpretation of information via all senses (Franz and Sarcina, 2009). Several factors dependent on individuals and their past personal experiences are used to determine perceived risk in the work environment (Stone, 2014).

(Behrens and Brackbill, 1993) looked at various industries and occupations. It was established that workers in work areas with high exposure, had low perception of their exposure. (Shilling and Brackbill, 1987) conducted a similar study across various industries, where workers were reporting perceived risk from their occupational exposures. The greater proportion of workers reported perception of adverse health effects such as lung, respiratory problems and hearing impairment, than any other related health implications.

In a study conducted by (Huang et al., 2021) for workers in Kaohsiung, Taiwan to explore the connections among the perceived control, safety attitude, and safety performance of WWTP workers. Analysis of the results indicated that the perceived control that the WWTP workers had significantly influenced their safety performance. In addition, when examining relationships among perceived control, safety attitude, and safety performance, a significant difference was noticeable across the different gender, age, operational area/skill levels, and seniority.

Although, no specific literature looked at WWTP knowledge and perception of emissions from the treatment plants. The data from these studies indicate the importance of occupational health training and awareness to eliminate or mitigate occupational health risks. In this study, we looked at WWTP workers' perception of the occupational exposure

resulting from emissions at WWTPs. The key to effective risk management strategies is to assess worker differences in knowledge and perception of risk associated with emissions from WWTPs (Trubetskaya et al., 2021).

2.8. Regulatory framework

There are several key legislations that guide South Africa's framework for environmental protection, including the management of WWTP emissions. They are primarily concerned with ensuring air quality, water quality, and public health.

National Environmental Management Act (NEMA) (No. 107 of 1998) provides the overarching framework to promote the principles of sustainable development and integrated environmental management. It emphasizes the precautionary principle, which mandates that measures be taken to avoid significant environmental harm.

The framework for air quality management is outlined in the National Air Quality Act (No. 39 of 2004). Wherein requirements for facilities that emit significant pollutants such as WWTPs to submit pollution prevent plans that ensure pollutants emitted don't exceed the prescribed air quality limits. Whilst the National Water Act (No. 36 of 1998) primarily focuses on the protection and sustainable management of water resources, it also plays a role in regulating wastewater discharges from WWTPs, ensuring that treated effluent does not negatively impact water quality. It provides a framework for the regulation of discharges into the environment, including airborne pollutants when they affect water bodies.

Studies have identified a variety of emissions from WWTPs that pose risks to both environmental and human health. Among those of significant concern, are VOCs emitted, particularly from aeration process and sludge handling. As these compounds affect urban air quality that leads to various respiratory illness (An et al., 2024). Whilst regulatory framework specifying ambient air limits for VOC emissions exists, enforcement and monitoring is inadequate to ensure compliance.

In addition, (Singh et al., 2023) highlighted that the inconsistent monitoring of WWTPs has led to poor compliance with air quality standards. As a result, the health risks posed by untreated or poorly treated emissions from these plants are often overlooked. (Senatore et al., 2021) found that older WWTPs in South Africa had inadequate treatment processes and emission controls, leading to higher emissions. Currently existing WWTPs were constructed

decades ago and are not equipped with modern Technologies for emission control, which exacerbate pollution levels and increase occupational health risk for personnel.

CHAPTER THREE

This chapter is on the research methodology of the study. The study design, the study sites, study population, the sampling techniques, data collection methods, and the data analysis framework are included in this chapter. The section further outlines procedure used for validation and reliability of the data collection instruments. In addition, study ethical considerations are outlined.

3. METHODOLOGY

3.1. Study Design

A descriptive cross-sectional study employing a convenient sampling technique was conducted to assess wastewater treatment plant (WWTP) workers' knowledge, perceptions, and self-reported health symptoms associated with occupational exposure to bioaerosols, volatile organic compounds (VOCs), and odours generated during WWTP operations. This study utilized quantitative research methods to characterize the extent of workers' awareness, risk perception, and knowledge in relation to these airborne contaminants.

3.2. Study sites

The study was conducted at three strategically selected wastewater treatment plants (WWTPs) within the City of Tshwane, chosen based on their geographical distribution and the predominance of domestic wastewater in their influent streams. The criterion was considered essential to ensure a representative assessment of occupational exposure to airborne emissions typical of domestic wastewater treatment processes. Two of the selected WWTPs are situated on the southern banks of the Apies River in Pretoria, providing services to the central, northern and western regions of the City of Tshwane. The treatment plants receive 98% domestic wastewater, servicing a population set of approximately 600 000, with a total treatment design capacity of 128 mega liters per day (ML/day). A total of 94 workers were employed at the WWTPS. The third WWTP is located approximately 10 km upstream of the Roodeplaat dam on the eastern bank of the Pienaar's river. The WWTP services predominantly Mamelodi township some suburbs in Pretoria East, few industries and Baviaanspoort correctional services, with a treatment capacity of 56 M*L*/day. At the time of the study, there were a total of 22 WWTP workers employed at this facility. Refer to Appendix 7 for the study sites area maps.

The treatment process at the selected WWTPs, involve screening, grit removal stage, primary clarifiers, surface aeration tanks and through to trickling biofilters. Secondary sedimentation uses biological treatment process using activated sludge and biofilters. The tertiary phase consists of chlorine disinfection in some of the treatment plants. For detailed process Refer to Error! Reference source not found. below for WWTPs process flow.

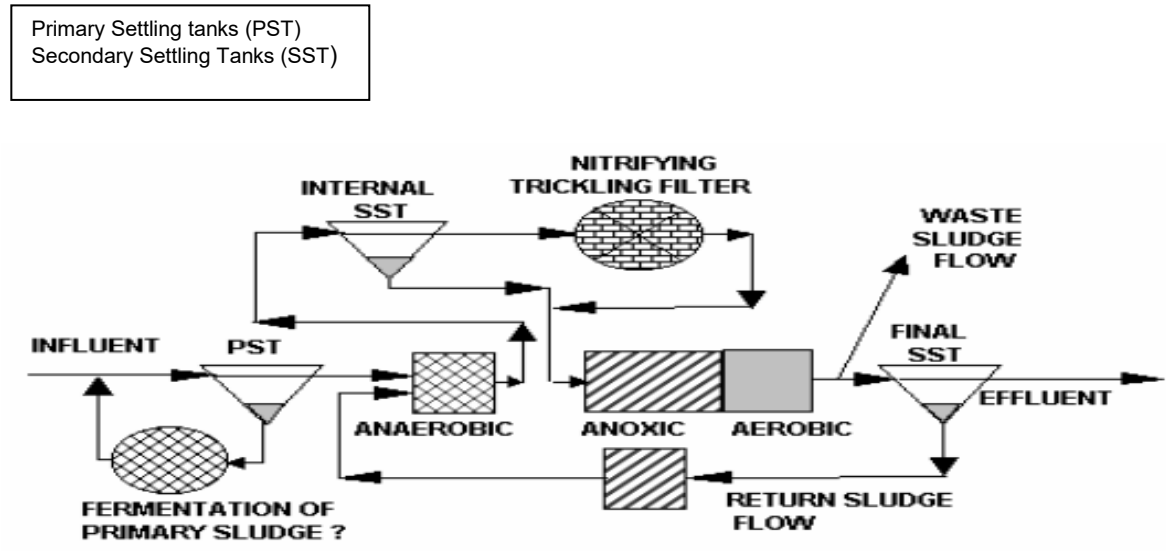


Figure 1: WWTP Process flow (Muller et al., 2007)

3.3. Study Population

The study population involved, WWTP workers at the three WWTPs in the City of Tshwane, who have been employed for over a year. The respondents included process controllers, mechanical technicians, general workers, maintenance contractors and security guards.

3.4. Sampling

A Convenient sampling method was used to recruit the participants for the study. At the time of the study there were a total 126 workers employed, at the three selected sites.

- **Participant Distribution by Site**

Out of the 126 eligible workers, a total of 32 participants consented to take part in the study. Their distribution across the three study sites was as follows:

WWTP A and WWTP B: Employed a combined total of 94 workers. Twenty of these workers participated in the study. WWTP C: Employed 22 workers, ten workers from this site participated in the study.

Workers were recruited as follows:

1. The researcher informed the site manager prior to coming to site, of the research purpose, request for eligible participants to participate and set appointments to visit the sites.
2. The researcher approached all the eligible workers from the total number, at each study site, to participate in the study.
3. Those who agreed to participate in the study were asked to sign a consent form.

3.4.1 Inclusion and Exclusion Criteria

The eligible minimum age to be included in the study was set at 18 years, eliminating ethical and legal issues regarding obtaining consent for participation in the study. The following workers were approached to take part in the study:

1. Workers within the target population that have had occupational exposure at the WWTP for over a year and were willing to sign informed consent forms.

2. Process controllers, operators, mechanical technicians, general workers, maintenance contractors, cleaners, and security workers at various WWTPs.

3.5. Data collection

Data was collected using a self-administered questionnaire (Appendix 3). The self-administered questionnaire used in this study was developed based on a review of relevant literature on occupational exposure to bioaerosols, volatile organic compounds (VOCs), and odours in wastewater treatment settings. Key sources included peer-reviewed studies and validated instruments from similar occupational hygiene research. In particular, the structure and content of the questionnaire were informed by studies such as (Jaremków et al., 2018) , who assessed WWTP workers' knowledge of harmful exposures; (Gebregiorgis Ambaye, 2016), who examined knowledge and safety practices in high-risk occupations in Ethiopia; and (Mohammed et al., 2022) who identified gaps in training and awareness among sewer workers in Egypt.

Input from subject matter experts, including the researcher supervisors and a statistician, was sought to ensure content validity. Prior to full deployment, the questionnaire was piloted with a small sample of WWTP workers to refine clarity, wording, and layout. Minor modifications were made based on feedback before final distribution at the three selected WWTPs.

The questionnaire with explanatory messages, was designed to explain the purpose of the study, response method, research objectives, and confidentiality clause to encourage higher response. It consisted of close-end questions coded after data collection, aiming to achieve research objectives and gather necessary data for discussion, conclusions, and recommendations.

The questionnaire was divided into the following sections:

- Demographics and social characteristics
- Educational background information
- Associated symptoms clusters
- Information on occupational exposure
- Information on knowledge on occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP.
- Information on perception on occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP.
- Information on hygiene and safety behaviour while at work.

3.5.1 Socio-demographic data collection

Socio-demographic data was collected using a structured self-administered questionnaire. The questionnaire included closed-ended questions designed to capture participants' gender, age, education level, job title, workstation, type of employment, years of experience at the wastewater treatment plant, and average daily working hours. The response was coded as indicated below:

Gender (Male=1, Female=2), ethnicity (African=1, White=2, Coloured=3, Indian=4), age (19-24 years=1,25-29 years=2, 30-44 years=3, 45 and above=4), educational level (No formal schooling=1, Primary School=2, High school=3, College and tertiary education=4), job title-(operator=1, cleaner=2, Technician=3, office based=4, security=5, general worker=6, driver=7), Workstation (Screening=1, primary water treatment=2, secondary

water treatment=3, tertiary water treatment=4, other=5), type of employment (permanent=1, temporary=2, contractor=3), years working at the WWTP (1-5 years=1, 6-10years and 11years and more=3), hour worked per day/shift (1-4hours=1, 5-8 hours=2, 9-12hours=3). The section on associated symptoms cluster had 4 categorized symptoms (Flu-like symptom, Respiratory symptoms irritation symptoms and gastrointestinal related symptoms), with the following experience responses coded as follows (never=1, rarely=2 and frequently=3). Section on occupational exposure had five questions, the section looked at awareness of hazardous from WWTP, (Yes=1, No=0), WWTP associated hazards (Chemical, Physical, Biological/microbiological, confined spaces, ergonomics and Psychological/mental health hazards), to which the responses were coded as (Yes=1, No=0), duration of exposure (2 hours=1, 4 hours=2, 8 hours=3). In addition this section looked at protective equipment used (respiratory protective equipment, gloves, safety goggles, protective clothing, safety boots, ear protection, hard hats, none of the above) coded as (Yes=1, No=0), Supervisory role,(Yes=1, No=0) .The sections on knowledge had 13 questions with a (I don't know=1/No=2/Yes=3) answer. The yes answer was deemed correct, and a mark was allocated for every correct answer to calculate the knowledge score (ranging from 0 -13). The questions on knowledge are listed in **Table 1,** below.

Table 1: Questions on the study participants' knowledge

Information on knowledge on occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP?
1. Work at the WWTP contributes to pollution?
*Bioaerosols-microorganisms in small water droplets we can't see. 2. Aeration stage of the wastewater treatment processes poses the greatest risk of exposure to bioaerosols?
3. Working in a WWTPs is dangerous to your health and safety?
4. The water droplets from aeration process are harmful?
5. Are you aware that some emissions may cause headaches/drowsiness/confusion?
6. Are you aware that some emissions may cause asthma?

7. Are you aware that some emissions may cause skin diseases?
8. Are you aware that some emissions may cause reproductive problems?
9. Are you familiar with the process required to enter confined spaces?
10. Have you been trained on WWTP health and safety?
11. Do you Know that it is necessary to wear PPE when working at WWTP?
12. Do you know that WWTP activities requires you to wear masks?
13. Do you Know that it is necessary to regularly wash hands?
14. Do you know that it's necessary to shower and change clothes before leaving work?

Information on perception of occupational exposure to BOVs was collected from the study participants. The participants were asked to what extent they disagreed with statements made and to what extent they agreed with the statements. The exposure perception questions had 2 responses, disagree (coded as 1) and agree (coded as 2). The participants were presented with the following statements: a) Risk associated with emissions at WWTP known to me, b) emissions generated during treatment of wastewater have the potential to make me sick, c) I can eat anywhere when I'm in the plant. I don't have to go to an eating area, e) I understand that wearing PPE is required to prevent occupational exposure at work but sometimes I see it as unnecessary.

3.5.2 *Outcome variables*

The study outcome variable was practice score which was calculated by allocating 2 for a correct practice (Always), while "sometimes" allocated a score of 1 and the "Never" was an incorrect practice and allocated a score of 0. We then added the correct practices to get an individual score (with a possible score ranging from 0-12). Outcome practice threshold set as 0-6 (poor practice); 7-9 (average practice) and 10-12 (good practice). The questions on practice are presented in **Table *2***.

Table 2: Practices associated practices Occupational health and safety.

1. I wear the correct PPE for the job.
2. I wear a Waterproof overall.
3. I wear goggles.
4. I wear rubber gloves.
5. I wear a face mask.
6. I frequently wash my hands at work.
7. I have undergone medical surveillance.
8. At the medical surveillance session, they checked: Hearing (Audiometry)
9. At the medical surveillance session, they checked: Lungs (Spirometry)
10. At the medical surveillance session, they checked: Eyes (Vision)
11. At the medical surveillance session, they: Follow up on health concerns
12. At the medical surveillance session, they took Biological Monitoring (Urine/mucous samples)

3.5.3 Practice score computation

Occupational hygiene practices were assessed using a set of structured questions embedded in the self-administered questionnaire. These questions captured behaviors such as PPE use, hand wash practices, medical surveillance, and adherence to safety protocols. Each response was scored using a scale (Always = 2, Sometimes = 1, Never = 0), and a composite practice score was calculated for each participant by summing the individual scores. The total

practice score ranged from 0 to 12. Based on literature benchmarks and the distribution of scores in the sample, hygiene practices were categorised as good (10–12), average (7–9), or poor (0–6)

3.6. Data Processing and Management

The data from the questionnaire was captured using Microsoft excel spreadsheet, cleaned for errors and a code sheet was developed. Descriptive statistics were performed to examine the central tendency and variability of the data, while frequencies and percentages were used to present categorical variables. Factors such as age, education, job title, work duration, occupational practices, and associated symptoms, information on knowledge of exposure to BVO's, information on perception of exposure to BVO's, associated health symptoms were considered.

3.7. Data Analysis

The data collected was first coded and entered into Microsoft Excel and then analysed using IBM SPSS Statistics, version 29.0.0. Descriptive statistics was used to summarise the data. Frequencies and percentages were used for categorical variables, while continuous variables were presented as means and standard deviations, and where appropriate, medians and ranges.

Inferential analysis was conducted to explore the relationships between socio-demographic factors and knowledge, perception, and practice scores. Bivariate (simple) linear regression was used to identify potential predictors. The following variables were treated as:

- Independent variables (predictors): Age, education level, and years of work experience
- Dependent variables (outcomes): Knowledge score, perception score, and practice score

Variables with a p-value ≤ 0.20 in the bivariate analysis were included in multiple linear regression models to determine independent predictors of each outcome. A p-value of < 0.05 was considered statistically significant in the final models.

In addition, the relationship between knowledge and perception scores was examined using Spearman's rank correlation coefficient (given the ordinal nature of the data).

Practice scores were computed based on responses to behaviour-related questions. Each response was scored, and the total practice scores were categorised into good (10–12), average (7–9), and poor (0–6) levels of occupational hygiene practice scores.

3.8. Reliability and Validity

The validity of the questionnaire was confirmed through literature review and expert advice of such as the researcher's supervisors and statistician and using closed-ended questions. Furthermore, the study question's reliability was checked through piloting prior to the actual study, with pilot results excluded from the study. The questionnaire's construction ensured adequate coverage of the research question.

3.9. Ethics

The study is part of a larger project for the Water Research Commission (WRC) titled, Characterisation of bioaerosol, volatile organic compounds, odour emissions in wastewater treatment plants, and assessment of the associated emerging epidemiological, occupational, and public health risks (ethics clearance certificate number M22O517). Ethics approval was granted by the University of the Witwatersrand Human Research Ethics committee (Medical), with a separate ethics clearance, certificate No. M240107 M240517-B-0001(Appendix 6).

Following receiving permission to conduct the study from Tshwane Municipal Management, the WWTP site manager provided the participants with information sheet outlining the research, data collection process, aim and objectives. Interested participants were briefed about the research, consent form and distress protocols. They were also informed about their rights, freedom, privacy and anonymity informed and the fact that their participation was voluntary, with an option to withdraw at any time during the process. The research aims to understand the potential risks associated with bioaerosol, volatile organic compounds, and odour emissions in wastewater treatment plants.

CHAPTER FOUR

This chapter presents the results found from the evaluation of knowledge and perception of WWTP workers occupational exposure to bioaerosols, VOCs & odours and their self-reported health symptoms associated with these emissions from WWTPs in the City of Tshwane, Gauteng. This chapter further presents results on the participants' demographic characteristics, self-reporting of associated symptoms, knowledge and perception of to bioaerosols, VOCs & odours emissions arising from WWTP, and practises employed, linked towards occupational Health and safety to minimise exposure.

4. Results

4.1. Demographic characteristics

The demographic of participants is represented in **Figure 2** below. A total number of 32 participants aged between 19 and above 60 years of age from selected WWTPs, participated in the study to have an insight into knowledge and perception of WWTP workers occupational exposure to bioaerosols, VOCs & odours and their self-reported health symptoms associated with these emissions from WWTPs in the City of Tshwane.

In terms of ethnicity, 97% of participants who took part in the study, were African, and 3% represented whites. The gender distribution for the workers and the various WWTPs is presented and there was a significant difference between the genders with 8 (25%) females and 24 (75%) males.

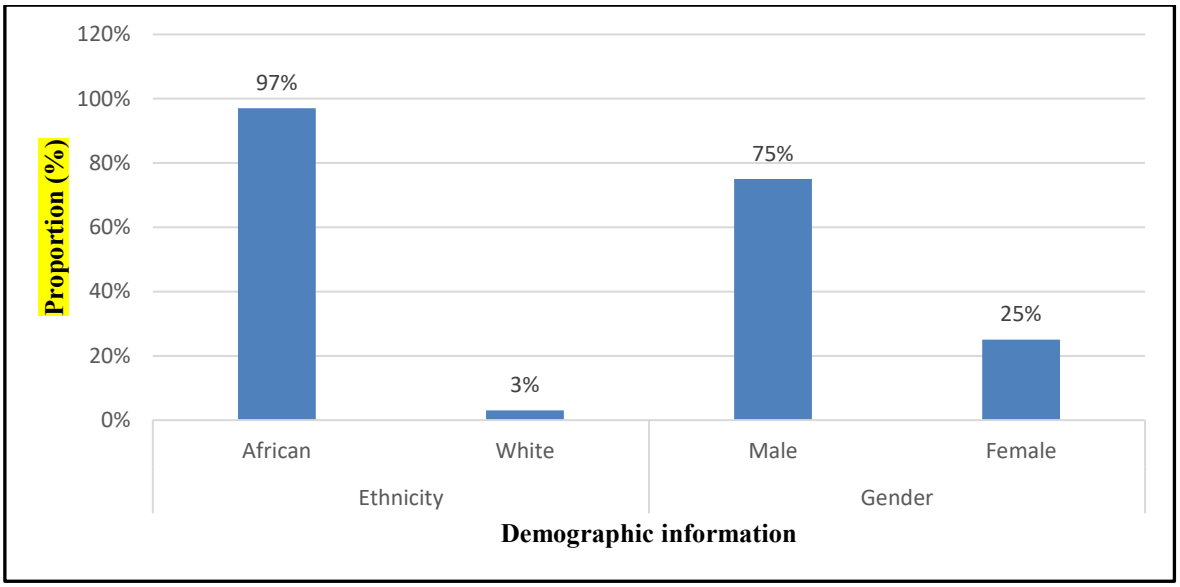


Figure 2: Demographic information of the study participants

The age analysis of the participants who took part in the study was as follows; Eighteen (18) participants were between the ages of 30 to 44 years old and 14 were from the age of 45 and above. Most of the participants were between the ages of 30 to 44 years of age, with 18 years being the minimum age, while 45 and above is the maximum age of the participants. **Figure 3** represents the age of the participants who took part in the study.

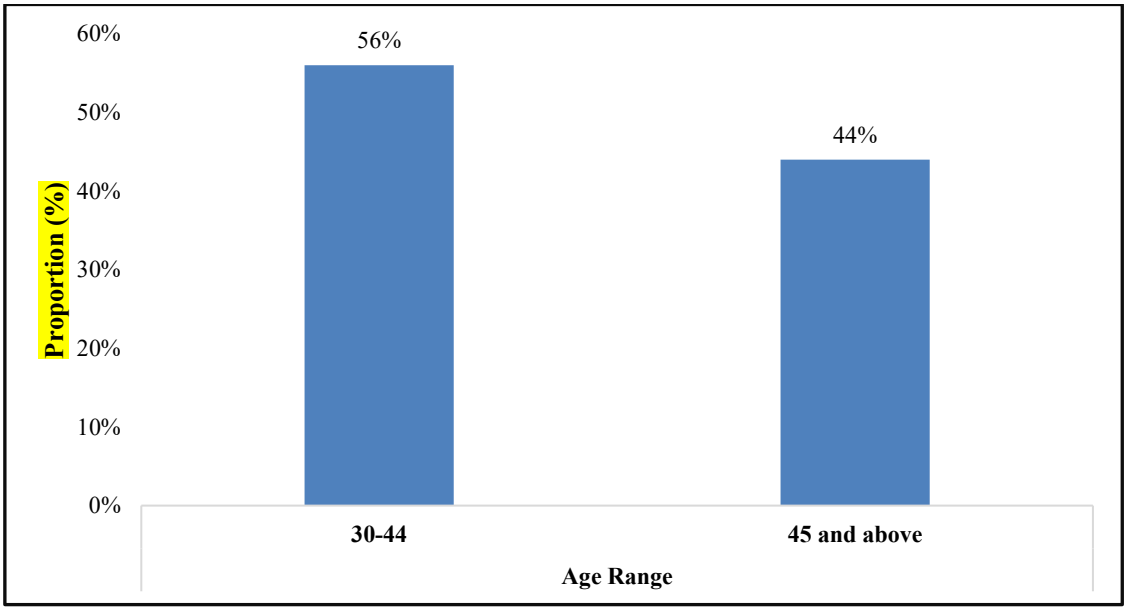


Figure 3: Age of participants

Results presented in **Figure 4** illustrate the level of education achieved by the participants. Among the study participants, not much of a notable diversity in educational attainment is observed. One (3%) participant reported to not have any formal schooling, while 3 (9%) of

participants reported to have completed primary schooling only. Majority of the participants, 21 (66%) reported to have completed high school, while only 7 (21%) of participants reported to have completed college and tertiary education.

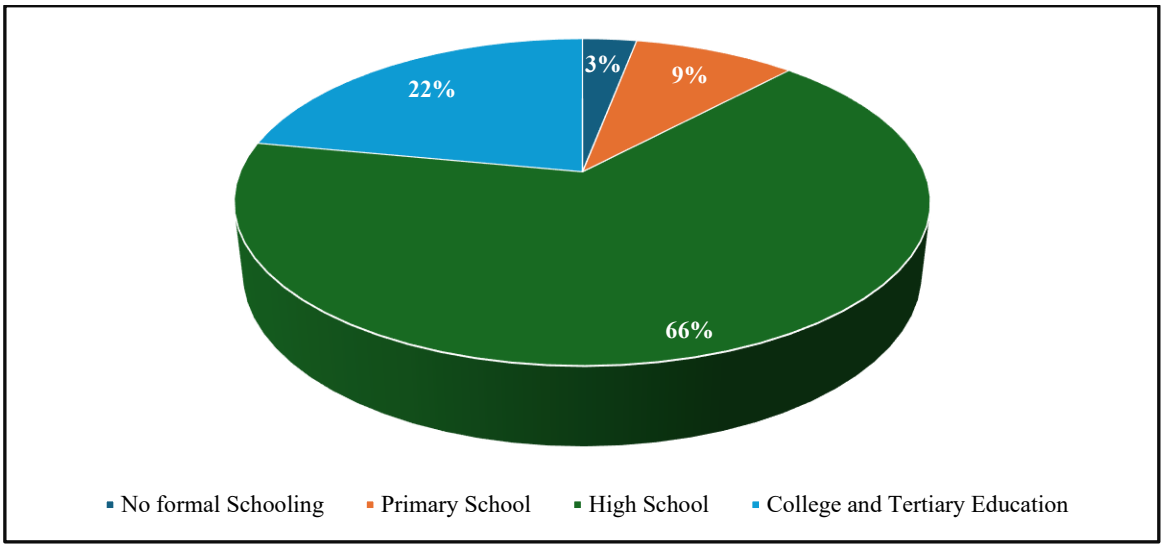


Figure 4: Level of education

Figure 5 below shows that, out of 32 participants, 4 (13%) work in the screening phase of WWTP, 10 (31%) work at the primary treatment stage, 3(9%) work at the secondary treatment stage, 1(3%) across all WWTPs worked at the tertiary treatment stage, whilst 14 (44%) work in all areas of the plant. In addition to this, a total of 21 (66%) participants reported to be working as plant operators, 1 (3%) working as a technician, 3 (9%) working as plant security, 2 (6%) working as general workers and 5(16%) working as drivers.

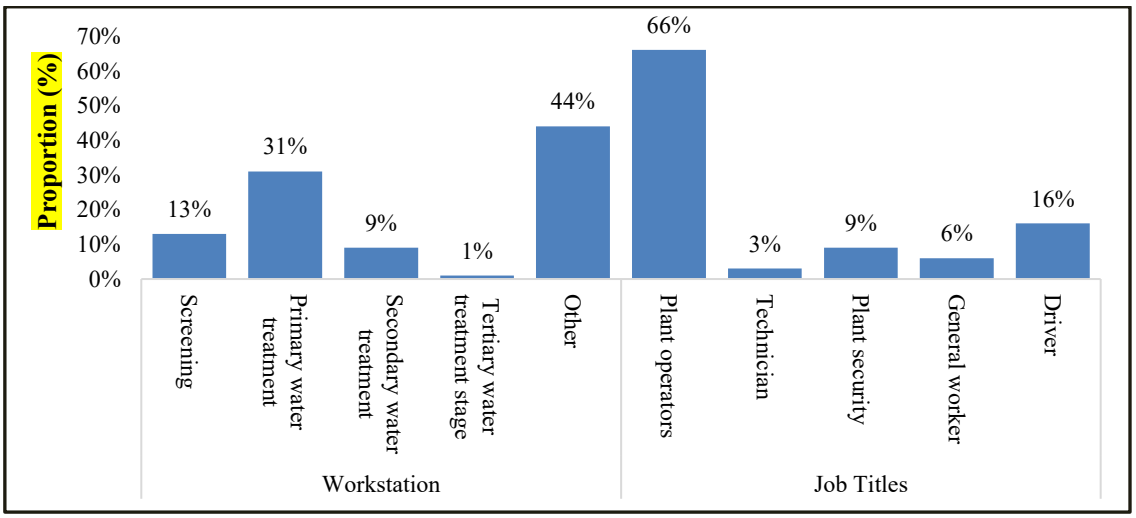


Figure 5: Workstations and Job titles

Figure 6 below illustrates the WWTP worker experience in the sector. Workers with 1-5 years' work experience accounted for 4 (12%) of the total, compared to 7(22%) of those with 6- 10 years of experience as well as those with 11 years and above of experience who accounted for 21 (66%).

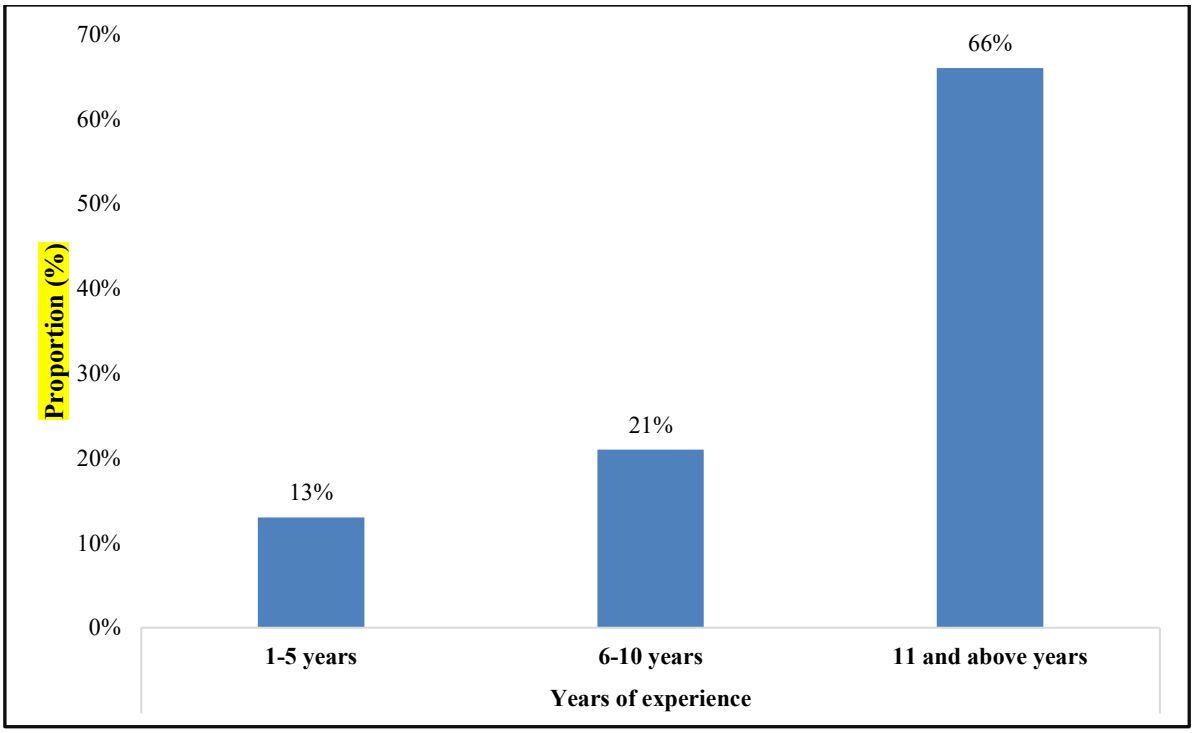


Figure 6: WWTP Workers' experience

The WWTP workers Occupational Exposure periods are depicted in **Figure 7**. Majority of the workers 20 (63%) indicated an exposure period for 5-8 hours in a day, which is a normal day shift. Whilst 12 (37%), indicated an occupational exposure period of 9-12 hours. The exposure period is correlated to the running of the WWTPs which are on a 24-hour operational period and require extended work shifts.

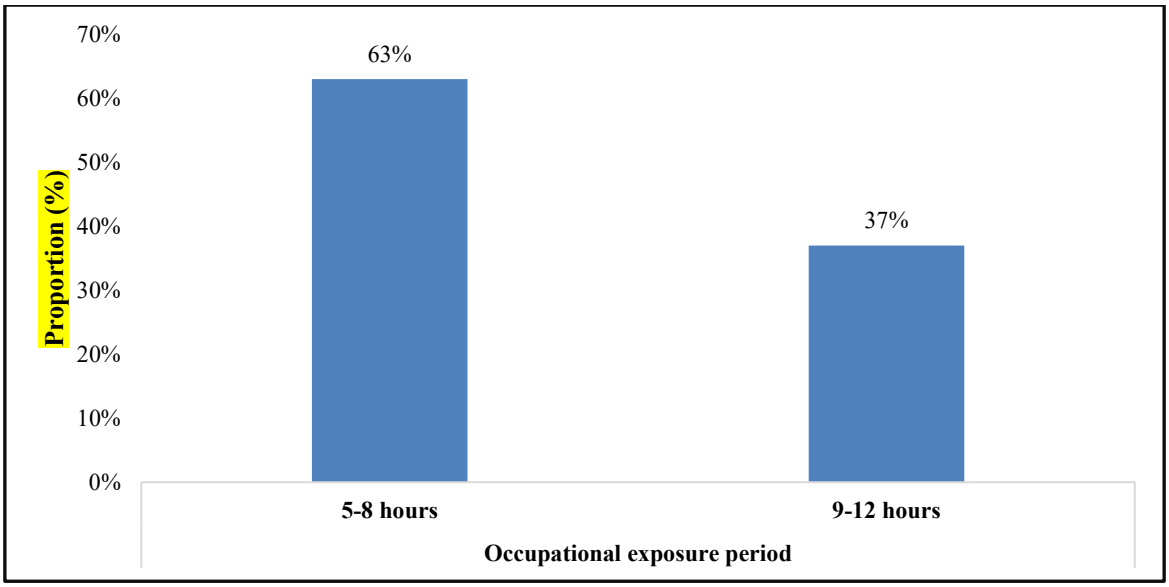


Figure 7: Occupational Exposure period

4.2. BVO Exposure associated symptoms clusters

Figure 8 below depicts the WWTP workers associated symptom clusters. The clusters were identified based on the emission exposure to VOCs, bioaerosols and odour emission that is of focus in this research study. In the flu-like symptom cluster, participants indicated their symptom experience- fever; shivering; feeling unwell; constant cough; unusual tiredness; muscle weakness and joint pains, in the last 6 months. 7(22%) indicated never, 14(44%) indicated rarely (1-3 episodes) and 11(34%) indicated they frequently (not less than 3 and greater than 4 episodes).

In the respiratory symptom cluster, participants indicated their symptom experience- allergic rhinitis; cough with no phlegm; cough with phlegm; shortness of breath; wheezing/whistling breath; chest tightness and breathlessness, in the past 6 months. 9(28%) of the participants indicated never, whilst 16(50%) indicated rarely (1-3 episodes) and 7(22%) indicated frequently (not less than 3 and greater than 4 episodes). In the irritant's symptom cluster, participants indicated their symptom experience- Nasal irritation; Throat irritation; sinus trouble; nose irritation; eye irritation; skin problems; skin rash; skin redness; itching skin; flaking skin and cracked skin, in the past 6 months.

About 8(25%) of the participants indicated never, whilst 12(38%) indicated rarely (1-3 episodes) and 12(38%) indicated frequently (not less than 3 and greater than 4 episodes). In the gastrointestinal symptom cluster, participants indicated their symptom experience- Lack of appetite; heartburn; nausea; diarrhea with fever; vomiting; indigestion; stomach

pain/cramps and constipation, in the past 6 months. 9(28%) of the participants indicated never, 14(44%) indicated rarely (1-3 episodes) and 9(28%) indicated frequently (not less than 3 and greater than 4 episodes).

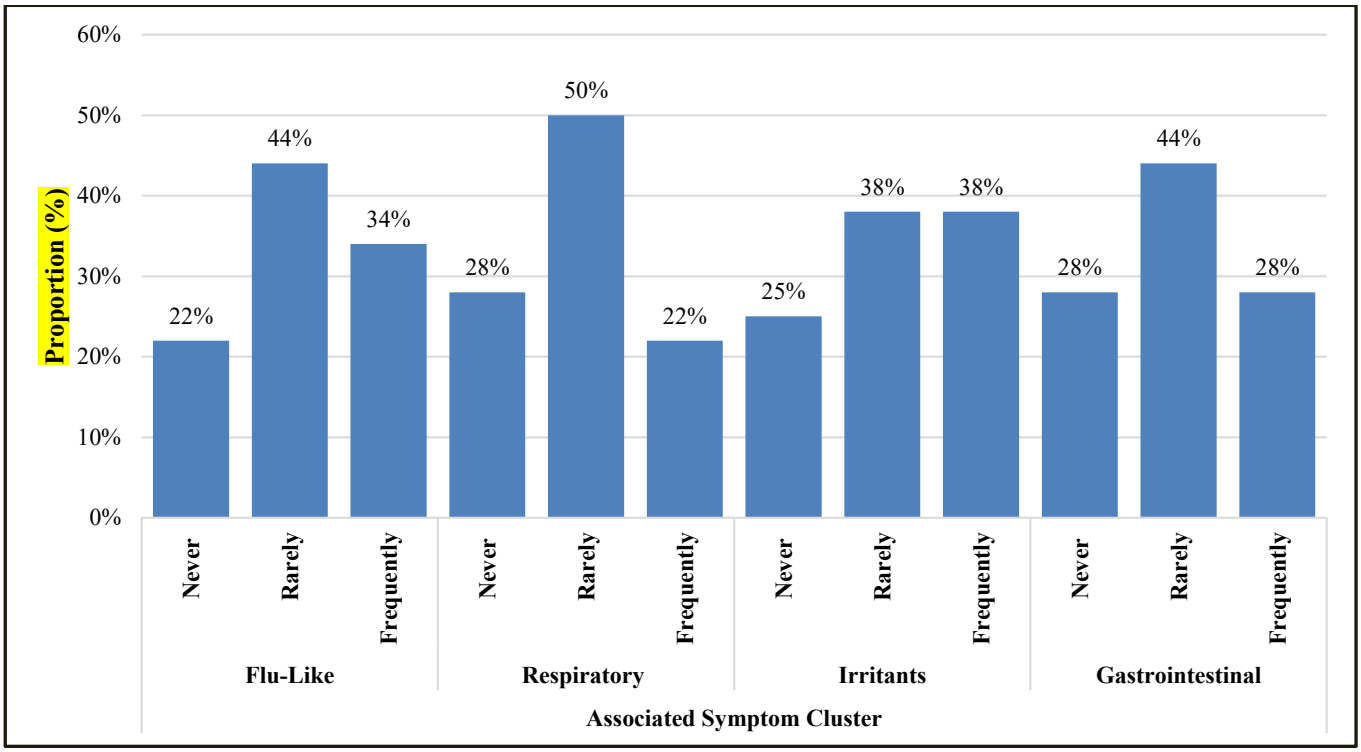


Figure 8: BVO Exposure associated symptoms clusters

4.3. Information on Occupational Exposure

4.3.1 Hazards associated with WWTP process

Figure 9 below illustrates information on WWTP workers occupational exposure. With a specific focus on hazards arising from treatment of wastewater. Approximately 29(91%) of the participants said yes to being aware of hazards that can arise from working at WWTP, whilst 3(9%) indicated no they not aware of hazards that can arise from working at the WWTP. As follow up questions, participants were asked if during their daily activities are they exposed to the following hazards and they responses were noted as follows: chemical hazards, 21(66%) indicated yes and 11(34%) indicated no; physical hazards (slip, trips, falls, machinery related, noise and electrical hazards), 29(91%) indicated yes and 3(9%) indicated no; microbiological or biological hazards 2(81%) indicated yes and 6(19%) indicated no. Regarding confined spaces,19(59%) indicated yes and 13(41%) indicated no. Ergonomics

hazards, 21(66%) indicated yes and 11(34%) indicated no. When it came to psychological related hazards 23(72%) indicated yes and 9(28%) indicated no.

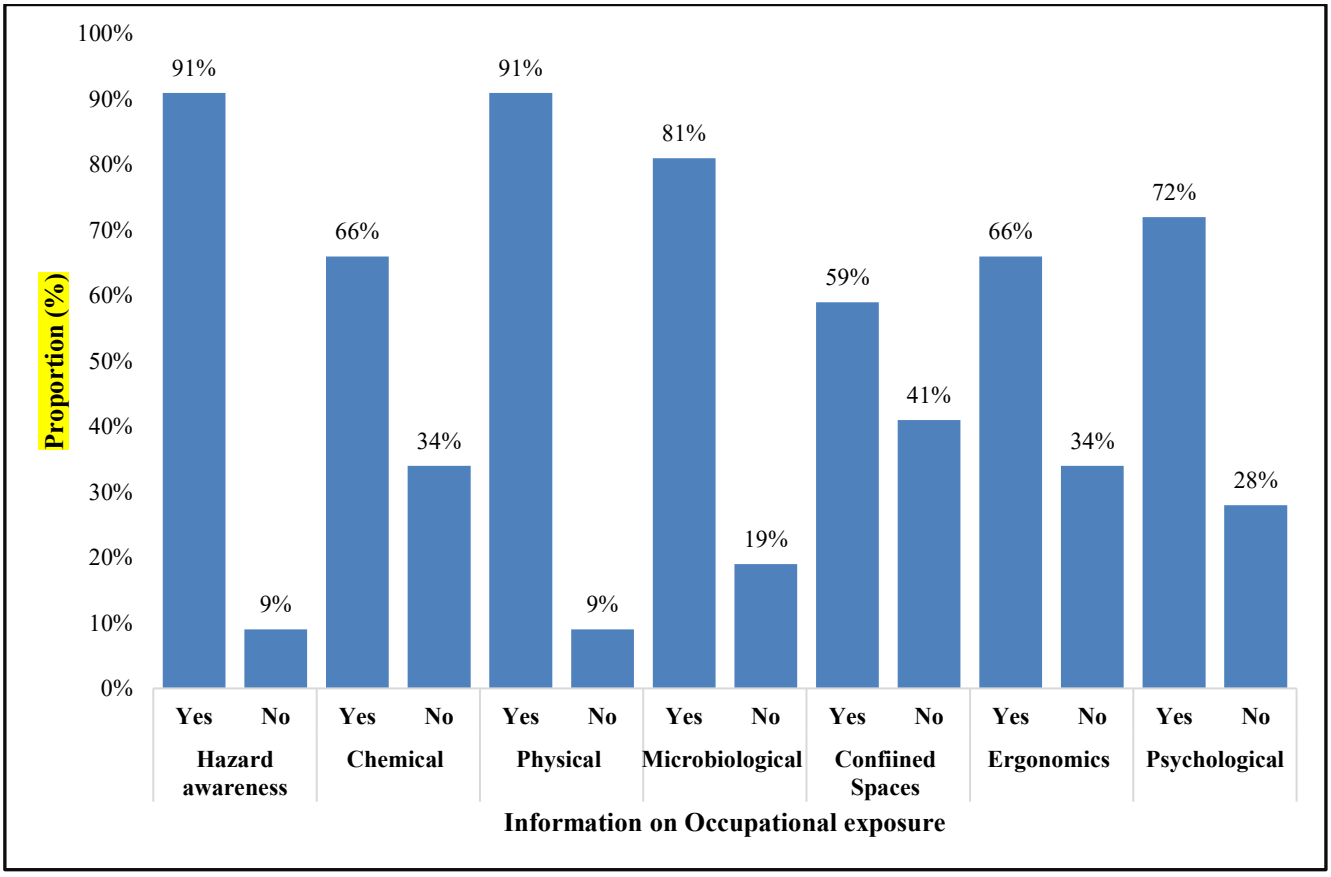


Figure 9: Information on occupational exposure

4.3.2 Personal Protective Equipment (PPE) used at WWTP based on hazards identified

Figure 10 illustrates PPE provided and used by WWTP workers at the sites addressed as part of the controls implemented for the hazards they expressed, they exposed to in figure 9. 17(53% indicate that they are provided and use respiratory protection (mask) whilst 15(47%) indicated no.

In addition 24(75%) indicated that they are provided and use rubber gloves in execution of their work and 8(25%) indicated no they are not provided with and do not use gloves); 9(28%) indicated they provided with and use goggles and 23(72%) indicated they not provided with and do not use goggles in execution of their work; With regards to being provided with and using protective clothing (Full body overalls) 26(81%) indicated yes and 6(18%) indicated no. This included office personnel and security staff).

Regarding the provision and use of safety boots, 30(94%) indicated yes and 2(6%) indicated no; Ear protection 8(25%) indicated yes and 24(75%) indicated no. On the provision and use of hard hats 6(18%) indicated yes and 26(81%) indicated no to being provided with hard hats.

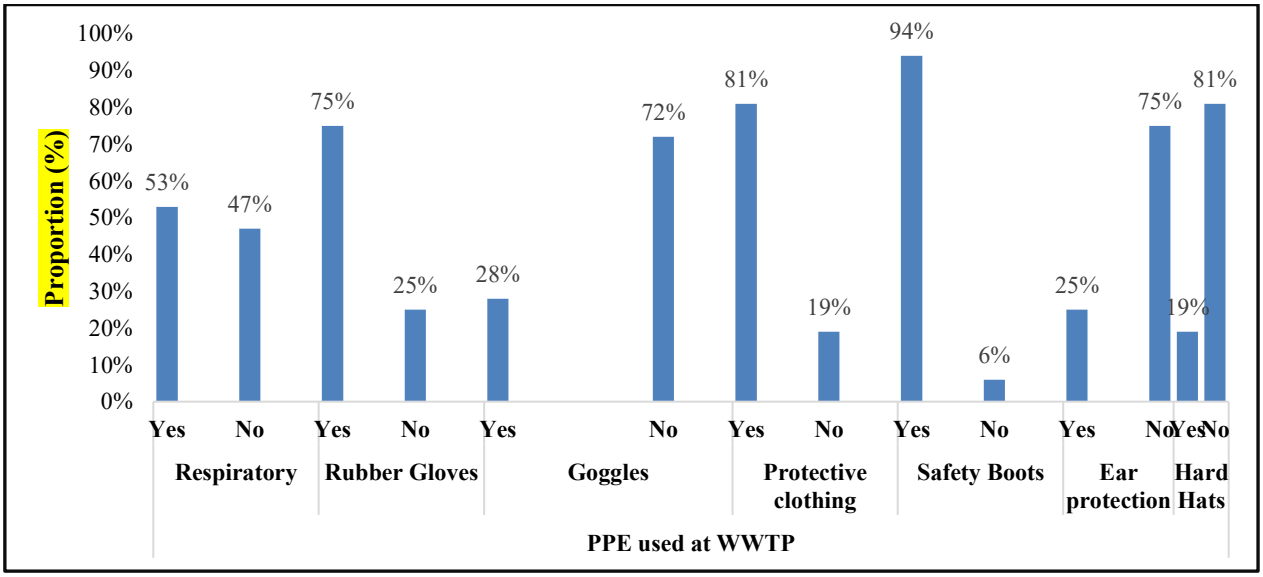


Figure 10: Personal Protective Equipment used at WWTP

4.3.3 Supervisors' role in promoting a safe work environment and minimizing occupational exposures.

Figure 11 illustrates supervisor's role in promoting a safe work environment to minimise occupational exposure to hazards. Workers were asked if supervisors sets an example to promote safe work practices, 12(38%) indicated yes supervisors do, whilst 20(63%) indicated they do not lead by example.

Approximately 13(41%) indicated yes to being provided regular health and safety training and 19(59%) indicated no. With regards to enforcement of protocols by supervisors, 14(44%) indicated yes and 18(56%) indicated no. Participants were asked if supervisors encourage reporting of concerns when it comes to what they exposed to in execution of their duties, 16(50%) indicated yes and the other 16(50%) indicated no. When it came to collaborating with workers to address root causes following an incident 13(41%) indicated yes and 19(59%) indicated no.

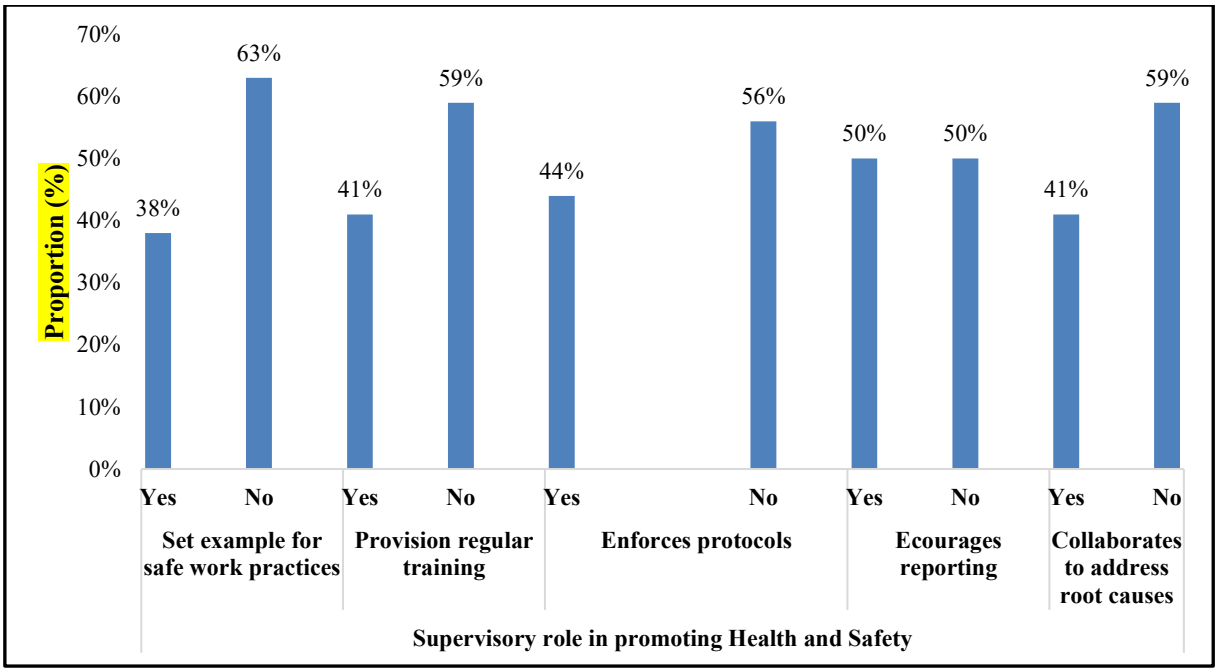


Figure 11: Supervisors role in promoting Health and Safety

4.3.4 Knowledge on occupational exposure of bioaerosols, VOCs and odours (BVOs) emissions

Figure 12 shows the participant's correct and incorrect knowledge response regarding BVOs emissions and associated health outcomes. This study revealed good knowledge regarding necessity of wearing the correct PPE for the job, regular washing of hands and importance of preventing cross contamination by showering/changing clothes end of shift with scoring of 97%, 100% and 97% respectively. In addition, participants had good knowledge regarding operations of the WWTP being a source of pollution to the environment, that emissions generated during the wastewater treatment can affect one's health and that the exposure to water droplets mostly occurs during the aeration process, with correct response of 81%, 84% and 84% respectively. Contrastingly, participants displayed fair knowledge, with 63% correct answers, when it came to bioaerosols, source of bioaerosols, emissions released causing skin related effects and respiratory effects, particularly asthma with 66% correct response. Significantly, 50 % incorrect knowledge responses were noted when participants were asked regarding emissions affecting reproductive health. Low scores of correct knowledge responses (56%) were also noted when participants were asked about procedures to enter confined spaces that houses pumps.

Furthermore, the average knowledge score was 2.87 with a standard deviation of 0.34 and the median was 3.00.

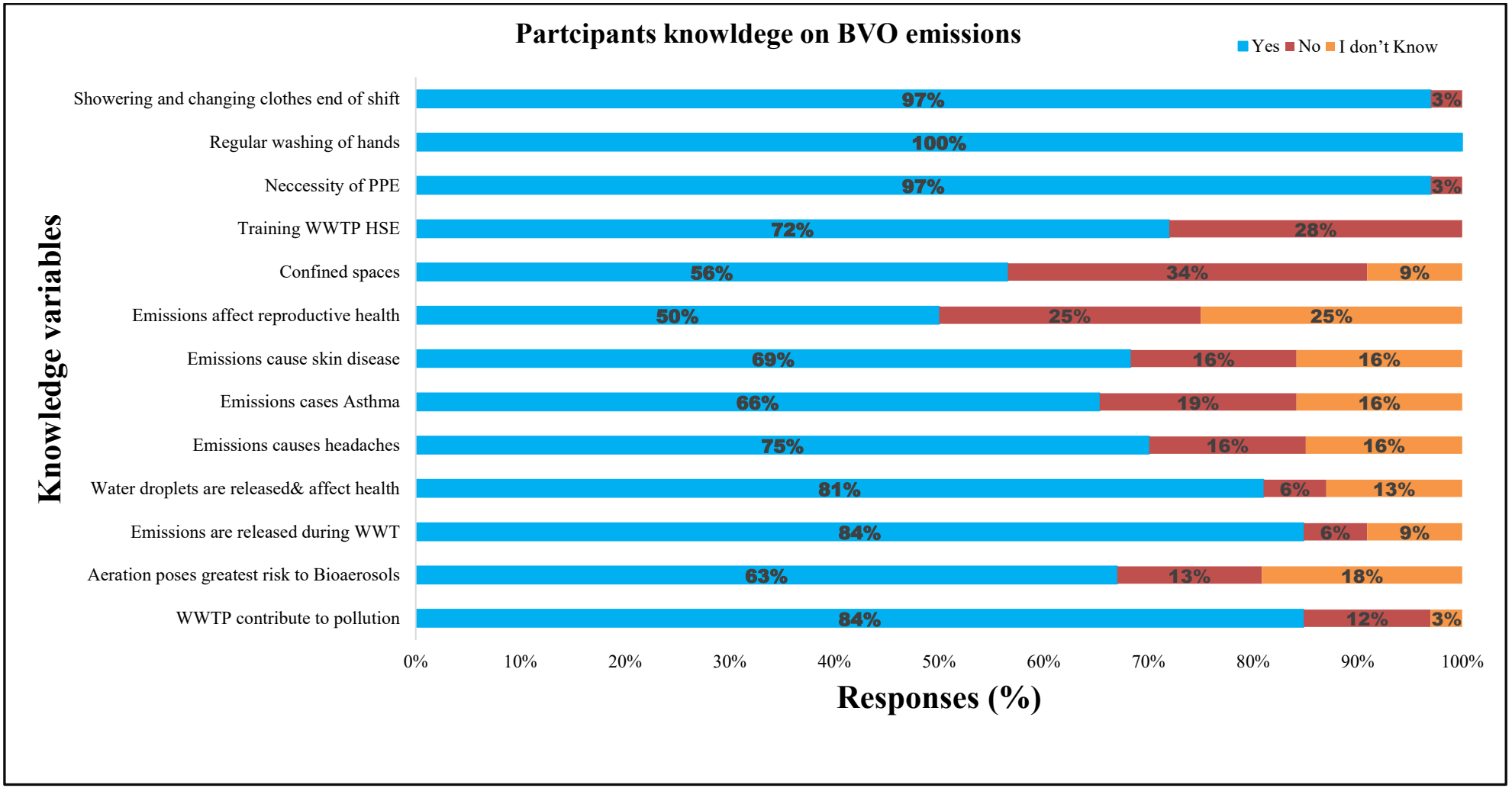


Figure 12: Participants knowledge response on BVO Emissions

4.3.5 Perception of workers on occupational exposure to bioaerosols, VOCs and odours (BVOs) emissions

Figure 13 illustrates perception responses of WWTP on occupational exposure to BVOs. Eighty four percent (84%) of the participants perceived to have known the risk associated with emissions from WWTP and perceived that emissions that arise from treatment of wastewater affects their health. About 81% of the workers agreed that you cannot just eat anywhere on the plant. Fifty three percent (53%) disagreed that wearing of PPE although it is a requirement to prevent exposure, however, sometimes we saw it as unnecessary practice. When it came to workers' perception of regularly washing their hands, 59% disagreed that this is an optional practice.

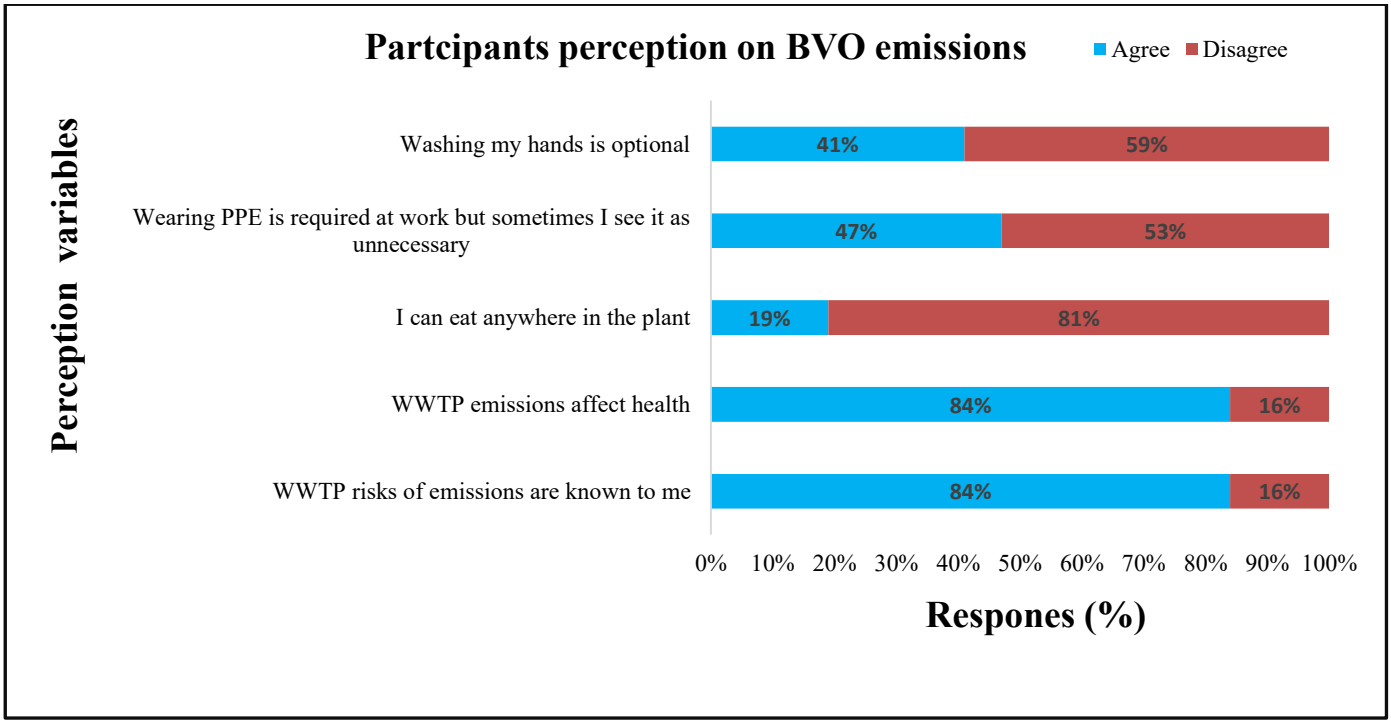


Figure 13: Workers' perception on BVO Emissions

4.3.6 Practices linked to prevention and protection against occupational exposure to emissions at WWTP

According to **Table 3** : Response on practices related Only 38% of participants who work in WWTP reported that they always be provided with the correct PPE and wearing the correct PPE for the job. Only 10% indicated they always wear waterproof overalls when working with wastewater. 38% indicated that they always wear rubber gloves when handling wastewater. Only 53% indicated that they have been provided and do wear face masks to prevent inhalation of pollutants. Approximately, 78% indicated to regularly wash their

hands. When it came to occupational health medical surveillance, only 9% indicated that there is a fixed programme and they are always taken for medical surveillance, 53% indicated inconsistency in the medical surveillance programme and 38% indicated they have never conducted medical surveillance. Looking at the detailed Occupational health medical surveillance programme: 12%, 10% and 3% indicated to have always been tested for hearing, vision and other health concerns respectively. Whilst 44%,19%, 34%, 16%, 18% have sometimes been checked for hearing, respiratory, vision, health concerns and have been requested for biological sampling respectively. 44%, 81%, 56%, 81% and 82% have indicated to have never been checked for hearing, respiratory, vision, health concerns and have been requested for biological sampling respectively.

Table 3 : Response on practices related to prevention of occupational exposure.

Question	**n(%)** Always	**n (%)** Sometimes	**n (%)** Never
1. I wear the correct PPE provided by my employer for the job	12(38%)	16 (50%)	4 (12%)
2. I wear waterproof overalls when handling wastewater	3(10%)	10 (31%)	19(59%)
3. I wear googles when handling wastewater	4(13%)	9(28%)	19(59%)
4. I wear rubber gloves when handling wastewater	12(38%)	12(38%)	8(25%)
5. I wear face mask when on site	7(22%)	8(25%)	17(53%)
6. I wash my hands regularly	25(78%)	6(19%)	1(3%)
7. I have undergone medical surveillance	3(9%)	17(53%)	12(38%)
8. I have undergone medical surveillance-hearing test	4 (12%)	14(44%)	14(44%)
9. I have undergone medical surveillance-Respiratory checks	(0%)	6(19%)	26(81%)
10. I have undergone medical surveillance-Vision checks	3(10%)	11(34%)	18(56%)

11. I have undergone medical surveillance-other health concerns	1(3%)	5(16%)	26(81%)
12. I have undergone medical surveillance-Biological monitoring	(0%)	6(18%)	26(82%)

4.3.7 Factors that influence knowledge information on occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP?

A bivariate analysis was conducted to assess the relationship between demographic factors and knowledge factors using linear regression as presented in **Table 4.**

Overall, the table depicts, very week positive and negative relationships, to no relationship between demographics and knowledge of aspects relating to occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP,

Positive relationships between worker characteristics and knowledge outcomes:

Positive relationships with modest effects between educational level and the following knowledge criterions were identified: Knowledge of Aeration poses greatest risk to bioaerosols; knowledge-WWTP emissions can affect reproductive health; knowledge-on entering confined spaces; knowledge-Training on WWTP HSE; knowledge-necessity of PPE can be seen.

Positive relationships with modest effect between age and the following knowledge criterions were identified: knowledge-Aeration poses greatest risk to bioaerosols; knowledge-WWTP emissions affects health; knowledge-WWTP emissions can cause skin diseases; knowledge-WWTP emissions can affect reproductive health; knowledge-necessity of PPE.

Positive relationships with modest effect between task the worker conducts, and the following knowledge criterions were identified: knowledge-WWTP emissions affects health; knowledge-WWTP emissions can cause headaches; knowledge-WWTP emissions can affect reproductive health; knowledge-training on WWTP HSE and knowledge-necessity of PPE.

Positive relationships with modest effect between the workers workstation, and the following knowledge criterions were identified: knowledge-Aeration poses greatest risk to

bioaerosols; knowledge-WWTP emissions affects health; Knowledge-water droplets affect health; knowledge-WWTP emissions can affect reproductive health; knowledge-Training on WWTP HSE and Knowledge-necessity of PPE.

Negative relationships between worker characteristics and knowledge outcomes:

Negative relationships with modest effect between the workers education level and the following knowledge criterions were identified: Knowledge-WWTP emissions affects health; knowledge-water droplets affect health; knowledge-WWTP emissions can cause skin diseases; and knowledge- showering and changing clothes end of shift.

Negative relationships with modest effect between age and the following age and knowledge criterions were identified: knowledge-water droplets affect health; knowledge-WWTP emissions can cause headaches; knowledge-on entering confined spaces; knowledge-training on WWTP HSE and knowledge- showering and changing clothes end of shift.

Negative relationships with modest effect between the task performed by worker the following age and knowledge criterions were identified: knowledge- Aeration poses greatest risk to bioaerosols; Knowledge-water droplets affect health; Knowledge-WWTP emissions can cause headaches; knowledge-WWTP emissions can cause skin diseases; knowledge-entering confined space and knowledge- showering and changing clothes end of shift

Negative relationships with modest effect between the workers workstation and the following knowledge criterions were identified: Knowledge-WWTP emissions can cause headaches; Knowledge-WWTP emissions can cause headaches; Knowledge-on entering confined spaces.

While some weak relationships were observed, only one statistically significant relationship could be identified between educational level and knowledge of WWTP emissions affecting health. Education level is seen as being inversely related to knowledge of emissions and their impact on health.

The other remaining demographic factors and knowledge criterion no statistically significant relationships could be identified, suggesting that the demographic factors analysed do not have a strong or reliable influence on the knowledge factors.

Table 4: Bivariate regression analysis of socio-demographics influencing knowledge information

	Correlation coefficient	**P-Value**	**95% Confidence Intervals**	
			Lower	Upper
Educational level - Knowledge-Aeration poses greatest risk to bioaerosols	0,008	0,966	-0,342	0,356
Educational level - Knowledge-WWTP emissions affect health	-0,369	0,038	-0,636	-0,023
Educational level - Knowledge-water droplets affect health	-0,125	0,497	-0,454	0,234
Educational level - Knowledge-WWTP emissions can cause headaches	-0,097	0,598	-0,431	0,261
Educational level - Knowledge-WWTP emissions can cause headaches	0,000	1,000	-0,349	0,349
Educational level - Knowledge-WWTP emissions can cause skin diseases	-0,131	0,476	-0,458	0,228
Educational level - Knowledge-WWTP emissions can affect reproductive health	0,029	0,876	-0,323	0,374
Educational level - Knowledge-on entering confined spaces	0,292	0,105	-0,063	0,581
Educational level - Knowledge-Training on WWTP HSE	0,165	0,367	-0,195	0,486
Educational level - Knowledge-necessity of PPE	0,017	0,926	-0,334	0,364
Educational level - Knowledge-showering and changing clothes end of shift	-0,017	0,926	-0,364	0,334
Age - Knowledge-Aeration poses greatest risk to bioaerosols	0,074	0,688	-0,282	0,412
Age - Knowledge-WWTP emissions affect health	0,090	0,625	-0,267	0,425

Age - Knowledge-water droplets affect health	-0,129	0,483	-0,457	0,230
Age - Knowledge-WWTP emissions can cause headaches	-0,018	0,920	-0,365	0,332
Age - Knowledge-WWTP emissions can cause headaches	-0,084	0,648	-0,420	0,273
Age - Knowledge-WWTP emissions can cause skin diseases	0,131	0,474	-0,228	0,459
Age - Knowledge-WWTP emissions can affect reproductive health	0,038	0,836	-0,315	0,382
Age - Knowledge-on entering confined spaces	-0,149	0,416	-0,473	0,211
Age - Knowledge-Training on WWTP HSE	-0,009	0,962	-0,356	0,341
Age - Knowledge-necessity of PPE	0,158	0,387	-0,201	0,481
Age - Knowledge- showering and changing clothes end of shift	-0,158	0,387	-0,481	0,201
Task - Knowledge-Aeration poses greatest risk to bioaerosols	-0,182	0,319	-0,499	0,178
Task - Knowledge-WWTP emissions affect health	0,302	0,093	-0,052	0,589
Task - Knowledge-water droplets affect health	-0,041	0,823	-0,384	0,312
Task - Knowledge-WWTP emissions can cause headaches	0,170	0,351	-0,189	0,490
Task - Knowledge-WWTP emissions can cause headaches	-0,085	0,643	-0,421	0,271
Task - Knowledge-WWTP emissions can cause skin diseases	-0,114	0,534	-0,445	0,244

Task - Knowledge-WWTP emissions can affect reproductive health	0,270	0,135	-0,087	0,565
Task - Knowledge-on entering confined spaces	-0,006	0,974	-0,354	0,343
Task - Knowledge-Training on WWTP HSE	0,005	0,977	-0,344	0,353
Task - Knowledge-necessity of PPE	0,124	0,499	-0,235	0,453
Task - Knowledge- showering and changing clothes end of shift	-0,124	0,499	-0,453	0,235
Workstation - Knowledge-Aeration poses greatest risk to bioaerosols	0,018	0,921	-0,333	0,365
Workstation - Knowledge-WWTP emissions affect health	0,235	0,196	-0,124	0,539
Workstation - Knowledge-water droplets affect health	0,154	0,401	-0,206	0,477
Workstation Knowledge-WWTP emissions can cause headaches	-0,069	0,709	-0,408	0,287
Workstation - Knowledge-WWTP emissions can cause skin diseases	-0,155	0,397	-0,478	0,205
Workstation - Knowledge-WWTP emissions can affect reproductive health	0,126	0,493	-0,233	0,455
Workstation Knowledge-on entering confined spaces	-0,095	0,605	-0,429	0,262
Workstation Knowledge-Training on WWTP HSE	0,225	0,216	-0,134	0,532
Workstation - Knowledge-necessity of PPE	0,268	0,139	-0,090	0,564
Workstation - Knowledge-showering and changing clothes end of shift	0,189	0,300	-0,171	0,504

4.3.8 Factors that influence perception information on occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP?

A bivariate analysis was conducted to assess the relationship between demographic factors and perception factors using linear regression as presented in **Table 5**.

Overall, the table depicts, very week positive and negative relationships, to no relationship between demographics and perception relating to occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP,

Positive relationships between worker characteristics and perception:

Positive relationships with modest effects between educational level and the following perception criterions were identified: Perception-WWTP emissions affect health and perception that air at WWTP affects health.

Positive relationships with modest effects between workers age and the following perception criterions were identified: Perception-I can eat anywhere in the plant; perception-wearing PPE is required but sometimes unnecessary and perception- Washing hands is optional.

Positive relationships with modest effects between type of employment and WWTP emissions affect health were identified.

Positive relationships with modest effects between workstation and the following perception criterions were identified: perception-WWTP emissions affect health and perception-Air at WWTP affects health.

Positive relationships with modest effects between years of service and the following perception criterions were identified: perception-WWTP emissions affect health; perception-I can eat anywhere in the plant; perception-wearing PPE is required but sometimes unnecessary and perception- Washing hands is optional.

Negative relationships between worker characteristics and perception:

Negative relationships with modest effect between the workers level of education and the following perception criterions were identified: perception-I can eat anywhere in the plant; perception-wearing PPE is required but sometimes unnecessary and perception- Washing hands is optional.

Negative relationships with modest effect between the workers age and the following perception criterions were identified: perception-WWTP emissions affect health and Air at WWTP affects health.

Negative relationships with modest effect between the type of employment and the following perception criterions were identified: perception-I can eat anywhere in the plant; perception-wearing PPE is required but sometimes unnecessary and perception- Washing hands is optional.

Negative relationships with modest effect between the workstation and the following perception criterions were identified: perception-I can eat anywhere in the plant; -perception-wearing PPE is required but sometimes unnecessary and perception- Washing hands is optional.

Negative relationships with modest effect between the years of service and perception-Air at WWTP affects health were identified.

While some weak relationships were observed, only two statistically significant relationship could be identified between educational level and the perception that workers can't eat anywhere in the plant. Including the perception information on type of employment - perception-Air at WWTP affects health.

The other remaining demographic factors and perception criterion, no statistically significant relationships could be identified, suggesting that the demographic factors analysed do not have a strong or reliable influence on the perception factors.

Table 5: Bivariate regression analysis of socio-demographics influencing information on perception

	Correlation coefficient	P-Value	95% Confidence Intervals	
			Lower	Upper
Educational level - perception-WWTP emissions affect health	0,041	0,824	-0,312	0,384
Educational level - perception-Air at WWTP affects health	0,012	0,948	-0,338	0,359
Educational level - perception-I can eat anywhere in the plant	-0,410	0,020	-0,664	-0,072
Educational level - perception-wearing PPE is required but sometimes unnecessary	-0,279	0,122	-0,572	0,077
Educational level - perception- Washing hands is optional	-0,079	0,669	-0,416	0,278
Age - perception-WWTP emissions affect health	-0,314	0,080	-0,598	0,038
Age - perception-Air at WWTP affects health	-0,143	0,435	-0,468	0,217
Age - perception-I can eat anywhere in the plant	0,061	0,742	-0,294	0,401
Age - perception-wearing PPE is required but sometimes unnecessary	0,055	0,764	-0,299	0,396
Age - perception- Washing hands is optional	0,040	0,828	-0,313	0,383

Type of employment - perception-WWTP emissions affect health	-0,157	0,391	-0,479	0,203
Type of employment - perception-Air at WWTP affects health	0,365	0,040	0,018	0,633
Type of employment - perception-I can eat anywhere in the plant	-0,155	0,398	-0,477	0,205
Type of employment - perception-wearing PPE is required but sometimes unnecessary	-0,087	0,635	-0,423	0,270
Type of employment - perception- Washing hands is optional	-0,266	0,141	-0,563	0,091
Workstation - perception-WWTP emissions affect health	0,039	0,831	-0,314	0,383
Workstation - perception-Air at WWTP affects health	0,088	0,634	-0,269	0,423
Workstation - perception-I can eat anywhere in the plant	-0,105	0,568	-0,438	0,253
Workstation - perception-wearing PPE is required but sometimes unnecessary	-0,006	0,973	-0,354	0,343
Workstation- perception-Washing hands is optional	-0,302	0,093	-0,589	0,052
Years of service - perception-WWTP emissions affect health	0,034	0,853	-0,318	0,378
Years of service - perception-Air at WWTP affects health	-0,114	0,535	-0,445	0,245

Years of service - perception-I can eat anywhere in the plant	0,295	0,101	-0,060	0,584
Years of service - perception-wearing PPE is required but sometimes unnecessary	0,142	0,437	-0,217	0,468
Years of service - perception- Washing hands is optional	0,287	0,111	-0,068	0,578

4.3.9 Correlation analysis of perception and knowledge

Table 6 represents the descriptive statistics for both perception and knowledge variables, providing insight into their means, standard deviation and Minimum and maximum ranges.

Workers have higher knowledge scores (2.73/4.0) compared to perception scores (1.53/4.0), suggesting they understand safety protocols but may underestimate risks associated with emissions that arise from WWTP.

The chi-square test (p-value = 0.5777) indicates no significant relationship between risk perception and knowledge of BVO emissions.

Strongest knowledge areas are hand hygiene and PPE requirements (3.0/4.0). Lowest perception scores are for eating on-site risks (1.19/4.0).

Table 6: Correlation and mean score for perception and knowledge

Variable	**Mean**	**Std Div**	**Min**	**Max**
IK_WWTP_and_pollution	2.8799	0.3407	2	3
IK_Aeration_risk_bioaerosols	2.6923	0.6178	1	3
IK_WWTP_and_Health	2.9310	0.2529	2	3

IK_Water_droplets_and_health	2.9286	0.2622	2	3
IK_Contaminants_headache	2.6562	0.6530	1	3
IK_Contaminants_Asthma	2.5	0.7620	1	3
IK_Contaminants_skin_disease	2.532	0.7620	1	3
IK_Contaminats_reproductive_health	2.25	0.8434	1	3
IK_Confined_Space_process	2.468	0.6712	1	3
IK_training_WWTP_HSE	2.7187	0.4568	2	3
IK_PPE_Requirements	2.969	0.1768	2	3
IK_Regularly_wash_hands	3	0	3	3
IK_Shower_and_change_end_shift	3	0	3	3
P_Risk_WWTP_known	1.8437	0.3689	1	2
P_Emissions_and_Health	1.8437	0.3689	1	2
P_Air_and_Ill_health	1.4375	0.50401	1	2
P_Eating_on_site	1.1875	0.39656	1	2

P_Wearing_PPE	1.4687	0.50700	1	2
P_Washing_hands_frequency	1.4062	0.49899	1	2
	Average score			
Average Knowledge score	2.73			
Average Perception Score	1.53			
Chi-Square Test results		**P-Value**		
	1.10	0.5777		

4.3.10 *Practice distribution scores*

Figure 14 represents practice scores among respondents ranging from 2 to 12, suggesting that all individuals demonstrated at least a basic level of safe occupational hygiene practices. The distribution indicates that approximately 7 respondents scored in the "good practice" range (10–12), around 15 fell into the "average practice" range (7–9), and about 7 scored in the "poor practice" range (2–6). This pattern, shown in the histogram, highlights a concentration of scores in the mid-range, with symmetrical tapering on either end. High compliance was most evident in practices such as frequent handwashing, correct use of personal protective equipment (PPE), and wearing rubber gloves. Conversely, lower compliance was observed in conducting medical surveillance, using waterproof overalls, and wearing safety goggles for eye protection.

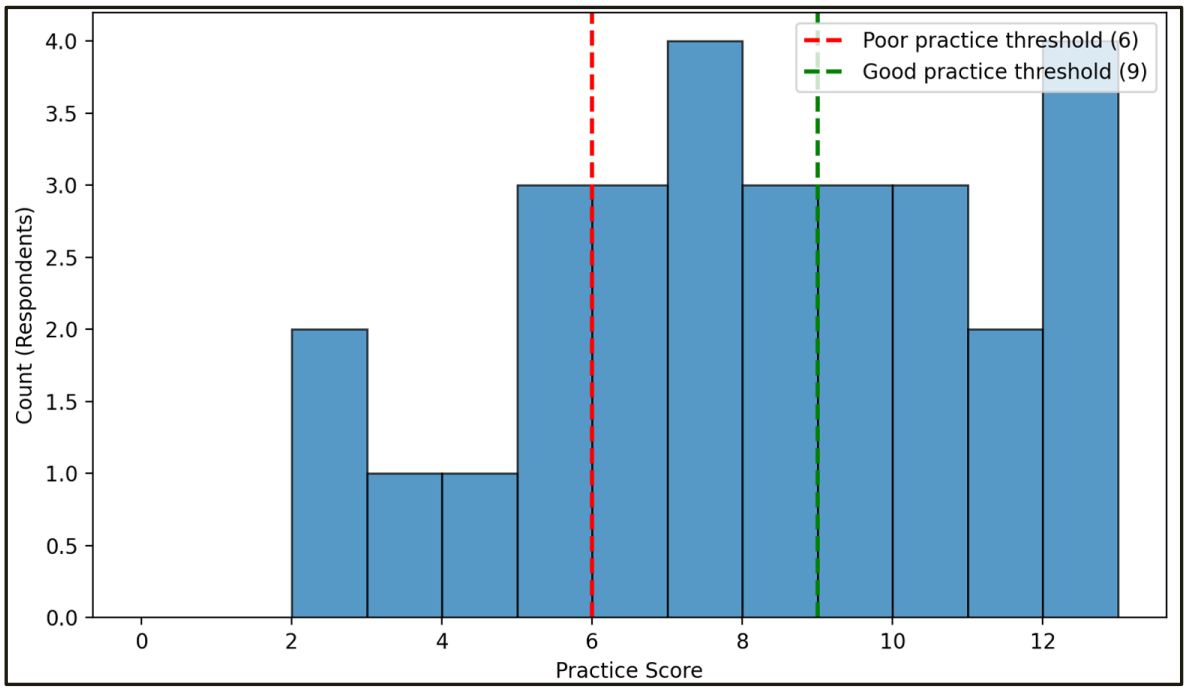


Figure 14: Distribution Practice

CHAPTER FIVE

This chapter discusses the study findings. The study aimed at evaluating knowledge and perception of WWTP workers occupational exposure to bioaerosols, VOCs & odours and their self-reported health symptoms associated with these emissions from WWTPs. Furthermore, the strengths and limitations of the study design, methodology and results are thoroughly discussed and compared with others from published studies. Additionally, practical recommendations are provided to improve health and safety practices at WWTPs and to improve occupational health monitoring strategies. Lastly, the chapter closes with a conclusion that highlights the scholarly contribution and policy impacts of this study.

5. DISCUSSION

The study provides insight into the occupational health landscape of WWTP workers, particularly concerning their knowledge and perception of emissions such as bioaerosols, volatile organic compounds (VOCs), and odours (collectively BVOs), as well as associated health outcomes.

The researcher assessed workers correct and incorrect knowledge response regarding BVO's emissions and associated health outcomes at selected WWTPs. Workers, who were predominantly male, with 56% of the study population aged between 30-44 years and approximately 66% of them having just high school level education, working at the respective plants for 11 and more years. The study revealed that workers have good knowledge regarding necessity of wearing the correct PPE for the job, regular washing of hands and importance of preventing cross contamination by showering/changing clothes at the end of shift. In addition, workers had good knowledge regarding operations of the WWTP being a source of pollution to the environment, that emissions generated during the wastewater treatment can affect their health and that the exposure to water droplets mostly occurs during the aeration process. Workers displayed fair knowledge when it came to bioaerosols, source of bioaerosols, emissions released causing skin related effects and respiratory effects, particularly asthma. Significantly, workers provided incorrect knowledge responses when asked regarding emissions affecting reproductive health.

WWTP workers understood hygiene practices that need to be in place, understood their work environment poses certain risk to the environment and human health. However, their knowledge when it came to BVO's, was average including the knowledge of health effects particularly relating to emission exposure to BVO's, based on the questionnaire utilized for

the study. This coincided with the study conducted by (Mohammed M Albahnasawi, 2018) looking at occupational health risks among workers in wastewater treatment plants in Gaza. The study concluded that although over 70% of the workers had good knowledge of the physical and chemical hazards that arise from wastewater treatment. More than half of the study participants had no knowledge regarding health associated with biological hazards from exposure to wastewater and related emissions. (Jaremków et al., 2018) concluded in their study, that the knowledge of the wastewater treatment plant workers about the biological and chemical factors present in their occupational environment is at an average level. Training programs that integrate practical examples with evidence-based insights on BVOs and long-term health outcomes could bridge this gap. Additionally, the development of mentorship initiatives where experienced workers share insights with newer employees may be a valuable strategy, particularly in settings where formal education levels are low.

Assessing how demographic factors influence knowledge of WWTP workers occupational exposure to bioaerosols, VOCs & odours. Positive relationships with modest effect between workers age, years of experience and knowledge scores was established, suggesting that older and more experienced workers tend to have higher knowledge about BVOs. However, the results were statistically insignificant.

Furthermore, the correlation between gender and knowledge scores was relatively weak, indicating that gender does not significantly influence knowledge levels in this study.

A negative relationship with modest effect between educational level and some knowledge scores, indicated that formal education does not directly correlate with specific knowledge about BVOs, possibly due to the type of insight required. This is in contrast to a study conducted by (Msaki et al., 2022), the study identified that the respondent's level of education was found to be a significant factor in influencing the respondent's knowledge over wastewater treatment technologies. This might be because education helps assists people to understand and explore hazards.

This might suggest that practical experience and age might be influential in determining knowledge levels about BVOs than formal education or gender. This could guide WWTP managers to focus on experience-based training and mentorship programs to enhance knowledge about occupational exposures.

Furthermore, WWTP workers perceived to have known the risk associated with emissions from WWTP and perceived that emissions that arise from treatment of wastewater affects

their health. In general workers perceived a certain level of risk and certain practices such as regular washing of hands were seen as non-negotiable.

While demographic factors like age, gender, and education were seen to influence perception, the effects were generally modest. Education seemed to have more substantial impact on how risks from WWTP were perceived, while age and gender have weaker correlations, indicating that they are not strong determinants of risk perception. (Sund et al., 2017) determined that education is a determinant for risk perception and that highly educated people had a lower risk perception.

In this study, the workers did not demonstrate the relevant knowledge to understand the emission characteristics, and their perception was based on the view of their physical work environment. Understanding that they are dealing with human waste. A link can also be made to the PPE used which focuses on protecting more against physical hazards. Similar findings in the study conducted by (Jaremków et al., 2018) reporting that the most difficult questions regarding awareness of hazards at WWTPs was topics centered around bioaerosols, where less than 50% correct answers were recorded for the study participants. Which was not the case when looking at chemical hazards.

Following assessing knowledge and perception of emissions relating BVO's, the researcher assessed self-reported symptoms associated with exposure to BVOs emitted from WWTP. Four predetermined associated symptom clusters were of focus. Majority of the WWTP workers indicated that in the past 6 months, they have experienced the associated symptoms in each cluster category 1-3 times. A few, 28% and below, in all cluster symptoms indicated they never experienced the associated symptoms. Irritation associated symptom (nasal irritation; throat irritation; sinus trouble; nose irritation; eye irritation; skin problems; skin rash; skin redness; itching skin; flaking skin and cracked skin). was indicated as the most experienced symptom by the workers. Indicating that they frequently experienced (4 times and more episodes in the past 6 months) the symptoms. The least reported symptoms frequently experienced (4 times and more episodes in the past 6 months), was respiratory related symptoms (allergic rhinitis; cough with no phlegm; cough with phlegm; shortness of breath; wheezing/whistling breath; chest tightness and breathlessness). Although (Jaremków et al., 2018) and (Thayyil et al., 2013) reported similar associated symptoms, in both the studies respiratory related symptoms were the most common symptoms reported

then followed by irritants. This could also be accounted to the difference in cluster categorisation of the symptoms in this study.

Overall, these findings point to the critical need for enhanced occupational health education that goes beyond routine safety measures and emphasizes biological and chemical hazard awareness.

5.1. Limitations of the study

I. This study was cross-sectional, using a structured questionnaire to capture participants' responses, and might have invited the response bias.

II. Limited availability of local literature on WWTP workers' knowledge and perception of bioaerosol, odour, and VOC emissions in South Africa posed a challenge when interpreting the findings. The scarcity of context-specific studies restricted the ability to benchmark results or validate the measurement tools against established local research.

III. The total workforce across the three selected wastewater treatment plants was 126, only 32 participants completed the questionnaire. This limited response was due to factors such as shift work schedules, operational demands at the WWTPs, limited researcher access during working hours, and voluntary participation constraints. The small sample size reduces the statistical power of the study and limits the ability to generalise the findings to all WWTP workers in the City of Tshwane or other similar settings.

IV. The study relied on self-reported data to capture symptoms experienced by WWTP workers, which introduces the risk of recall bias and subjective interpretation. Participants may have inaccurately attributed symptoms to occupational exposures. Additionally, the study did not include clinical verification or medical records to objectively confirm these symptoms, which limits the strength of the associated symptoms experienced.

5.2. Strengths of the study

This is relatively the first study to fill the research gap on knowledge and perception of WWTP workers exposure to BOVs emission as a collective, in South Africa. By assessing the current knowledge of WWTP workers concerning BOVs emissions, specific areas where

mitigation strategies need to be improved can be identified. Understanding workers' knowledge and perceptions regarding emissions is critical for public health and environmental safety. The findings aim to inform workplace practices and occupational health policies focused on reducing exposure to bioaerosols, VOCs, and odours in wastewater treatment environments. Furthermore, the study provides insight into exposure risks from the perspective of frontline workers (Practical relevance) highlighting gaps in knowledge, perception, and practices—which are often overlooked in traditional, compliance-driven risk assessments

5.3. Recommendations

The following recommendations are made to assist WWTP managers and also policy enforcers to mitigate exposure of BVO's:

I. Enhance training programs: Increase training on the importance of PPE usage and the health risks associated with emissions, as there is a gap between knowledge and practice. Training programs to integrate practical examples with evidence-based insights on BVOs and long-term health outcomes.
II. Improve medical surveillance programme: Implement regular health monitoring and follow-up for workers to address reported health symptoms, matters relating to mental health and ensure early detection of potential health issues. Medical surveillance programme should be risk-based and consistently applied for all WWTP workers exposed.
III. Increase awareness campaigns: Conduct awareness campaigns to reinforce the perception of risks associated with emissions relating to BVO's and the importance of safety protocols.
IV. Future studies should aim to include a larger, more representative sample of WWTP workers across multiple municipalities. This will improve the generalisability of findings and allow for comparisons across different operational and regulatory settings.
V. In addition, future studies to incorporate clinical evaluations of workers' health (e.g., lung function tests, biomonitoring), coupling it with longitudinal studies to evaluate the long-term health effects of chronic BVO exposure among WWTP workers. This would strengthen the evidence linking exposure to reported symptoms and address the limitation of relying solely on self-reported data.

These recommendations aim to bridge the gap between knowledge and practice, enhance worker safety, and reduce health risks associated with WWTP emissions related to BVO's. In addition, contribute to the body of knowledge regarding occupational exposure for WWTP workers, to improve exposure controls.

5.4. Conclusion

The study revealed that while workers demonstrated adequate knowledge of general hygiene practices and PPE use, there was inadequate understanding of the specific nature, sources, and health effects of BVOs. Specifically, knowledge gaps were evident regarding less visible health impacts, such as reproductive and long-term respiratory outcomes, emphasising the need for targeted educational interventions that address biological and chemical hazards more comprehensively.

Furthermore, the perception from workers that emissions from WWTPs can pose a health risk was primarily based on observable workplace surroundings (handling of human waste) rather than informed understanding of BVO characteristics. This indicates a gap where workers recognize risk but may lack the conceptual tools to accurately articulate that risk. Highlighting the importance of reinforcing perception through informed, evidence-based training.

Workers reported experiencing symptoms consistent with BVO exposure, with irritant-related symptoms being most prevalent. However, the relatively lower frequency of reported respiratory symptoms, compared to findings in other studies, may reflect normalisation of symptoms within the work environment. This further illustrates the disconnect between lived experience, health outcomes, and formal knowledge of occupational exposures.

Collectively, the study bridges these identified gaps by linking practical experience with scientific evidence, revealing the inadequacy of current knowledge and perception levels in addressing complex occupational hazards such as BVOs. The findings advocate for enhanced occupational health strategies that incorporate experiential learning, structured education on biological exposures, and tailored risk management. Addressing these gaps could enhance overall worker safety.

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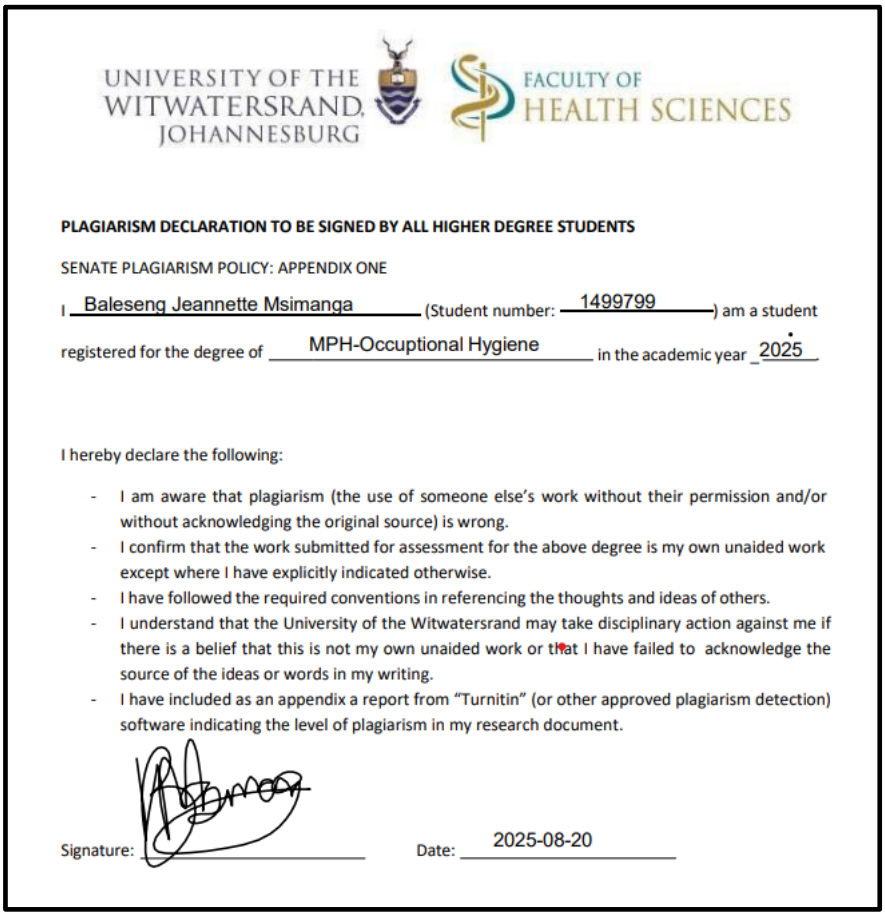
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Appendix1: Plagiarism declaration form



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PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Baleseng Jeannette Msimanga (Student number: 1499799) am a student registered for the degree of MPH-Occuptional Hygiene in the academic year 2025.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.
- I have included as an appendix a report from "Turnitin" (or other approved plagiarism detection) software indicating the level of plagiarism in my research document.

Signature: _____ Date: 2025-08-20

Appendix 2 Questionnaire

Title of Project: Worker's knowledge and perception on occupational exposure related to emissions at wastewater treatment plants, in the City of Tshwane, South Africa

Name of Researcher: Baleseng Jeannette Msimanga

Instructions: Please read each question carefully. Kindly tick the most appropriate response. All information gathered during the study will be kept strictly confidential and the information will only be used for this research.

A. DEMOGRAPHIC AND SOCIO-ECONOMIC CHARACTERISTICS	
1. What is your gender?	1. ☐ Female 2. ☐ Male 3. ☐ Other _____
2. What is your Ethnicity?	15. ☐ African 16. ☐ White 17. ☐ Coloured 18. ☐ Indian
3. What is your age?	1. ☐ 19- 24 years 2. ☐ 25- 29 years 3. ☐ 30- 44 years 4. ☐ 45 or above
4. What is the highest Qualification you have completed? (Choose one only)	1. ☐ No formal schooling 2. ☐ Primary School (Sub A-Std 5/Gr 1-7) 3. ☐ High School (St 6-std 10/Gr 8-12) 4. ☐ College/Tertiary education
19. Main jobs or tasks (Choose one only)	1. ☐ Operator 2. ☐ Cleaner 3. ☐ Technician 4. ☐ Security 5. ☐ Other _____
20. Which division/workstation you are working?	1. ☐ Primary water treatment 2. ☐ Secondary water treatment 3. ☐ Tertiary water treatment 4. ☐ Other_____
21. Type of employment	1. ☐ Permanent 2. ☐ Temporary 3. ☐ Contract 4. ☐ Other_____

22. How long have you been working in this job (Choose only one)	1. ☐ 1-3 years 2. ☐ 4-5 years 3. ☐ 6-10 years 4. ☐ 11years and more
23. How many hours do you work per day? (Choose only one)	1. ☐ Less than 4 hours 2. ☐ 5-6 hours 3. ☐ 7-8 hours 4. ☐ 9-10 hours 5. ☐ More than 10 hours
B. ASSOCIATED SYMPTOMS CLUSTERS	
24. Have you experienced any of the following symptoms, in the past 6 months?	
Symptoms	
Flu -like symptoms Fever; Shivering; Feeling unwell; Cough; Unusual tiredness; Muscle weakness and joint pains.	1.☐ Frequently 2. ☐ Rarely 3. ☐ Never
Respiratory symptoms Allergic rhinitis; Cough with no phlegm; Cough with phlegm; Shortness of breath; Wheezing/whistling breath; Chest tightness; Breathlessness.	1.☐ Frequently 2. ☐ Rarely 3. ☐ Never
Irritation symptoms *Nasal* irritation; Throat irritation; Sinus trouble; Nose irritation; Eye irritation; Skin problems; Skin rash; Skin redness; Itching Skin; Flaking skin; Cracked skin	1.☐ Frequently 2. ☐ Rarely 3. ☐ Never
Gastrointestinal related symptoms Lack of appetite; Heartburn; Nausea; Diarrhoea; Vomiting; Indigestion; Stomach pain; Constipation; Fever.	1.☐ Frequently 2. ☐ Rarely 3. ☐ Never
C. INFORMATION ON OCCUPATIONAL EXPSOURE	
25. Have you been made aware of hazards related to working at the wastewater treatment plant (WWTP)?	1.☐ Yes 2. ☐ No
26. Which of the following hazards can be associated with working at the wastewater	1. ☐ Chemical Hazards 2. ☐ Biological/microbiological hazards

treatment plant (WWTP) that you have been made aware of?	3. ☐ Slips, trips, and falls due to wet environments 4. ☐ Equipment and machinery hazards 5. ☐ Confined space hazards and entrapment hazards 6. ☐ Electrical/electrocution hazards 7. ☐ Noise and vibration-related hazards 8. ☐ Ergonomics hazards 10. ☐ Psychological stress and mental hazards 11. ☐ All of the above 12. ☐ None of the above
27. How often do you come into contact with potentially hazards as part of your job?	1. ☐ 1-2 hours daily 2. ☐ 2-4 hours daily 3. ☐ 4-8 hours daily
28. What kind of protective equipment do you use to safeguard yourself when working at the wastewater treatment plant (WWTP)?	1. ☐ Respiratory protection (e.g., masks or respirators) 2. ☐ Gloves 3. ☐ Safety goggles or face shields 4. ☐ Protective clothing (e.g., overalls or suits) 5. ☐ Safety boots 6. ☐ Ear protection (e.g., earplugs or earmuffs) 7. ☐ Hard hats 8. ☐ None of the above
29. What role do your superiors/supervisors play in promoting a safe work environment and minimizing occupational exposures?	1. ☐ Actively lead and set an example for safe work practices 2. ☐ Provide regular training and guidance 3. ☐ Enforce protocols and regulations 4. ☐ Encourage reporting of concerns and incidents 5. ☐ Collaborate with workers to identify and mitigate hazards 6. ☐ All of the above 7. ☐None of the above
D. Information on knowledge on occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP?	
30. Work at the WWTP contributes to pollution?	1.☐ Yes 2. ☐ No 3. ☐ I don't know
*Bioaerosols-microorganisms in small water droplets we can't see. 31. The aeration stage of wastewater treatment processes pose the greatest risk of exposure to bioaerosols?	1.☐ Yes 2. ☐ No 3. ☐ Don't know

32. Do you know that working in a WWTPs is dangerous to your health and safety?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
19. Do you know that the water droplets from aeration process are harmful?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
20. Are you aware that some emissions may cause headaches/drowsiness/confusion?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
21. Are you aware that some emissions may cause asthma?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
22. Are you aware that some emissions may cause skin diseases?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
23. Are you aware that some emissions may cause reproductive problems?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
24. Are you familiar with the process required to enter confined spaces?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
25. Have you been trained on WWTP health and safety?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
26. Do you know that it is necessary to wear PPE when working at WWTP?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
27. Do you know that WWPT activities requires you to wear masks?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
28. Do you know that it's necessary to regularly wash hands?	1.☐ Yes 2. ☐ No 3. ☐ Don't know
29. Do you know that it's necessary to shower and change clothes before leaving work	1.☐ Yes 2. ☐ No 3. ☐ Don't know

E. Information on Perception regarding occupational exposure of bioaerosols, VOCs and odours (BVO) emitted from WWTP?

30. To what extent do you agree with the below statements:

	1. Strongly disagree	2. Disagree	3. Agree	4. Strongly Agree
a) Risk associated with emissions at WWTP known to me.				
b) Emissions generated during treatment of wastewater have the potential to make me sick.				
c) The air I breath at work cannot make me sick.				
d) I can eat anywhere when I'm in the plant. I don't have to go to an eating area.				
e) I understand that wearing PPE is required at work but sometimes I see it as unnecessary.				
f) Washing my hands is optional.				

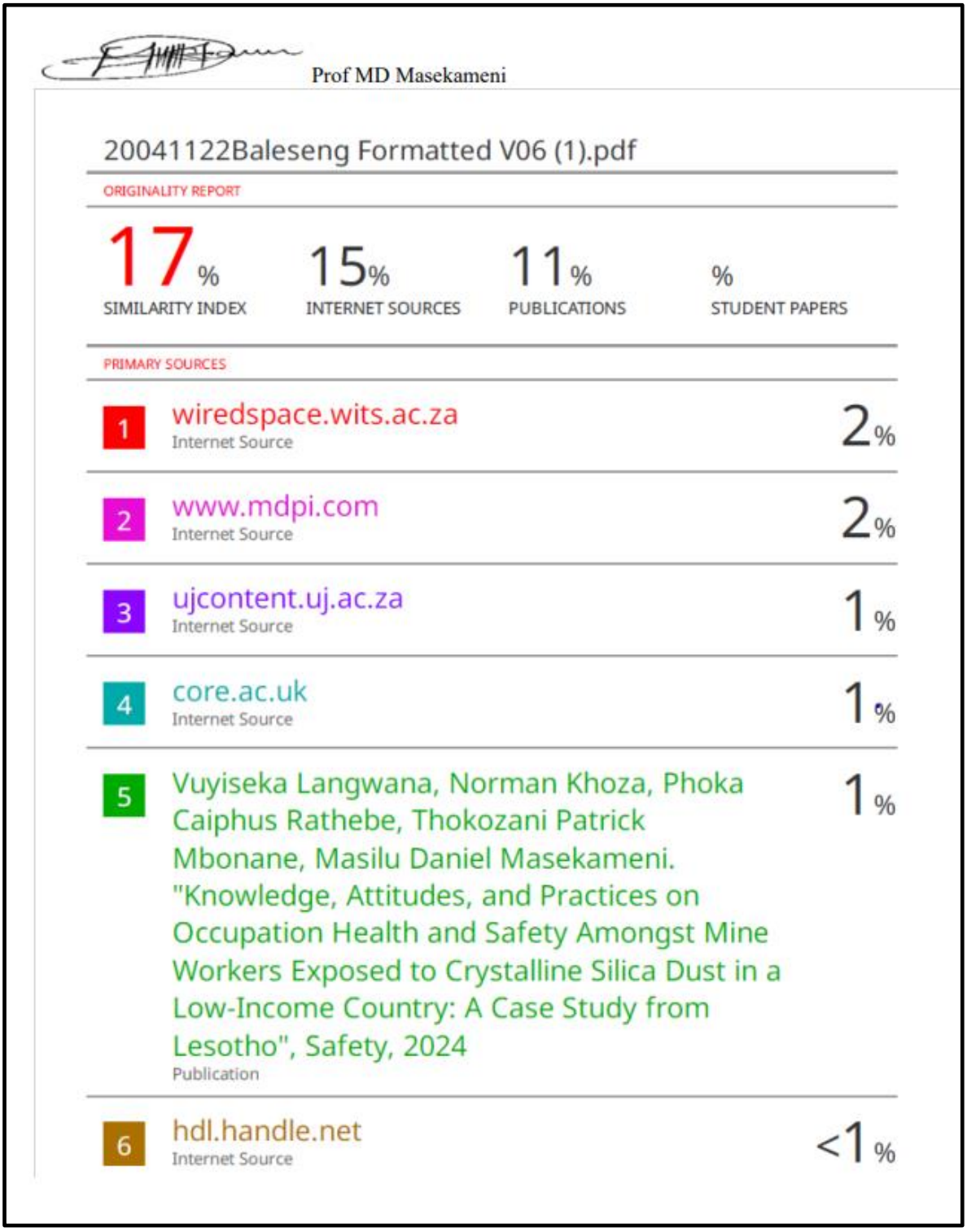
F. Practices towards Occupational Health and Safety

31. How often do you take any of the following precautions when at work? Please check one for each of the following.

	Never	Sometimes	Always	
g) I wear the correct PPE for the job.				
h) I wear a Waterproof overall.				
i) I wear goggles.				
j) I wear rubber gloves.				
k) I wear a face mask.				
l) I frequently wash my hands at work.				
m) I have undergone medical surveillance. Where the check ed for:				
-Hearing (Audiometry)				
-Lungs (Spirometry)				
-Eyes (Vision)				
-Follow up on health concerns				
-Biological Monitoring (Urine/mucous samples)				

Thank you very much for your participation.

Appendix 3: Turn it in report



Prof MD Masekameni

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ORIGINALITY REPORT

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6	hdl.handle.net Internet Source	<1%

Appendix 4: City of Tshwane-Study approval letter to conduct research at wastewater treatment plants.

CITY OF TSHWANE
IGNITING EXCELLENCE

Water and Sanitation

Room A704 I 7th Floor I Capitol Towers North I 225 Madiba Street I Pretoria I 0002
PO Box 1022 I Pretoria I 0001
Tel: 012 358 3773 I 012 358 4101
Email: steven@tshwane.gov.za I www.tshwane.gov.za | www.facebook.com/CityOfTshwane

My ref:	W9/1//2/1	Tel:	012 358 0693
Your ref:	WITS	Fax:	-
Contact person:	DR Ntsowe	Email:	davidn@tshwane.gov.za
Section/Unit:	Bulk Water and Waste Water Services		

15 September 2022

Dr Daniel Mmereki
Occupational Health Division
Faculty of Health Sciences
University of Witwatersrand
Johannesburg
2193

By Email: Daniel.mmereki@wits.ac.za

RESEARCH AT SELECTED WASTE WATER TREATMENT WORKS BY UNIVERSITY OF WITWATERSRAND

Your letter dated 14 July 2022 regarding the above subject matter refers.

Your request to conduct research from selected Waste Water Treatment Works has been granted, ending 31 December 2025.

The name of the treatment plants must not be revealed in any publication that may result from the work and we will be glad to receive feedback of these investigations. The information gained must be solely used for the purpose stated in your request, and not for any other purposes.

The following official can be contacted to provide the required information:
- Mr Kerneels Esterhuyse – Acting Director: Waste Water Treatment

012 358 0702/ kerneelse@tshwane.gov.za

Trust you will find the above in order.

Regards

Stephens Notoane
GROUP HEAD: WATER AND SANITATION
Date: 2022/09/21

On request, this document can be provided in another official language.

Water and Sanitation • Lefapha la Metsi le Kgelelobeswe • UmNyango wezaManzi neHlwengiso • Kgoro ya Meetse le Tlhwekišo • Ndzawulo ya Mati na Mbhasiso • Umnyango Wezamanzi Nokuthuthwa Kwendle • Water en Sanitasie • Muhasho wa zwa Maḓi na Vhuthathazwitzhili

Appendix 5: Research Ethics Clearance Certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R14/49 Mrs Baleseng Msimanga

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M240107 M240517-B-0001

NAME: (Principal Investigator)	Mrs Baleseng Msimanga
DEPARTMENT:	Public Health - Occupational Hygiene City of Tswane: Water and Sanitation
DEGREE:	Master of Public Health
TITLE:	*Worker's knowledge and perception on occupational exposure related to emissions at wastewater treatment plants, in the City of Tshwane, South Africa*
DATE CONSIDERED:	26/01/2024
DECISION:	Approved unconditionally
CONDITIONS:	
NOTE:	Application Number: MED23-10-362
SUPERVISOR:	Dr D. Masekameni and Dr D. Mmereki
APPROVED BY:	Mrs M. van Niekerk, Co-Chairperson, HREC (Medical)

DATE OF APPROVAL: 17/05/2024 **EXPIRY DATE:** 17/05/2029

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

I/we fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report** in the month date of convened meeting each year until study is closed. Failure to submit annual report will result in ethics clearance certificate suspension. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. Unreported changes to the application may invalidate the clearance given by the HREC (Medical). Login to upload signed copy of this ethics clearance certificate prior to commencing with the study https://www.witsethics.co.za/login.aspx. Email a signed copy of ethics clearance certificate to HREC-Medical.ResearchOffice@wits.ac.za.

Principal Investigator Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix 6: Distress protocol



DISTRESS PROTOCOL

When a participant indicates during the question answering process that he/she is experiencing a high level of stress or emotional distress, OR exhibits behavior such as a trembling voice, crying or shaking, do the following:

Distress

- The Partcipant verbalises they are distressed
- The participant exhibits behaviours suggestive that they are in distress. For example crying, shaking, agitation or anger.

Response

- Stop the research (Request that they do not proceed completing the questionaire)
- Offer support (ask them how they're feeling, listen with empathy and give them time to recover)
- Ask the partcipant if they feel safe

Review

- Ask the partcipant if they feel comfortable to continue (consider making adjustments to the schedule to avoid further distress)
- If the partcipant is unable to carry on, move on to the second response.

Second Response

- End data collection
- ntact LifeLine Pretroria (24/7) counseling line on 0861 322 322 or lling on 071 247 6656/082 541 4357.
- Or with consent offer a member of the research team to contact the appropriate contact point on their behalf

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Follow Up

- If participant consents follow up with a courtesy phone call. OR
- Encourage the participant to call if they experience increasing levels of distress in the hours/days post interview.
- All participants to be given debrief with relevant organisations' contact details and places for support (LifeLine Pretroria (24/7) counseling line on 0861 322 322 or HUMANITAS for online coumselling on 071 247 6656/082 541 4357)

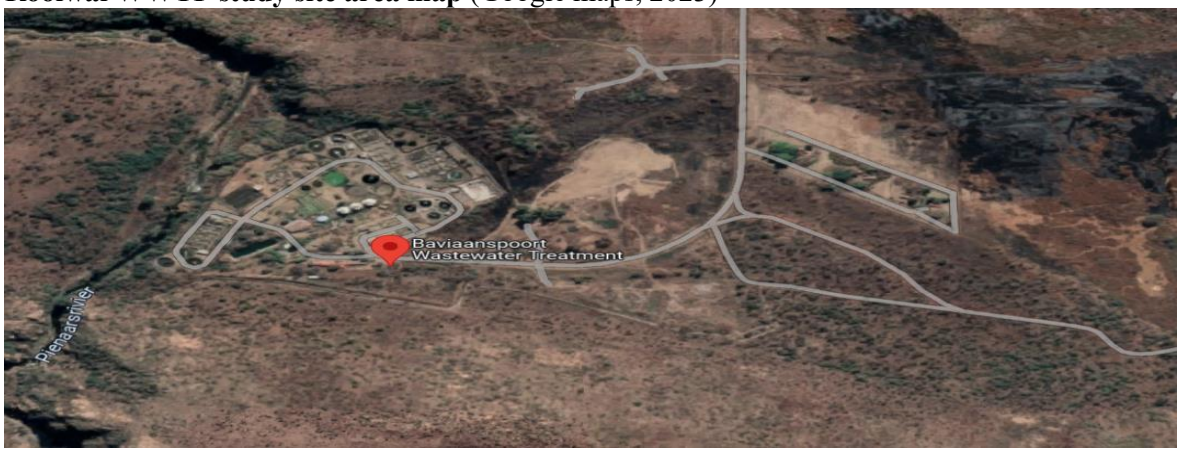
Appendix 7: Study site area map



Daspoort WWTP study site area map (Google Maps, 2023)



Rooiwal WWTP study site area map (Google maps, 2023)



Baviaanspoort WWTP study site area map (Google maps, 2023)