



Persistent Organic Pollutants (POPs) Removal by Drinking Water Treatment Plants. (DWTPs): A Case Study of the Buffalo River Catchment

BT Addey

 **orcid.org 0000-0001-8865-3839**

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Supervisor: Prof CW Malherbe

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ABSTRACT

The Buffalo River is the main source of potable water for residents of King William's Town, Bisho, and Mdantsane hence it is key for public health. It therefore follows that the well-being of the local population is a function of the quality of the water provided by drinking water treatment plants (DWTPs) like the Umzonyana Drinking Water Treatment Plant which sources its raw water from the Buffalo River. Persistent Organic Pollutants (POPs), including organochlorine pesticides (OCPs), organochlorine pesticides (OCPs) and polycyclic aromatic hydrocarbons (PAHs) are probable contaminants that may potentially pollute both raw and treated water.

Assessment of the efficiency of DWTPs in removing these pollutants is important. This research delves into the problem of finding out the removal efficiency of POPs by DWTPs in the Buffalo River catchment, with a focus on the Umzonyana Water Treatment Plant.

The aim of this research was to evaluate the effectiveness of the Umzonyana Water Treatment Plant in removing POPs from the Buffalo River source water. The study especially sought to understand the removal or persistence of POPs in the water treatment process and do an assessment on the potential implications for public health.

The methodology involved collecting raw and treated water samples from the Buffalo River and the Umzonyana Water Treatment Plant. The collected samples were analysed using Gas Chromatography-Mass Spectroscopy (GC-MS) in the identification and quantification of various POPs concentrates. The analysis provided information into the occurrence of PAHs, PCBs, and OCPs in both the raw and treated water.

The results of the GC-MS analysis indicated that the concentrations of POPs in both raw and treated water were within the regulatory limits of established standards, thereby suggesting that the Buffalo River may be experiencing minimal contamination from POPs. This likely may be arising from limited industrial discharge, agricultural runoff, or other pollution sources. Furthermore, the treatment methodologies at the Umzonyana Water Treatment Plant are apparently effective in reducing the concentration of these

contaminants, with levels falling below detectable limits. Notwithstanding these positive findings, it was picked up that the staff at the Umzonyana Water Treatment Plant possess adequate knowledge in general water treatment processes but had limitations in their understanding of POPs removal, since they do not routinely monitor for these pollutants.

Based on the findings, this dissertation recommends continued monitoring and analysis of both the source and treated water from the Buffalo River and the Umzonyana Water Treatment Plant respectively. More sensitive methodologies should be employed to detect trace amounts of POPs, and long-term monitoring of source water quality should be implemented. Future studies should explore a broader range of POPs, evaluate the removal efficiencies under varying water quality conditions, and develop enhanced analytical techniques for POP detection. It is recommended additionally that an enhanced training program for plant staff regarding POPs and their removal be introduced, alongside investment in modern technologies and collaboration with researchers and policymakers to ensure optimal POP removal and public health.

Keywords:

Persistent Organic Pollutants (POPs), Drinking Water Treatment Plants (DWTPs), Buffalo River Catchment, water quality, Organic micropollutants, surface water contamination, water treatment efficiency, advanced water treatment technologies, POPs removal mechanisms, activated carbon filtration

KEY DEFINITIONS

Persistent Organic Pollutants - any chemical organic substance that persist in the environment, accumulate in living organisms, travel long distances, and are toxic to humans and wildlife.

Drinking Water Treatment Plant (DWTP) - is a facility that treats raw water from natural sources, such as rivers, lakes, or groundwater, to remove physical, chemical, and biological contaminants, making it safe and suitable for human consumption in accordance with health and safety standards.

Water Quality - describes the physical, chemical, and microbiological characteristics of water.

Raw Water - water found in the environment that has not undergone any treatment to remove properties.

Analytical Techniques – various methods used to detect and quantify POPs like Gas Chromatography-Mass Spectrometry (GC-MS).

Water Treatment Processes – processes of flocculation, coagulation, sedimentation, filtration, and disinfection as pertains to the treatment of raw water by conventional DWTPs.

Regulatory Standards – Guidelines from bodies like the South African National Standard (SANS) or WHO for permissible levels of pollutants in drinking water.

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CHAPTER 1 INTRODUCTION

1.1 Background

Water is such an important resource for the survival of humans, maintenance of ecological balance, and a tool for socio-economic balance. According to the World Health Organization (WHO) data from 2016, it was estimated that around 1.2 billion people worldwide lack access to clean drinking water (WHO, 2017b). Access to clean drinking water is a human right, vital for maintaining good health, and an integral part of successful health protection policies (WHO, 2022); hence, this statement not only underscores the importance of access but also the quality of water. Besides adhering to intricate regulations surrounding the production of drinking water from surface sources due to health concerns, there are regulations on source water and the minimum treatment required for surface water in South Africa (SABS, 2015; RSA, 1998).

Human actions such as excessive pesticide and fertilizer usage, improper solid waste disposal, septic tank leaks, and industrial effluent dumping into water bodies have caused significant harm to our surface and groundwater reserves (Meffe and Bustamante, 2014). Thereby resulting into the trophic transfer of contaminants from water to plants and the upper parts of the food chain (including humans), who are the final consumers of natural resources (Nair and Perumal, 2022). The impact of low levels of organic contaminants in drinking water on public health remains unclear and debated, as there is limited data on the direct health effects of drinking water consumption (Villanueva et al., 2014). Despite this uncertainty, various efforts have been launched to tackle these issues.

Persistent Organic Pollutants (POPs) are organic chemical compounds containing conjugated bonds that pose toxicity risks to both humans and wildlife (Fujitani et al., 2020). Persistent Organic Pollutants can be resistant to environmental degradation processes and have a tendency for bioaccumulation and biomagnification in biota. Their persistence and toxicity, long-range transport potential, bioaccumulative nature, and environmental, as well as potential human health effects, are the key characteristics of POPs that make them hazardous (Jones, 2021). Humans can be exposed to POPs through multiple routes, such as eating contaminated fish, drinking polluted water, inhaling contaminated air, or absorbing them through the skin (Krithiga et al., 2022)

Common health effects reported in those exposed to POPs in varying concentrations over time include cancer, endocrine disruption, reproductive and developmental effects, immune suppression, and general toxic effects, among others, depending on the type of POP, the level of exposure, age of the exposed, and the duration of the exposure (Krithiga et al., 2022).

The Buffalo River Catchment, which is the largest river system situated in the Eastern Cape, is of ecological and socio-economic importance (O'Keefe et al., 1996). Largely uncontrolled urbanization, poor waste management practices, inadequate infrastructure and enforcement, and passiveness from the public impose major challenges for the river's management (River Health Programme RHP, 2004). The Buffalo River is a vital resource for supplying drinking water to a large and water-stressed community, and these potential risks need to be urgently addressed. The challenges the river faces include amongst others, poor wastewater treatment, poor sanitation by residents in informal settlements along the river, agricultural runoff, and lack of effective monitoring and prevention (Chigor et al, 2013; O'Keefe et al, 1996). There have been earlier studies on the Buffalo River on various POPs namely Organochlorine Pesticides (OCP) (Yahaya et al., 2017), polynuclear aromatic hydrocarbons (PAH) (Adeneji et al., 2019) and phenolic compounds and their derivatives (Yahaya et al., 2019).

Three DWTPs depend on the Buffalo River as a source of raw water within the catchment. They include King William's Town, Amathole, and the Umzonyana DWTPs. The principal aim of a DWTP is to produce water that is safe for domestic use using treatment processes that produce desired water quality from a raw water source (Schutte and Focke, 2006). Drinking water treatment plants in South Africa are regulated by major promulgated legislation for instance, the National Water Act, 36 of 1998, that came into effect in 1998, and the Water Services Act, 108 of 1997, effective from 1998. The former gives the mandate to municipalities to ensure access to safe drinking water and sets out the responsibilities for quality control monitoring (Republic of South Africa, 1997). The latter broadly focuses on Water Resources Management by seeking to protect the availability and quality of water resources; thereby complementing the Water Services Act (Republic of South Africa, 1998).

Besides legislation, The Blue Drop Certification program assists in water management. The Blue Drop Certification Programme functions as a regulatory incentive program

from South Africa's Department of Water and Sanitation (DWS) that evaluates and improves drinking water quality delivered by Water Services Institutions (WSIs). The evaluation process assesses multiple factors that include water quality compliance together with technical skills, infrastructure management, and risk mitigation strategies. The WSIs achieving 95% or higher scores obtain Blue Drop Certification demonstrates their outstanding drinking water management practices (DWS, 2023). The Blue Drop assessments occur regularly. The latest thorough review, for the 2021 to 2022 year was finished in 2023. The upcoming audit, for the 2023/2024 fiscal year is scheduled with the outcome anticipated in 2025. The 2023 Blue Drop Report assessed the Eastern Cape province through examinations of 14 WSAs and 154 water supply systems. No Blue Drop Certifications were granted as none of the WSAs met the 95% threshold, for certification. Only 46.1% of systems were categorized as low risk, indicating areas needing improvement, and 27 systems were identified as being in a critical state, necessitating urgent interventions. (DWS, 2023).

1.2 Problem statement and rationale for the study

Shah et al. (2004) submits that there are more than 100000 synthetic chemicals used in agricultural applications, industrial and domestic use. Many of these compounds fall within the plasticizers, detergents, and pharmaceutical categories that persist in the aquatic environment (Stackelberg et al., 2010). There have been several reviews of these compounds, which are also called Persistent Organic Pollutants (POP) (Girones et al., 2021; Said and El Zokm., 2024), in aquatic and wastewater environments, for instance, those done by Halling-Sorensen et al. (1998); Daughton (2001); Metcalfe et al. (2004), and Focazio et al. (2008). Halling-Sørensen et al. (1998) looked at the pathways through which pharmaceutical enters aquatic systems and their adverse effects on organisms even at low concentrations whilst Daughton and Ternes (1999) through the introduction of the concept of "pseudo-persistence" explored how contaminants mostly from sewage effluents can persist in aquatic environments, notwithstanding their short environmental half-lives. Metcalfe et al. (2004) highlighted the pervasive nature of POPs, by demonstrating how POPs could be transported long distances to contaminate places even with minimal human activity. Focazio et al. (2004) underscored the challenges in removing antibiotics, hormones, and other pharmaceuticals through the conventional

Drinking Water Treatment Plant (DWTPs) when they identified a wide prevalence of these chemicals in untreated sources of drinking water.

Because some of the known effects of POPs include reproductive impairment (Bergman and Olsson, 1985), and defects in eyes (Michałowicz and Duda, 2007) amongst others, it has grabbed global attention. Zamxaka et al. (2004), Chigor et al. (2013), Yahaya et al. (2017; 2019) and Adeneji et al. (2019) established the presence and to some extent the contamination by POPs in sections of the Buffalo River. Chigor et al. (2013) found that PCB concentrations in the Buffalo River varied seasonally and spatially. In summer, concentrations ranged from below detection limits to 482 ng/L, while in autumn, levels reached up to 2.383 ng/L. What has not been established is how efficient the DWTPs in the river catchment are in removing POPs from the raw water.

The challenge affects South African national policy development because it directly impacts the country's strategic water governance priorities. The National Water Resource Strategy III (NWRS-3) requires water quality protection and pollution risk management through integrated water resource management to achieve sustainable water supply for all users (Department of Water and Sanitation, 2023). The National Water and Sanitation Master Plan (NW&SMP) emphasizes the need for better water treatment facilities and technical expertise because insufficient funding combined with substandard operations threatens water security (Department of Water and Sanitation, 2018). South Africa has adopted the National Implementation Plan (NIP) for the Stockholm Convention on Persistent Organic Pollutants (2012) to identify and monitor POPs while working toward their complete elimination because of their long-lasting nature and their ability to accumulate in living organisms and their severe threats to human health and environmental systems (Department of Environmental Affairs, 2012)

The policy commitments do not match the actual conditions in underdeveloped areas such as the Eastern Cape. The Buffalo River catchment continues to contain POPs while DWTP managers face challenges with treatment effectiveness and insufficient technical skills which requires immediate research to address this knowledge deficit. The research investigates POP treatment plant performance and water service provider readiness to handle POP risks which directly supports South Africa's national water strategies and Stockholm Convention obligations

The justification of this study further stems from the fact that the Buffalo River serves as the main source of raw water for the catchment treatment plants. These plants produce potable water for the people of King William's Town, Bhisho, Ginsberg, and Mdantsane (O'Keefe et al., 1996). Therefore, it is worth determining how efficient the plants are in removing POPs from the raw water. Furthermore, the question is whether the knowledge of plant managers on POPs is sufficient to enable them to test and understand the presence of POPs in drinking water. A recent Blue Drop report in Key Performance Areas on Water Service Providers for the Eastern Cape has indicated low ratings regarding Technical Management and Drinking Water Quality (DWS, 2023).

1.3 Research aims and objectives

The aim of this research was to understand the removal or non-removal of POPs from DWTPs in the Buffalo River catchment and the attendant capacity of DWTP staff in doing that.

To achieve the aim as stated above the following objectives have been set out:

- Objective 1: Determine the treatment efficiency for POPs from the Buffalo River.
- Objective 2: Ascertain the knowledge of POPs removal by personnel of the Umzonyana DWTP in the Buffalo River Catchment.

1.4 Assumptions and limitations

It is assumed that the technical staff of the DWTPs have relevant and requisite training with regard to the water treatment process and water pollutants. Since there are hundreds of thousands of POPs this study has limited itself to those that have been found in previous studies on the Buffalo River namely organochlorine pesticides (OCP) (Yahaya et al., 2017) Polynuclear Aromatic Hydrocarbons (PAH) (Adeneji et al., 2019) and phenolic compounds and their derivatives (Yahaya et al., 2019). Due to the large size of the catchment, this study concentrated on one DWTP within the Buffalo City Metropolitan Municipality (BCMM) i.e. the Umzonyana Drinking Water Treatment Plant.

1.5 Potential contribution of the research

Findings from this study will give further insight with regards to the raw water quality used by the DWTPs within the catchment subsequent previous studies and how to address them by relevant stakeholders. It would also inform decisions on the need or otherwise for the implementation of a water monitoring programme on POPs by the Department of Water Affairs and Sanitation (DWS). Information from the treated water would state to what extent, POPs are being removed during the water treatment process which may inform some fine-tuning of the treatment process if necessary. The findings of the interview would reveal possible areas of training by the technical staff on the removal of emerging organic pollutants to which POPs belong. In general findings of this study would go a long way to affect policy by the Buffalo River Catchment Management Agency (CMA), the DWS, and assist in evaluating the success of the implementation of the Stockholm Convention on POPs.

1.6 Structure and outline of the dissertation

This dissertation consists of five chapters with the following content:

- The first chapter introduces the background, states the problem statement as well as the rationale behind the study, research aim and objectives of the study, scope of the research, assumptions and limitations, and finally potential contributions of the research.
- Chapter Two constitutes the literature review where an introduction with regards to where the literature was sourced is given. Subsequently, thematic literature was reviewed on POPs, the Stockholm Convention on POPs, POPs pollution globally and in South African water bodies, POPs occurrences in the Buffalo River, a description of the Buffalo River Catchment, conventional water treatment in a DWTP and factors affecting it, and the WHO and the National Drinking water Guidelines, and conclude with the need to determine the removal of POPs by DWTPs within the Buffalo River Catchment.

- Chapter Three details the study areas, sampling sites, interviews and the laboratory and data analysis procedures used.
- Chapter Four presents and discusses the study findings in comparison to other research studies.
- The conclusions, recommendations, and limitations of the study are discussed in Chapter Five.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter provides a theoretical foundation on POPs, essential for comprehending the study. It also explores the water quality issues encountered in South Africa and the Buffalo River Catchment coupled with the processes of DWTPs in producing treated water that abides by regulations governing drinking water compliance in the nation. The focus of the review is on the removal efficiency of DWTPs in the removal of POPs and the role players herein.

2.2 Persistent organic Pollutants - Characteristics, Sources, and Potential Harm

Nordberg et al. (2009) define POPs as an environmentally durable chemical compound that remains stable, has the potential for widespread distribution, can accumulate in the tissues of humans and animals, and may pose substantial risks to both human health and the ecosystem. Instances include tetrachlorodibenzodioxin (dioxin), polychlorinated biphenyls (PCBs), and dichlorodiphenyltrichloroethane (DDT). Persistent organic pollutants are known to be water contaminants that are discharged into the environment as byproducts of various human activities, including industrial processes, waste disposal, oil spills, and the combustion of fuels (Barletta et al., 2019).

Among the various contributors to water pollution, agricultural byproducts, particularly pesticides, play a pivotal role. Certain pesticides within this category possess characteristics that make them endure, stable, and resistant to degradation (Duttagupta et al., 2020). Within this context, surface waters face a heightened susceptibility to contamination by POPs, primarily due to rain transporting these pollutants from distant locations to major water reservoirs (Figure 1). Consequently, the primary concern revolves around the potential infiltration of pesticides into surface and groundwater sources (Vasseghian et al., 2020), with a substantial portion, with at least 76% of pesticides entering surface water and 46% infiltrating groundwater. Nations located in tropical regions endure consistently higher temperatures throughout the year compared to those in temperate and polar zones. The POPs are distributed across various

environmental compartments (depicted in Figure 2) and undergo diverse environmental processes, transforming from one phase to another based on the medium of transportation. The fate of organic pollutants in the environment results from multiple processes such as physical transport, multimedia partitioning, and biogeochemical reactions (Lohmann et al., 2007). Organic carbon significantly influences the fate of POPs, contributing to their spatial, horizontal, and vertical variability in soil (Cousins et al., 1999). Additionally, soot carbon serves as a crucial vector for the transport and partitioning of POPs in marine environments (Lohmann et al., 2005; Persson et al., 2002). The reintroduction of sediment into the water column in a water body is attributed to sediment resuspension (Jurado et al., 2007). Figure 1 below illustrates an example of how pesticides are transported and distributed in the environment.

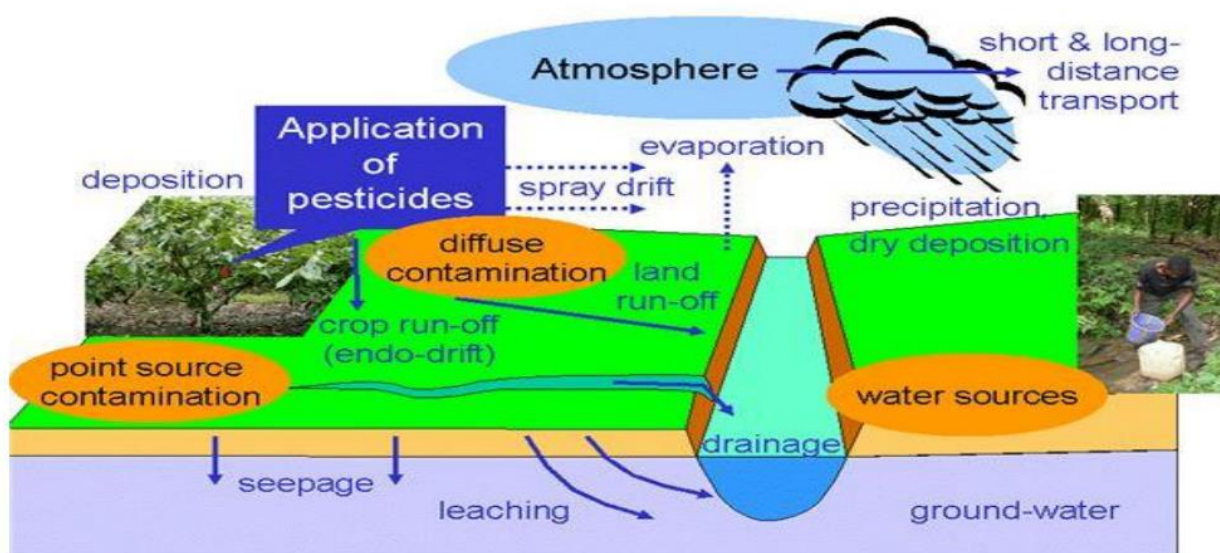


Figure 1: Environmental Fate of POPs in Pesticides (adapted from Achema and Alhassan, 2022).

This is apparent since the utilization of certain pesticides in tropical agriculture, particularly during the warmer and wetter growing seasons, can accelerate the quick dispersal of POPs through both air and water (Ritter et al., 1995).

The key physical attributes that hold significant importance amongst POPs include their solubility in water, vapor pressure, Henry's law constant (H), the partition coefficient between octanol and water (K_{OW}), and the partition coefficient between organic carbon

and water (KOC) (Ritter et al., 1995). Halogenated hydrocarbons represent a significant category of POPs, with organochlorines being the predominant subgroup within this classification (Ritter et al., 1995). Notable members of this organo-halogen group include dioxins and furans, polychlorinated biphenyls (PCBs), hexachlorobenzene, mirex, toxaphene, heptachlor, chlordane, and DDT (Ritter et al., 1995). Halogenated compounds, particularly those containing chlorine, have become deeply ingrained in modern society. The chemical industry extensively employs them for manufacturing various products, including polyvinyl chloride (in millions of tonnes annually), solvents (in several hundreds of thousands of tonnes), pesticides (in tens of thousands of tonnes), as well as specialty chemicals and pharmaceuticals (ranging from thousands of tonnes to kilogram quantities) (Ritter et al., 1995).

What is of even graver concern is the health hazards that POPs pose. For instance, DDT has the ability to accumulate in predatory birds due to its lipophilic properties and exhibits high toxicity to various living organisms, including marine creatures like sea shrimp, crayfish, daphnids, and numerous fish species (Thakur and Pathania, 2020). Health impact on humans is depicted in the Fig. 2 below.



Figure 2: Health effects of Persistent Organic Pollutants (adapted from Thakur and Pathania, 2020).

Persistent organic pollutants act as endocrine disruptors, interfering with hormonal functions and the development of the fetus. Notable pesticides with endocrine-disrupting properties include dieldrin, toxaphene, chlordane, DDT, mirex, and others. These substances have been observed to mimic estrogen and potentially alter the development of sex organs (Geyer et al., 2000; Gregoraszczuk and Ptak, 2013).

Besides being endocrine disruptors POPs also impact reproductive systems. Reproductive systems affected by POP contamination have notorious effects on organs. Reproductive issues linked to exposure to POPs encompass a range of problems such as birth defects, preterm birth, developmental disorders, low birth weight, impotence, reduced fertility, and menstrual disorders. The impact of POP exposure is evident in compromised sperm quality and quantity, altered sex ratios, early puberty in females, pregnancy-related complications, and the occurrence of endometriosis (Hung et al., 2016a;2016b; Odabasi et al., 2016; Jepson and Law, 2016).

Cancer-inducing POPs encompass organochlorine pesticides, PBDEs (polybrominated diphenyl ethers), polychlorinated dibenzo-p-dioxins, dibenzofurans, PCBs, and similar substances. Elevated levels of POPs have been associated with an increased risk of breast cancer, impacting polymorphisms in genes involved in xenobiotic metabolism and estrogen biosynthesis. Notably, women with higher levels of PFOS and perfluorooctanoic acid have been observed to face an elevated risk of breast cancer (Anttila et al., 2016; Tsai et al., 2016).

Yet another health impact of POPs is diabetes. Chlorinated pesticides and PCBs impact the onset of metabolic syndrome, specifically leading to insulin resistance. Persistent organic pollutants like polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans have been observed to contribute to diabetic issues in children (Muñoz-Arnanz et al., 2016; Lammel et al., 2016).

In addition to obesity contributing to cancers, osteoarthritis, heart diseases and other ailments, obesity which is a significant health concern in the 21st century, is persistently rising among both adults and children. The elevated accumulation of POPs at high concentrations raises the risk of obesity and dyslipidemia (Fujii et al., 2007; Ugranli et al., 2016).

Lastly, heart diseases which include cardiac arrhythmias, and most especially hypertension which is more prevalent in low- and middle-income countries have POP as a contributor (Thakur and Pathania, 2020). Consuming food contaminated with Persistent Organic Pollutants (POPs) is linked to the onset of health issues, including diabetes and obesity. POPs, being lipophilic, accumulate in high concentration lipoproteins, leading to various cardiovascular problems and diseases. Elevated concentrations of dioxins and PCBs have been associated with conditions such as high blood pressure, metabolic syndrome, increased triglycerides, and glucose intolerance (Ren et al., 2018; Mwakalapa et al., 2018).

2.3 Physical and chemical factors that affect distribution of POPs in water bodies

Various physical and chemical factors regulate the dispersion of organic substances within the aqueous phase. This may partly explain the wide variation in the concentration of organic compounds in surface waters and groundwaters globally and at different times (Spurgeon et al., 2022). Various literature reviews examine the dispersion of hydrophobic organic substances in natural settings such as air, soil, and water (Jonker and Koelmans, 2002). However, very little data are available concerning the behaviour and distribution of POPs in a particular type of water body i.e. flowing water bodies. This is important because lotic systems are known to be greatly affected by river hydrodynamics, regarding, for example, the retention time of the water, following classical formulas, and the settling velocity of particles or aggregation states, due to the amount of shearing force and turbulence in these complex systems, allowing the deposition of the suspended material in most cases along the outer banks (Kumar et al., 2021).

2.4 Hydrodynamics of water bodies

The hydrodynamics of Persistent Organic Pollutants (POPs) describes the movement patterns of toxic substances through aquatic systems because of water movement processes including currents and turbulence and sediment interactions. The mode of distribution of POPs varies depending on factors such as total flow, flow depth, flow

character, maximum flow velocity, and inclination (Kumar et al., 2021). There are fixed characteristics for complete mixing (along a transect oriented towards flow) and incomplete mixing (labile and conservative) (Kellerman et al., 2023).

It is also worth noting that the chemistry of the river and the flow hydrodynamic states govern the residence time and corresponding equilibrium due to the presence of a boundary layer corresponding to the depth of flow (Algaidy and El Shrif, 2023). The hydrophobic nature of POPs leads them to bind with suspended particles and sediments which determines their movement based on water flow and particulate matter behavior (Jones and De Voogt, 1999).

2.5 The Stockholm Convention on POPs

Based on the environmental and health impacts of POPs as discussed earlier brought into organizing the Stockholm Convention of POPS. The Stockholm Convention on POPs is an international treaty established to address and control the production, use, and release of certain persistent organic pollutants. The convention was adopted in 2001 and entered into force in 2004. The primary objective of the Stockholm Convention is to protect human health and the environment from the adverse effects of POPs (UNEP, 2009).

The Stockholm Convention identifies and lists specific POPs, including well-known substances like DDT, PCBs, and dioxins. The treaty aims to eliminate or restrict the production and use of these substances, promote the development of alternatives, and facilitate the environmentally sound management of existing stockpiles and waste (UNEP, 2009). Key objectives include:

- Implement Best Available Techniques (BAT) and Best Environmental Practices (BEP) for controlling emissions.
- Encourage national implementation plans (NIPs) to identify and address local POPs issues.
- Protect human health, especially vulnerable populations like infants and pregnant women, from POPs exposure.

- Promote international cooperation in research, information exchange, and policy development.

Countries that are parties to the Stockholm Convention commit to taking measures to eliminate or reduce the release of POPs into the environment. The treaty encourages international cooperation in research, information exchange, and the implementation of best practices to minimize the global impact of persistent organic pollutants. The convention has played a crucial role in addressing the transboundary nature of POPs and promoting concerted efforts to mitigate their harmful effects on a global scale.

2.5.1 South African National Implementation Plan for the Stockholm Convention on POPs

South Africa, as a signatory to the Stockholm Convention on POPs, has taken various steps to implement the provisions of the Convention. The plan was developed with input from various stakeholders, including government departments, industry representatives, NGOs, and research institutions. This has been done through the following measures:

National Implementation Plan (NIP): South Africa has developed and started implementing a National Implementation Plan that outlines the country's strategies and actions for reducing or eliminating the production, use, and release of POPs (Fischer et al., 2012). It provided details on risk assessment, import/export controls, training for pesticide use, and promoting the role of NGOs in the management of the environment (InforMEA, 2012)

Legislation and Regulations: South Africa has enacted national legislation and regulations to control and regulate the production, use, import, export, and disposal of POPs. This includes the Hazardous Substances Act, the National Environmental Management: Waste Act, and other relevant by-laws (Fischer et al., 2012).

Inventory of POPs: South Africa has developed an inventory of POPs to identify sources of these pollutants in the country and to track their levels and trends over time. (Fischer et al., 2012).

Monitoring and Reporting: South Africa has tried establishing monitoring programs to assess the levels of POPs in the environment, in food, and in human populations but

not on a general scale. However, specific studies for instance were completed on the Umgeni River has been a form of monitoring. More so when the National Implementation Plan itself concedes and admits that South Africa is the number one source of unintentional PCDD/Fs amongst 47 sub-Saharan countries and further advocates for specific POPs monitoring in water and the development of guideline values for POPs in water which still has not been completed (Fischer et al., 2012).

Capacity Building: South Africa has undertaken capacity-building activities to raise awareness about POPs among policymakers, industry stakeholders, and the general public. This includes training programs, workshops, and outreach activities. (Fischer et al., 2012). It further emphasized the strengthening of institutional capacity on the chemical safety standards and safe disposal of POPS. (InforMEA, 2012)

Research and Development: South Africa supports research and development initiatives aimed at finding alternatives to POPs, as well as technologies for the environmentally sound management of these chemicals (Fischer et al., 2012).

International Cooperation: South Africa collaborates with other countries and international organizations to exchange information and best practices on POPs management and to strengthen regional and global efforts to eliminate these pollutants (Fischer et al., 2012).

These are some of the measures that South Africa has taken to implement the Stockholm Convention on Persistent Organic Pollutants. The country continues to work towards reducing the impact of POPs on human health and the environment through these and other initiatives.

2.6 Studies of POPs in South African water resources

Past research supported by the Water Research Commission (WRC) indicated the presence of dioxin-like POPs in South Africa's aquatic environments, with the most elevated concentrations observed according to Roos et al (2011) in industrialized regions. Another important study that was done on POPs in South Africa was on the Umgeni and Mzunduzi Rivers in 2016. Like numerous other waterways across South

Africa, these two rivers face a looming danger of pollution. Notably, they play a crucial role in providing water to the nearby communities. Consequently, the research endeavoured to examine and track the levels, alongside the seasonal and geographical fluctuations of specific organic contaminants within these rivers as they flow through their respective paths (Moodley et al., 2016).

Christiaan et al. (2015) conducted tests on water from municipal water treatment plants (potable water) across various cities and towns in South Africa, as well as on tap water from various neighbourhoods in Bloemfontein, screening for 700 emerging contaminants. The study identified 28 different pollutants, including herbicides, pharmaceuticals, industrial chemicals, antifungals, and antibacterial agents. Their studies identified two common herbicides namely terbuthylazine and atrazine in most of the municipal drinking waters across the country (Christiaan et al., 2015). All detected CECs were in ng/L range—thousands to millions of times lower than acute toxicity levels.

Wood et al. (2015) collected surface water samples from various locations across South Africa, including dams, rivers, wastewater treatment facilities, and tap water. They tested for a range of drugs used in HIV treatment (such as abacavir, didanosine, efavirenz, lamivudine, stavudine, zalcitabine, zidovudine, nevirapine, indinavir, lopinavir, ritonavir, tenofovir, and xanthines) and for caffeine. They discovered that three of the drugs, namely nevirapine, lopinavir, and zidovudine, were consistently detected across the samples. The highest average concentrations were noted for stavudine, nevirapine, and zidovudine, all of which were found at levels in the nanograms per liter (ng/L) range.

The sources of POPs pollution in South African rivers are diverse and include both point and non-point sources. Industrial activities, such as manufacturing, mining, and chemical production, are major contributors to POPs contamination. For instance, a study by Amdany et al. (2014a) identified industrial discharges as significant sources of PCBs and OCPs in rivers in Gauteng and Mpumalanga provinces, respectively. In addition to industrial sources, agricultural practices, such as pesticide use and livestock farming, contribute to POPs pollution through runoff and leaching of chemicals into water bodies. Urban areas also contribute to POPs contamination through stormwater runoff carrying pollutants from roads, landfills, and residential areas. Amdany et al. (2014) employed the use of semipermeable membrane devices (SPMDs) as passive

sampling tools. These devices were used to collect freely dissolved polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and organochlorine pesticides (OCPs) from the water to study seasonal variations in their concentrations.

Another POP study conducted on the Buffalo River was the one done by Yahaya et al. also in 2017 and 2019 which gathered that in all locations sampled in two seasons, the levels of OCPs in the study area consistently exceeded the 100 ng/L limit set by the United States Environmental Protection Agency (USEPA). (Yahaya et al., 2017; 2019). Their study included the subjection of water samples under liquid-liquid extraction to isolate OCPs and phenolic derivatives, followed by separation and quantification of the compounds using gas chromatography with electron capture detection. These two studies established the likely pollution of the Buffalo River by POPs. The testing methodology of Yahaya et al. (2017; and 2019) used Gas Chromatography similar to what was employed in this study; however, that of Amdany et al. (2014) used Semipermeable Membrane Devices (SMPDs) as passive samplers in investigating the presence of POPs.

2.7 Conventional drinking water treatment plant

Conventional drinking water treatment plants (DWTPs) are essential for delivering safe and clean drinking water to communities globally. These facilities employ a variety of physical and chemical methods to purify water from natural sources like rivers, lakes, and reservoirs. Measures of conventional drinking water treatment typically can remove the contaminants, but it depends on the characteristics of the contaminants and the nature of the treatment (Gilca et al., 2020). This brief review will discuss the existing research on the primary processes used in DWTPs, such as coagulation, flocculation, sedimentation, filtration, and disinfection. It will also evaluate the efficiency of these processes, the challenges encountered in water treatment, and the recent trends and developments in the industry. A typical conventional DWTP and the processes that take place is depicted in Figure 3.

WATER TREATMENT

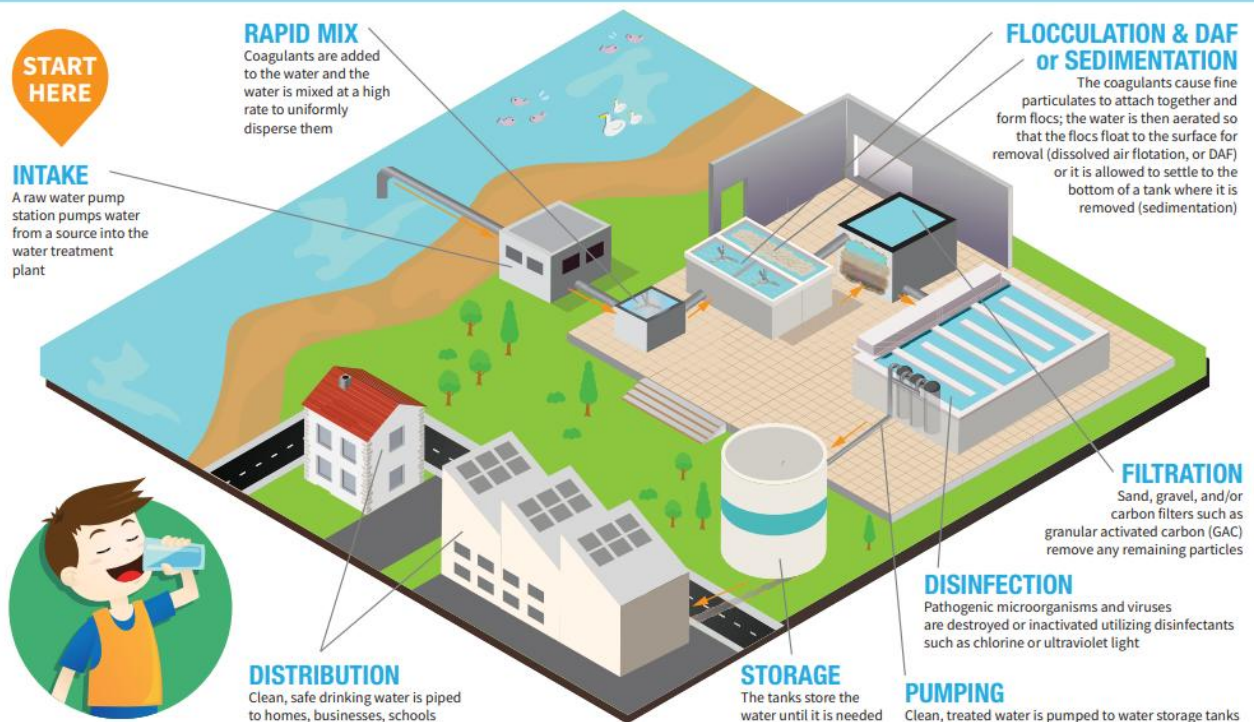


Figure 3: Processes in a Conventional Drinking Water Treatment Plant (Tata and Howard, 2015).

Coagulation and Filtration

In the coagulation stage, chemicals like alum or ferric chloride are introduced to the untreated water to destabilize suspended particles and promote their clustering into larger flocs. Flocculation involves gently stirring the water to aid in the formation of bigger flocs, which can be more easily extracted during sedimentation (Schutte and Focke, 2006). Research by Walsh et al. (2009) revealed that selecting the appropriate coagulant and adjusting the mixing intensity during flocculation significantly affects the size and strength of the flocs, which in turn influences the efficiency of the following treatment steps. Moreover, fine-tuning the coagulant dosage and mixing conditions can enhance the removal of organic substances and other impurities.

In agreeing with the above statement, the research findings from Tahraoui et al. (2024) demonstrated that coagulation–flocculation treatment effectively removes various raw water pollutants when coagulant dosage and mixing conditions were optimized for maximum contaminant removal.

Sedimentation

Sedimentation consists of letting the flocs created during coagulation and flocculation settle out in a sedimentation basin. The clear water is then extracted from the top of the basin (Schutte and Focke, 2006). A study by Sharp et al. (2006) showed that using computational fluid dynamics (CFD) modelling can optimize the design and operation of sedimentation basins. The research indicated that refining the flow patterns within sedimentation basins can improve particle removal efficiency and minimize the risk of short-circuiting.

Filtration

Following sedimentation, the water is filtered through layers of sand, gravel, and activated carbon to eliminate any remaining particles and impurities. Filtration plays a vital role in effectively removing microorganisms and other contaminants (Schutte and Focke, 2006).

Research by Sillanpää et al. (2018) emphasized the significance of optimizing filtration media and operational parameters to enhance filter efficiency and extend its life. Additionally, advanced filtration techniques like ultrafiltration and nanofiltration have been investigated as possible replacements for conventional sand filtration for improved removal of pathogens and micropollutants.

Disinfection

Disinfection is the final stage in water treatment, using chemical or physical agents to destroy or deactivate harmful microorganisms. Common disinfectants include chlorine, chloramine, and ozone (Schutte and Focke, 2006).

A study by Krasner et al. (2009) investigated the formation of disinfection by-products (DBPs) during chlorination and the related health risks. The research stressed the importance of balancing effective disinfection with reducing DBP formation by adjusting disinfectant dosage and contact time. Alternative disinfection methods, such as ultraviolet (UV) light and advanced oxidation processes, have been explored for their potential to offer effective disinfection without generating harmful by-products.

2.8. Removal of POPs by conventional DWTPs and other processes (PAH, PCB and OCP)

Bioaccumulation of POPs in humans primarily occurs through the consumption of contaminated drinking water and food (Jones, 2021). Therefore, it is crucial to assess the effectiveness of conventional drinking water treatment plants (DWT) in removing these chemicals.

Various methods have been implemented to decrease these pollutants which largely centre around using water treatment plants as a mechanism to prevent human exposure to these pollutants via water. This involves developing understanding of the presence and transport of these pollutants in water together with the final piece of treatment which is to provide a safe drinking supply that is clear of these pollutants (Mukhopadhyay et al., 2022).

Conventional drinking water treatment plants are designed to treat water from surface water sources and shallow ground water which have been contaminated by organic, inorganic compounds, and microorganisms (Schutee and Focke, 2006). The general objective of the treatment of surface waters and shallow groundwaters is the removal of all materials that may cause harm to the public or may make the water unfit to drink. This often involves removing contaminants that affect the colour, taste, and odour of the water, in addition to those toxic materials that do not produce sensory effects in the water, and the microorganisms often responsible for disease (Hasan and Muhammad, 2020).

Moreover, to ensure the production of safe water, the decentralized treatment train must be capable of handling sudden changes in the feed water. Additionally, to consistently

guarantee safe water, the personnel managing the treatment system must be aware of the contamination risks from the water source to various users and must evaluate the necessary actions to address these risks (Verlicchi and Grillini, 2020) in the various stages of drinking water treatment.

Coagulation and Flocculation

Coagulation and flocculation are widely used methods for eliminating particulate matter and some dissolved organic pollutants. Chemical coagulants like alum or ferric chloride are introduced to raw water to destabilize and clump suspended particles, including organic pollutants. Flocculation then promotes the creation of larger flocs for easier removal. Research by Bratby (2016) revealed that employing advanced coagulants such as polyaluminum chloride and chitosan-based coagulants can enhance the removal of specific POPs from water during coagulation and flocculation. Also the combination of organically modified clay coagulant aids with alum or PAC results in 71–100% pesticide removal (e.g., DDT, lindane) from water according to Shabeer et al. (2014).

Furthermore, choosing the right coagulant and optimizing dosage and mixing conditions can lead to improved removal of organic pollutants.

Advanced Oxidation Processes (AOPs)

Advanced oxidation processes (AOPs) employ strong oxidizing agents to degrade persistent organic pollutants into less harmful substances. These methods encompass ozonation, UV-based oxidation, and combinations like UV/hydrogen peroxide. Research by Esplugas et al. (2007) showcased AOPs' ability to break down different POPs in water, including chlorinated solvents and endocrine-disrupting compounds. The study noted that adjusting process parameters such as oxidant dosage and contact time can improve the efficiency of POP removal. Also Daramola and Adebayo (2022) gives credence to the role of AOPs in POPs degradation through the generation of reactive hydroxyl and sulphate species which tend to break aromatic and halogenated bonds.

Membrane Filtration

Membrane filtration techniques, including reverse osmosis (RO) and nanofiltration (NF), are very efficient at eliminating persistent organic pollutants from water. These methods work by pushing water through a semi-permeable membrane that captures pollutants while permitting clean water to pass through.

Nghiem et al., (2021) showed strong effectiveness of NF and RO membranes in removing a range of POPs such as herbicides and pharmaceuticals. Nevertheless, challenges like membrane fouling and high energy consumption need to be addressed to enhance the long-term sustainability of these methods.

Granular Activated Charcoal has been shown to be more effective at removing organic contaminants than other methods of conventional water treatment and may be capable of removing some synthetic organic chemicals to levels that are approaching the detection limit. Adsorption with GAC is an equilibrium driven process, thus more polar or water-soluble contaminants tend to be adsorbed less readily than non-polar substances. (Norra and Radjenovic, 2021). Studies investigating the effect of GAC characteristics on POP adsorption have produced conflicting results. Generally, though, it has been found that better removal of POPs is achieved by using GAC with a smaller particle size, higher surface area, and lower pore volume than with GAC that has been physically or chemically treated to change its surface chemistry (Titchou et al., 2021).

Studies on PAH Removal

Ozonation has been shown to be effective in removing PAHs from water, which is a step ahead of conventional water treatment (Li et al., 2021). Regarding physicochemical treatment methods, the most frequently used techniques for PAH removal from water include: membrane filtration (such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis) (Li et al., 2019), adsorption (Dai et al., 2020), advanced oxidation processes (including ozonation, electrochemical oxidation, Fenton reagents, and UV) (Badawy et al., 2006; Gaurav et al., 2021), and chemical precipitation (Smol and Włodarczyk-Makula, 2017).

Studies On PCB Removal

In general, it has been found that the more hydrophobic the PCB compound, the more likely it is to be removed from the water phase (Burkhard et al., 1985). Activated carbon is a commonly employed technique for the removal of both inorganic and organic hazardous chemicals through the process of adsorption (Sil et al., 2020). At the Hunters Point Shipyard near San Francisco, a pilot study showed that over a 60-month period, around 73% of PCBs were transferred from sediments to water bodies, primarily due to the introduction of activated carbon (3.7% dry weight) into the sediment (Choi et al., 2009). Another study on the removal of PCB was by using ultrasonic radiation and it demonstrated that it could achieve PCB removal efficiencies exceeding 90% from various environmental matrices (Lu et al., 2009). Other removal methods that have been studied include electrokinetic remediation (Acar et al., 1993) and magnetic nanomaterials (Huang et al., 2017).

Studies on OCP Removal

Nanoparticle adsorbents and carbon-based adsorbents display nearly 100% effectiveness in eliminating pesticides from aquatic environments. A review of existing literature determined that two types of surface-water treatments, chemical coagulation and slow sand filtration, are effective primarily in removing pesticides with low solubility, such as organochlorine compounds (Verma et al., 2017, and Kouras et al., 1998). Sahmarani et al. (2021) conducted research on activated carbon made from *Phoenix dactylifera* date stones to show its effectiveness in OCPs removal through its large surface area and porous structure. Researchers at the University of South Australia studied the process of reducing powdered activated carbon particle size to boost its organic pesticide adsorption capacity which resulted in better drinking water contaminant removal (Duan et al., 2024). The research demonstrates how scientists continue to develop water treatment methods for removing dangerous pesticides from water sources (Duan et al., 2024).

2.9 South African Drinking Water Guidelines (SAN 241), South African Water Quality Guidelines and WHO Drinking Water Guideline on POPs (PAH, PCB and OCP)

Polycyclic aromatic hydrocarbons (PAHs), PCBs, and organochlorine pesticides (OCPs) are examples of POPs that can contaminate drinking water sources and pose risks to human health and the environment. This review explores the regulations established by the South African Drinking Water Guidelines (SANS 241), South African Water Quality Guidelines, and World Health Organization (WHO) guidelines on drinking water, focusing on the presence and control of PAHs, PCBs, and OCPs.

Polycyclic Aromatic Hydrocarbons (PAHs)

The PAHs are organic compounds that can be formed during the incomplete combustion of organic matter and are also present in fossil fuels.

- SANS 241: The South African National Standard for drinking water quality sets a limit for total PAHs in drinking water at 0.01 mg/L (10 µg/L) (John and Trollip, 2009). This overall limit for all PAHs aims to safeguard public health from the harmful and cancer-causing effects of PAHs (DWA, 2015).
- South African Water Quality Guidelines: These guidelines offer health-based standards and monitoring advice for PAHs in sources of drinking water (Department of Water Affairs and Forestry, 1996). The minimum limit is 0.00017 µg/L (DWAF, 1996).
- WHO Water Quality Guidelines: Among the polycyclic aromatic hydrocarbons (PAHs), only Benzo[a]pyrene (BaP) had enough substantiated toxicological evidence to establish a guideline value. A health-based guideline value of 0.00001 mg/L was recommended for BaP (WHO, 2022).

Polychlorinated Biphenyls (PCB)

According to the World Health Organization (WHO, 2022), PCBs are a group of man-made organic chemicals which were manufactured and used in a number of different industries throughout the world.

- SANS 241: The South African Water Quality Guidelines for drinking water recommend concentrations several orders of magnitude lower than toxic levels, although they do not specify exact values for individual or total PCBs (DWA, 2015).
- South African Water Quality Guidelines: The South African Water Quality Guidelines acknowledges that PCBs are pollutants that can contaminate water sources through industrial and agricultural activities and should not exceed 0.000045 µg/L (DWAF, 1996).
- WHO Water Quality Guidelines: The tolerable reliable dose (TRD) for the induction of enzyme production is the critical effect for the establishment of a guideline value for PCBs in drinking water. The nature of the dose-response relationship between the intake of PCBs and the increase in enzyme production is not known; therefore, it is not possible to estimate a safe exposure level to PCBs. However, the situation has been that WHO has recommended a value of 10 µg/L for drinking water (WHO, 2022).

Organochlorine Pesticides (OCP)

Organochlorine pesticides, such as DDT, aldrin, dieldrin, and chlordane, are known for their high lipid solubility and persistence, qualities that once made them highly effective for sustained pest management. These substances were used in agriculture to safeguard crops against numerous pests, and in public health initiatives, they were mainly employed to control mosquitoes and prevent malaria and other diseases transmitted by vectors (ATSDR, 2002).

- SANS 241: Organochlorine pesticides, including DDT, dieldrin, and aldrin, are classified as persistent organic pollutants (POPs) known for their environmental and health risks. The SANS 241 standard is designed to mitigate the dangers posed by these pesticides, encouraging their safe and responsible application.

Some of the key requirements of SANS 241 (SABS, 2015) include:

- ❖ **Safe Handling and Storage:** Pesticides should be kept in a secure and well-ventilated space, separate from any food and animal feed (SABS, 2015).
- ❖ **Transportation:** Pesticides need to be transported following regulatory guidelines and must include a safety data sheet (SABS, 2015).
- ❖ **Disposal:** Pesticides should be eliminated via a certified waste management facility (SABS, 2015).
- ❖ **Residue Limits:** The standard sets out maximum allowable limits for pesticide residues on food and in the environment (SABS, 2015).
- ❖ **Packaging and Labelling:** Pesticides need to be properly labelled and packaged as per regulatory standards and must come with safety instructions and warnings (SABS, 2015).
- ❖ **South African Water Quality Guidelines:** The threshold values in the SAWQG for OCP chemicals are - Aldrin and dieldrin: 0.03 µg/L DDT: 1.0 µg/L, Endosulfan: 0.1 µg/L, Heptachlor: 0.1 µg/L, Heptachlor epoxide: 0.1 µg/L, Hexachlorobenzene: 0.05 µg/L, Lindane: 2.0 µg/L, Methoxychlor: 10.0 µg/L, Mirex: 0.1 µg/L and Toxaphene: 0.4 µg/L (Department of Water Affairs and Forestry, 1996).
- ❖ **WHO Drinking Water Quality Guidelines:** The guidelines stipulate that organochlorine pesticides should be detected at extremely low levels, typically in the range of parts per billion (ppb) or even parts per trillion (ppt), to ensure the safety of drinking water. These stringent limits are based on scientific evidence about the toxicity of each pesticide and its potential to cause health issues such as cancer, neurological disorders, and reproductive problems. Specifically, the WHO guidelines offer detailed limits for individual pesticides. For instance, the threshold for HCH (Chlordane), a well-known organochlorine, is set at very low concentrations for example 0.2 µg/L.

2.10 Factors that influence the efficiency of a drinking water treatment plant

Several factors affect the efficiency of a water treatment plant, including season, raw water quality, plant design, the availability or level of training of plant operators, adherence to applicable legal standards, chemical dosage, and financial and management challenges. A crucial step in providing safe drinking water is selecting the

best available water source. Selecting the optimal water source is a critical initial step in guaranteeing the provision of safe drinking water. LeChevallier et al. (1981) noted that the quality of raw water significantly impacts both the effectiveness and the expense of the treatment process. Furthermore, Sasakova et al. (2018) and Edokpayi et al. (2017) discovered that the majority of surface water sources are of poor quality, requiring extensive treatment to produce safe drinking water.

Additionally, many small water treatment plants employ operators who have a limited technical understanding of the treatment processes. This is important since the expertise and abilities of process controllers are crucial not just for the daily management of a water treatment plant, but also for ensuring compliance with national water quality standards (Sorlini et al., 2015). For instance, this often results in either too much or too little coagulant and chlorine being used (Momba et al., 2009). This is further attested to by the argument that suggests that both during apartheid and in the post-apartheid era, the state did not sufficiently develop the technical expertise at the municipal level necessary for constructing and managing basic water and sanitation services (Koelble and Lipuma, 2010).

CHAPTER 3 METHODS

3.1. Introduction

This study focused on water quality in terms of persistent organic pollutants and aimed to provide pertinent information on the levels of these pollutants, examine whether they are present in drinking water resources, and examine treatment options that may be implemented to reduce these levels. This was carried out with the aim that it will provide data, which may be employed to alleviate the health of the river and hence, the quality of water resources in the future.

3.2. Research approach and design

The approach to this study as the name suggests was a case study where the researcher investigated the POP removal by a DWTP within the Buffalo River Catchment. This had a direct bearing on the research question which was “What is the removal efficiency of POPs by DWTPs in the Buffalo River Catchment”? The study involved the identification (qualitative) and measurement of concentration (quantitative) of POPs in raw and treated water from a DWTP within the Buffalo River catchment. The researcher's adoption of this method agreed both with Yin (2014) and Creswell and Creswell (2003) who described the mixed method as the collection and analysis of both qualitative and quantitative data with the benefits being richness and completeness, better contextualization, robustness of findings, and pragmatism (Yin, 2014) and benefit of complementarity, triangulation, new perspectives and expansion of the scope of research (Creswell et al., 2003).

3.3. Case study selection

According to Yin (2014), case studies produce an in-depth understanding of the subject matter, practical relevance since it addresses real-life problems, and adaptability to different research questions, contexts, and disciplines. The research study involved a scientific component that answers the ‘what’ as in the efficiency of the DWTP in

removing POPs and a social component that answers the 'why' as in the reasons for the status of the DWTP and hence this approach is best suited for this research. This selection would allow for ascertaining the potential pollution of the Buffalo River by POPs and the performance of the Umzonyana DWTP in removing POPs from the raw water.

Rivers naturally accumulate contaminants as they flow downstream due to various anthropogenic activities (Champeau et al., 2020). The Buffalo River shows similar patterns to other water bodies because studies have found elevated levels of POPs in its lower sections. The research by Yahaya et al. (2017) showed that organochlorine pesticides (OCPs) were detected throughout the Buffalo River while their concentrations rose as the river approached the estuary. The research by Yahaya et al. (2018) detected substantial polychlorinated biphenyls (PCBs) concentrations in the river's downstream areas. The research shows that downstream water contains higher pollutant levels which makes the Umzonyana DWTP's site suitable for testing treatment effectiveness under difficult conditions.

3.4 Description of the Buffalo River Catchment

The Buffalo River passes one of the most densely populated regions along the eastern coast of southern Africa and not only supplies water but also serves as a channel for waste disposal (O'Keefe et al., 1996; Netshithothole et al., 2024). The catchment area sustains a fast-growing population, with the main towns being King William's Town, Zwelitsha, Mdantsane, and East London, all of which rely on the river for their water supply (O'Keefe et al., 1996). The river originates in the Amatole Mountains and flows southeast for 125 km until it reaches the sea at East London. As seen in Figure 4, it can be divided into three sections: the upper reaches, extending to King William's Town, include the mountain stream flowing through montane forest to Maden Dam, followed by the foothill zone passing through agricultural areas downstream of Rooikrans Dam; the middle reaches consist of the urban and industrial area from King William's Town/Zwelitsha to Laing Dam, along with agricultural land downstream of Laing; and the lower reaches, downstream of Bridle Drift Dam, feature coastal forests and an estuary that forms East London's harbour (O'Keefe et al., 1996).

The primary tributaries of the Buffalo River are the Mqgakwebe, Ngqokweni, and Yellowwoods Rivers, all of which join the main river upstream of Laing Dam (CES, 2003). The average annual rainfall is 736 mm (O’Keeffe et al., 1996), ranging from 500 to 2000 mm (Palmer and O’Keeffe, 1990), with notable seasonality—rainfall in summer is roughly twice that of winter (O’Keeffe et al., 1996). The river features clear, turbulent water starting in the mountain areas, with high-quality water in the upper reaches providing about 40% of the water for this catchment area (O’Keeffe et al., 1996).

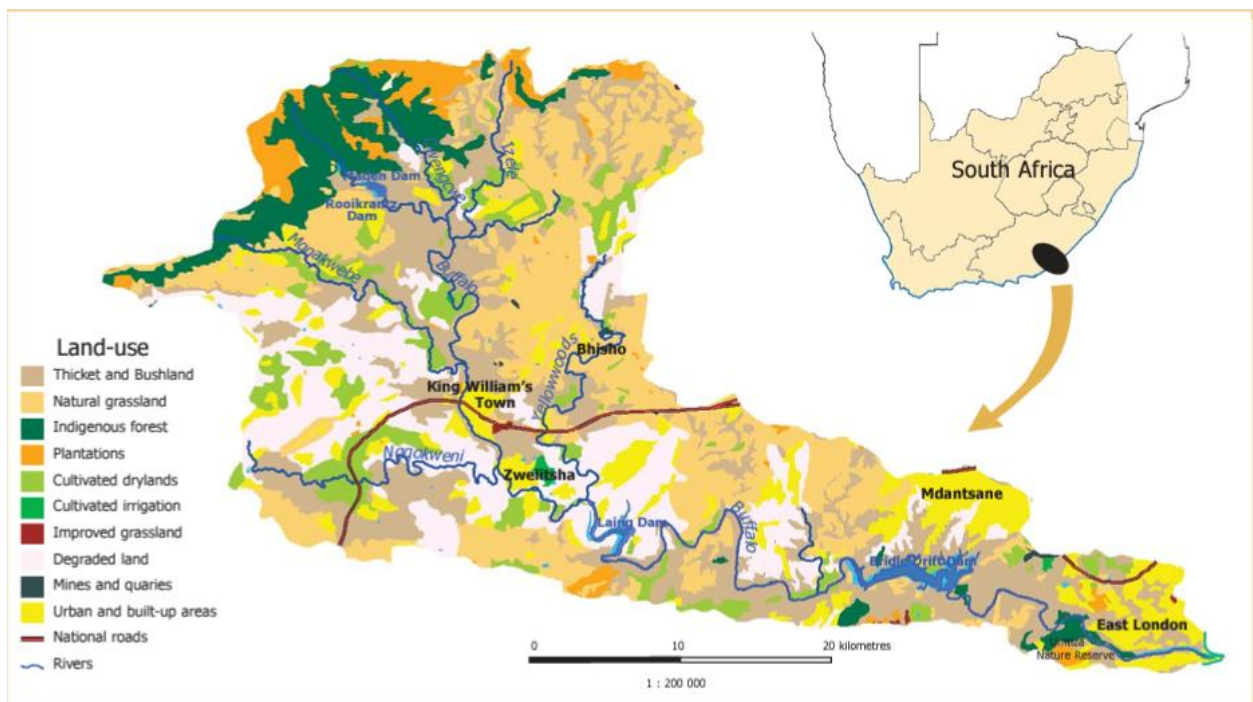


Figure 4: The Buffalo River Catchment (DWS, 2004).

The Umzonyana (Umzoniana) Drinking Water Treatment Works (UDWTW) was built in the early 1900s as the main water supply to the borough of East London and has been progressively enlarged from the initial small, slow sand filtration plant to the existing sophisticated treatment works with an output of 120 Ml/d of purified water (Infrastructurenews, 2013). The treatment plant/work has a holding reservoir with feed water from the Buffalo River as depicted in Figure 5.



Figure 5: Google Earth Map of Umzinyana Water Treatment Plant.

The Umzinyana DWTP stands as an ideal selection because it possesses both a strategic position and access to reliable water sources. The Buffalo River serves as the main water source for Umzinyana DWTP while also being the central focus of the investigated catchment area. The direct water supply relationship between this treatment plant and the Buffalo River makes it an ideal location to study both the entry points of contaminants and the effectiveness of water treatment processes.

The selection of this DWTP as the research site is appropriate because of its significant role in the region. The Umzinyana DWTP operates as one of the biggest drinking water treatment facilities in the Eastern Cape region because it provides water supply to Buffalo City Metropolitan Municipality and East London and nearby communities. The research at this facility produces results that directly impact public health because it serves a substantial number of people.

The Buffalo River catchment faces multiple pollution threats because it receives contaminants from urban runoff and industrial waste and agricultural pesticides and informal settlement waste. The presence of POPs in mixed-use catchments requires the

Umzonyana DWTP to serve as a critical site for studying their occurrence and treatment effectiveness.

The practical limitations of time and resources and logistical challenges make it impossible to perform complete monitoring at multiple treatment plants during a Master's dissertation. The researcher can perform detailed sampling and analysis at one strategically important DWTP because it provides access for a complete study within the boundaries of a Master's degree research period.

The research conducted at Umzonyana DWTP will help develop catchment management plans while ensuring South African drinking water standards and supporting national water and sanitation policies through the National Water and Sanitation Master Plan and NWRS-3.

3.5. Sampling process

Raw water taken from Umzonyana reservoir at -32.984636, 27.819706 and treated water samples at -32.984811, 27.822203, on the 21st of August 2024 were collected in triplicate using clean, sterile containers made of glass or amber 2.5 L Winchester glass bottles that had aluminium-lined caps (USEPA, 2019). A grab sampling technique was employed, which involves taking a single sample at a particular moment and location (WHO, 2011). Samples from the surface water were collected while ensuring they were collected about 10-15 cm beneath the surface (ISO, 2019). The samples were acidified with concentrated sulfuric acid to lower the pH (USEPA, 2019) and thereafter hexane to facilitate the extraction of POPs (USEPA, 2019). The sample to be tested for PAH was not acidified. The single event samples were then kept in a cold dark cooler box to avoid any degradation (USEPA, 2019).

3.6. Sample size

Samples were collected in 2.5 L amber bottles. The samples were kept chilled at 4°C in cooler boxes during transport to the respective laboratories and maintained at this temperature until analysis. Sample preparation and preservation were done according

to USEPA methods 3535A (Solid Phase Extraction) (Nelson, 2003) and 8270 (Analysis of Semi-volatile Organic Compounds) (Nelson, 2003).

3.7. Data collection

Qualitative Data

Data was obtained from the Gas Chromatography and Mass Spectroscopy test results of raw water from the Umzonyana reservoir (Buffalo River) and treated water samples from the Umzonyana DWTP for analysis. The qualitative analysis report provides data that identified compounds present in the test sample by way of the name of compound, retention time, and CAS number. The analysis showed that compounds survive treatment processes thus revealing current purification method constraints. The information serves to enhance treatment optimization and regulatory compliance and protect water quality.

Quantitative Data

The quantitative analysis report also provides data that showed the concentrations of the targeted compounds in µg/L, in addition to their detection and quantitation limits. The combination of quantitative data from GC/MS analysis of untreated and treated water samples with questionnaire responses from drinking water treatment plant personnel creates a complete understanding of water quality and operational effectiveness. The quantitative analysis reveals which treatment-resistant compounds need supplementary mitigation approaches. The questionnaire data offers essential operational context about plant operations and maintenance practices chemical usage and staff knowledge of potential contaminants. The combined data sources enable a complete evaluation of the treatment process which supports better system performance and staff training and decision-making to improve drinking water supply safety and reliability

3.7.1. Water Quality Data

To obtain water quality data the POPs were extracted from the water sample using Solid Phase Extraction (SPE) which involves the passing of the sample through a

cartridge containing a sorbent material (USEPA, 2019), cleaned using gel permeation and then analysed using GC-MC (USEPA, 2019). Samples were tested at the SANAS ISO/IEC 17025-accredited water analysis Wear Check laboratory in Johannesburg for POPs.

3.7.2. Survey Data

The qualitative aspect of the research design, through the administering of a questionnaire, was employed to gather data from workers at the Umzonyana drinking water treatment plant. Purposive sampling was applied to choose selected participants who were interviewed using a semi-structured guide, which provided both consistency and flexibility in the discussions. The data obtained from the questionnaire in the appendix speaks to the general operation of the DWTP, and capacity to remove POPs, and the knowledge of the personnel in POPs removal from raw water in the production of potable water.

3.8. Data analysis

The data from the GC-MS (Gas Chromatography-Mass Spectrometry) was processed using Visual Inspection which examined the chromatogram and mass spectra for peak identification, which helped in identifying and quantifying the Persistent Organic Pollutants (POPs) found in the samples (Innovatech lab, n.d). Compounds were identified by analysing their retention times and mass spectra, and confirmation was made using authentic standards (Innovatech Labs, n.d,). The GC-MS data for both the raw and treated water samples were compared to detect any variations in the types and concentrations of POPs present in each sample. The analysis also included a comparison of the results with water quality standards and local and international regulatory agency limits.

With regard to the survey or interview data, thematic analysis was employed to detect and categorize themes and patterns within the data. This analysis concentrated on exploring the experiences, challenges, and strategies of workers involved in the removal of POPs from raw water. Microsoft Excel was used for statistical analysis and was also used to quantify responses to put nominal values to the responses given.

3.9. Participant selection

Personnel of the Umzonyana DWTP involved in the management and production of treated water were interviewed. They were selected because they possess direct knowledge of the technical difficulties encountered in water treatment operations, including equipment malfunctions, inefficiencies in the process, and addressing unforeseen issues. Notwithstanding the desired category of personnel for the interview, participation was voluntary and anonymous. A request to take part in the interview, which in essence was a questionnaire was done through the Plant Superintendent. The roles the personnel interviewed play in the plant and the number of them interviewed are indicated in Table 1.

Interviews with these selected personnel helped in pinpointing precise training requirements and highlighted areas needing more support. The choice of the selected personnel was important since the input from managers, process controllers, laboratory technicians, and plant operators could be used to customize training initiatives to meet the specific needs of the facility, thus improving both skill levels and operational efficiency.

Table 1: Number of DWTP personnel interviewed with their positions.

Interviewee Position	Number Interviewed
Plant Manager / Superintendent(s)	1
Process Controller(s)	4
Plant Operator(s)	3
Laboratory Technician(s)	2

3.10. Ethical considerations

The research was cleared by the North-West University Ethics Committee with Ethics Clearance Number: NWU-01210-24-A9. Permission was also sought to interview

relevant personnel as attached in the sample Letter of Consent in Appendix 2. The research problem was clarified for the respondents. Furthermore, each participant was guaranteed anonymity for their contributions and informed that their involvement in the study was entirely voluntary. It was also emphasised that they had the right to withhold any information at any time without providing reasons, should they feel uneasy.

3.11 Methodological assumptions and limitations

This research assumes that the raw water from the Buffalo River has consistent characteristics throughout the study period. However, this assumption may not fully consider potential variations in water quality that can occur due to seasonal fluctuations, agricultural runoff, or industrial discharges, which could impact the study's findings. The exigencies of time did not make for repeated sampling and testing in this study to accommodate variations. Resource constraints affected and limited the amount of sampling that could be done and the number of events. The implementation of complete monitoring programs needs substantial financial backing together with extensive logistical resources.

The research functioned as a preliminary investigation to detect POPs instead of measuring extended exposure periods because of restricted resources. Also the researcher faced difficulties in accessing treatment facilities because the superintendent needed to be present for these activities.

The research could presume that the techniques employed to identify and measure POPs, like GC-MS, are sufficiently precise and sensitive to detect trace amounts of these contaminants. The dependability of the data relies heavily on how well these instruments are calibrated and maintained.

It is assumed that the DWTP functions under steady conditions and that operational factors (such as flow rate, chemical dosing, and filtration settings) remain constant, although this may not always reflect the reality of real-world situations.

With regard to the limitations, the timing and frequency of sampling might not be sufficient to capture brief variations in POP levels caused by sporadic incidents or

abrupt shifts in river water quality. Additionally, the selected sampling sites may not adequately reflect the overall water quality entering the treatment facility.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results, its interpretation, and discusses the findings. First and foremost, the water quality data are presented and analysed to determine the level of pollution of the raw water that supplies the DWTP. Lastly, the questionnaire survey results are presented and analysed to determine the role of personnel in the removal of POPs as well as their knowledge about POPs.

4.2 Gas chromatography – mass spectrometry testing results

Using Gas Chromatography-Mass Spectrometry (GC-MS), this study analysed raw and treated water samples from the Umzonyana Drinking Water Treatment Plant, which draws its raw water from the Buffalo River and provides treated water to Mdantsane and East London, to detect and quantify specific organic pollutants in both untreated and treated water. The study analysed three main types of organic pollutants namely: organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and polyaromatic hydrocarbons (PAHs). The results from the tests revealed that pollutant concentrations in both treated and raw water samples were uniformly low, with OCPs and PAHs levels below 0.1 µg/L and PCBs levels below 0.2 µg/L.

The analytical justification for using GC-MS to test for POPs in water stems from its high sensitivity, specificity, resolution, and regulatory validation. The tool provides essential qualitative and quantitative results which makes it essential for environmental monitoring and compliance testing of POPs in drinking and surface waters.

4.3 Overview of detected pollutants

The following section explores the significance of the study's findings by:

- Determining the compliance and potential risks after comparison of the results with local and international water quality standards and guidelines.

- Evaluating the effectiveness of the Umzonyana Water Treatment Plant in removing POPs pollutants from the raw water sourced from the Buffalo River.
- Placing the findings in a local and global context by comparing them with similar studies from around the world

There has been some research completed in the Buffalo River that detected POPs in the Buffalo River. Table 2 indicates the research that has been completed in the Buffalo River on POPs.

Table 2: List of POPs detected in the Buffalo River in previous studies

Compound	Date of Detection	Site of Detection	Concentration (µg/L)	Researchers
DDT	2004	Course of the river	0.0055-0.06	Fatoki and Awofolu (2004)
Chlordane			0.0206	
Dieldrin			0.0057	
HCB			0.01-0.15	
OCPs	2017	Course of the river	0.313 to 4.303 from summer to autumn	Yahaya et al. (2017)
PCB	2018	Various sampling sites on the Buffalo River	BDL to 0.082 in summer and BDL to 2.383 in autumn.	Yahaya et al (2018)
PAH	2019	Buffalo River and estuary	14.91–206	Adeneji et al., 2019
Phenolic Compounds	2019	Various sampling sites on the Buffalo River	< LOD to 12.246 in summer and < LOD to 0.713 in autumn	Yahaya et al., 2019

4.3.1 Organochlorine pesticides in local and international perspectives

Several studies have investigated the presence, distribution, and behaviour of organochlorine pesticides (OCPs) in South African water systems. For example, Fatoki and Awofolu (2004) measured OCP levels across six selected freshwater bodies and sediments in the Eastern Cape Province. Their results showed total OCP concentrations in water samples ranged from trace levels (2,4'-DDD) to 450 ng/L (β -BHC), while in sediment samples, levels varied from trace (aldrin and 2,4'-DDD) to as high as 184,000 ng/kg (β -BHC). They also identified the presence of certain endocrine-disrupting compounds, including 2,4'-DDT, 4,4'-DDT, 2,4'-DDE, heptachlor, endosulfan, and various chlordanes (Fatoki and Awofolu, 2004).

The test results, as depicted in Table 3 from the Buffalo River and the Umzonyana DWTP in South Africa, show that none of the organochlorine pesticides were present at detectable levels. These findings suggested that the Buffalo River was not heavily polluted with organochlorine pesticides, and the Umzonyana DWTP is either effectively removing or not contributing to the presence of these pesticides in the treated water.

Table 3: Once-Off GC-MS Results for Organochlorine Pesticides on Raw and Treated Water from the Umzonyana DWTP Sourced from the Buffalo River (22.08.2024).

	Raw Water	Treated Water
Organochlorine-Pesticides ($\mu\text{g/L}$)		
α -HCH	<0.10	<0.10
β -HCH	<2.00	<2.00
γ -HCH	<0.10	<0.10
Δ -HCH	<0.10	<0.10
α -Chlordane	<0.10	<0.10
β -Chlordane	<0.10	<0.10
Aldrin	<0.10	<0.10
Dieldrin	<0.20	<0.20
Heptachlor	<0.10	<0.10
Heptachlor Epoxide Isomer B	<0.10	<0.10

4-4'-DDD	<0.10	<0.10
4-4'-DDE	<0.10	<0.10
4-4'-DDT	<0.10	<0.10
Methoxychlor	<0.10	<0.10
Endrin	<0.10	<0.10

The research results as presented in Table 4 demonstrate that the entire group of OCPs existed at levels below detection limits in both untreated and treated water samples. The findings indicate two key implications: The Buffalo River shows evidence of reduced OCP contamination at present and the Umzonyana DWTP demonstrates success in eliminating these pollutants from treated water.

The research findings presented by Yahaya et al. (2017) show significant OCP contamination in the Buffalo River. The multi-seasonal study by Yahaya et al. (2017) detected various OCPs that surpassed the 100 ng/L drinking water limit established by the United States Environmental Protection Agency (USEPA). The researchers from Yahaya et al. (2017) collected samples at six sites during summer and autumn and found DDT and its metabolites (DDD, DDE), aldrin, dieldrin, and hexachlorocyclohexane isomers reaching 4,403 ng/L concentrations. The measured values proved that agricultural runoff and possible urban water sources caused contamination throughout the river catchment.

Several factors likely explain the significant variation between the two research findings. The Yahaya et al. (2017) research obtained more detailed seasonal and runoff-driven pollution data through its expanded temporal observation period. This study obtained data at only one point in time; thus, it might have missed the occurrence of brief pollution events. This research shows that one-time measurements have their limitations for studying river systems that experience anthropogenic impacts.

The analytical techniques used by the researchers might have resulted in differences between the findings. The analytical method employed by Yahaya et al. involved gas chromatography with electron capture detection (GC-ECD) which shows high sensitivity to halogenated compounds including OCPs, yet this study used gas chromatography–mass spectrometry (GC-MS) which has slightly different detection limits for specific

analytes. The non-detection of pollutants in this study confirms the low levels of pollutants in the samples at the time of collection despite both methods being accepted worldwide (WHO, 2017).

The measured β -HCH levels which showed less than 2 $\mu\text{g/L}$ in raw and treated water require careful analysis of the findings. The trace amount of β -HCH in the environment indicates the need for continued monitoring despite the value being below critical thresholds.

The research indicates two possible reasons why OCP levels remain low in the Buffalo River: better environmental management has reduced pollutant sources or the OCPs in river sediments and upstream areas did not enter the water during sampling. The Umzonyana DWTP demonstrates successful pollutant removal because conventional treatment systems do not specifically target OCPs yet the absence of detectable levels in treated water suggests that some OCP reduction occurs through adsorption to activated carbon and coagulated flocs (Wang et al., 2017). The research showed positive indications about low OCP presence in the Buffalo River and treated water at Umzonyana DWTP, yet its results need consideration with the more extensive temporal data from Yahaya et al. (2017). Future studies need to focus on monitoring water quality over time, along with seasonal comparisons and sediment examination, to build comprehensive data about pollution patterns and treatment performance.

The OCPs are classified as POPs and have been extensively utilized in agriculture, especially in developing nations, despite international bans and restrictions (Qu, 2017). Their continued use is concerning due to their long-lasting presence in the environment and their ability to accumulate in the food chain (Qu, 2017). Besides the study on OCPs in the Buffalo River as indicated in Table 4 there have been other studies on OCPs in water bodies in South Africa. For instance, the one on the Jukskei River catchment by Rimayi et al. (2011) which analysed OCP residues in water from the Jukskei River, focusing on agricultural runoff and industrial waste contributions to contamination. The study detected important OCPs such as aldrin and DDT, highlighting the impact of historical pesticide use.

One can also talk of the Johannesburg Water Bodies Assessment by Amdany et al. (2014a) which used passive sampling methods to evaluate OCP bioavailability in water

bodies around Johannesburg, revealing significant contamination linked to urban and industrial activities and their monitoring study on the Hartbeespoort Dam where OCPs, were measured using advanced passive sampling techniques. That study emphasized long-term contamination of aquatic systems and the necessity for robust regulatory monitoring. With regards to the test of treated water for OCPs, a Rand Water study by Ncube et al. (2012) investigated the effectiveness of the drinking water value chain in removing organic contaminants, including OCPs, from source water. It gathered that while treatment processes reduced OCP concentrations, some residues persisted, suggesting the need for advanced treatment methods.

The OCPs have been extensively studied worldwide due to their persistence, bioaccumulative properties, and potential ecological and human health risks (Taiwo, 2019). Several efforts during research have investigated OCP contamination in water bodies across various countries, analysing their concentrations, sources, and compliance with international water quality standards, such as those set by the World Health Organization (WHO) and the European Union (EU). Notwithstanding the fact that some regions exhibit compliance, many studies highlight contamination levels that exceed safe limits, particularly in areas with high agricultural and industrial activity. A few study examples from various countries are found below.

KENYA: In their 2018 study, "Organochlorine Pesticide Residues in Sediment and Water from Nairobi River, Kenya: Levels, Distribution, and Ecological Risk Assessment," Ndunda et al., (2018) investigated the presence and distribution of organochlorine pesticides (OCPs) in the Nairobi River to assess potential ecological risks.

Organochlorine pesticide residues were identified in sediments and water samples from the Nairobi River. Sediment and water samples were collected from three sites along the river and screened for 17 OCPs (Ndunda et al., 2018). The samples underwent extraction and cleanup procedures, followed by quantification using gas chromatography equipped with an electron capture detector (GC-ECD) (Ndunda et al, 2018). Results from sediment samples for OCP concentrations ranged from 0.01 to 41.9 µg/kg (Ndunda et al., 2018). Compounds such as α-HCH, β-HCH, γ-HCH, heptachlor epoxide, and p,p'-DDD were consistently detected across all sediment samples (Ndunda et al., 2018). Results on water samples for OCP concentrations

varied from below detection limits to 39.7 ng/L. Detected compounds included α -HCH, γ -HCH, δ -HCH, heptachlor epoxide, endosulfan I, and endrin.

The detected OCP levels in water samples were below the World Health Organization's (WHO) maximum allowable limits for surface water. This suggests that, at the time of the study, the Nairobi River's water quality, in terms of OCP contamination, complied with WHO standards. However, the presence of these persistent pollutants, even at low concentrations, raises concerns about potential long-term ecological impacts (Ndunda et al., 2018).

INDIA: A study conducted by Ali et al. (2008) analysed the presence of organochlorine pesticides (OCPs) in the Hindon River, India. The research was aimed at understanding the distribution and concentration of these persistent pollutants in the river and assessing their compliance with water quality indices. The study employed Solid-Phase Extraction (SPE) and Gas Chromatography (GC) techniques to quantify the concentration of OCPs in river water samples (Ali et al., 2008). The study found significant levels of organochlorine pesticides in the Hindon River including α -BHC, β -BHC, γ -BHC, aldrin, endosulfan, DDE, DDD and methoxychlor. The concentration range of the detected pesticides was 8.1 to 26.8 $\mu\text{g/L}$. The highest recorded concentration was for α -BHC (26.8 $\mu\text{g/L}$). The most abundant pesticide detected was α -BHC, followed by methoxychlor and endosulfan. Agricultural runoff and industrial waste were identified as primary sources. (Ali et al., 2008).

The detected OCP concentrations in the Hindon River far exceeded the permissible limits set by WHO, U.S. EPA, the Indian Bureau of Standards and other international regulatory bodies (Ali et al., 2008). Aldrin, DDE, and DDD were found at dangerously high levels, exceeding the EPA's safe drinking water standard by over 5000 times (Ali et al., 2008).

These levels pose serious health risks, including carcinogenicity, endocrine disruption, and neurological disorders, particularly for populations using the river as a drinking water source (Ali et al., 2008). The study by Ali et al. (2008) provides critical evidence of severe organochlorine pesticide contamination in the Hindon River, far exceeding international water safety limits. The findings call for urgent intervention measures, including:

- Public awareness campaigns to educate farmers and industries on safe pesticide use and disposal (Ali et al., 2008).
- Strict enforcement of pesticide bans to prevent illegal use of hazardous OCPs. (Ali et al., 2008).
- Regular monitoring programs to track pesticide levels and ensure compliance with WHO and EPA water quality standards (Ali et al., 2008).

TURKEY: The study by Aydin et al. (2013) investigated the presence of organochlorine pesticides (OCPs) and metals in surface waters of the Konya Closed Basin (KCB) in Turkey. The study aimed to assess contamination levels, determine the primary pollutants, and compare the results against the study against regulatory standards.

The researchers selected nine monitoring stations across the Konya Closed Basin for sample collection. Water samples were gathered in March and August of 2012 to capture seasonal variations (Aydin et al., 2023). The study focused on detecting 17 OCPs, including various isomers of hexachlorocyclohexane (HCH), DDT and its metabolites (DDE and DDD), and other pesticides like aldrin, dieldrin, endrin, heptachlor, heptachlor epoxide, methoxychlor, chlordane I, and chlordane II. Additionally, concentrations of heavy metals such as arsenic (As), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), and nickel (Ni) were analysed (Aydin et al., 2023).

For OCP analysis, water samples underwent liquid-liquid extraction followed by gas chromatography-mass spectrometry (GC-MS) to quantify pesticide residues. The OCP contamination was detected in surface waters of the Konya Closed Basin, with certain pesticides exceeding European Union regulatory limits. The detected levels of OCPs were compared against:

- The Turkish Water Quality Regulation
- World Health Organization Guidelines
- European Union Drinking Water Directives and
- United States Environmental Protection Agency (US. EPA) Standards

The study highlighted the need for stricter water quality monitoring. From 0.015 to 0.065 µg/L, HCH is the most abundant of all the HCH isomers. The DDE isomer had the highest concentration, ranging from not detected to 0.037 µg/L. DDE, DDD, and DDT

were nearly detected in all samples. Among all the OCPs that were examined, aldrin had the highest concentration at 0–220 µg/L (Aydin et al., 2013).

4.3.2 Polychlorinated Biphenyls in local and national perspective

Some researchers have recently focused on assessing PCB concentrations in specific water bodies across the country. Amdany et al. (2014b) conducted one such study examining the levels of freely dissolved PCBs and two other classes of persistent organic pollutants (POPs), focusing on their seasonal variations in the water of Hartbeespoort Dam, South Africa. Their findings revealed concentrations ranging from 38 pg/L to 150 pg/L, with most compounds showing higher concentrations in winter compared to other seasons. Similarly, Kampire et al. (2017) measured the levels of six indicator PCBs (28, 52, 101, 138, 153, and 180) in surface sediments from North End Lake in Port Elizabeth, a site heavily impacted by runoff, industrial waste, and urban effluents from nearby areas. Using gas chromatography-mass spectrometry (GC/MS), they found total PCB concentrations between 1.60 and 3.06 ng/g dry weight (dw), with the highest contributions from the more chlorinated compounds. With regards to the study done by Yahaya et al. (2019) on the Buffalo River, PCB concentrations in the Buffalo River showed considerable variation, ranging from undetectable levels to as high as 482 ng/L in the summer and peaking at 2.38 ng/L in the autumn. This pronounced seasonal shift indicates that PCB levels may be influenced by environmental factors, potentially connected to river flow dynamics and activities on adjacent lands. The test using Gas Chromatography-Mass Spectrometry (GC-MS) for this study revealed PCB levels of less than 0.1 micrograms per litre (µg/L) in both the raw and treated water samples. The results are depicted in Table 4 as shown below.

PCBs are industrial compounds that were once widely utilized in hydraulic fluids, plasticizers, and electrical equipment. However, they have since been banned in many countries because of their toxic properties and their persistence in the environment. The PCBs are highly hydrophobic and tend to bind to sediments and organic matter, making their removal during water treatment processes more challenging (Sil et al., 2020). They were not detected in the test results as indicated in the Table 4.

Table 4: Once Off GC-MS Results for Polychlorinated biphenyls on Raw and Treated Water from the Umzonyana DWTP Sourced from the Buffalo River (22.08.2024).

	Raw Water	Treated Water
Trichlorobiphenyls (µg/L)		
PCB28	<0.10	<0.10
Tetrachlorobiphenyls (µg/L)		
PCB44	<0.10	<0.10
PCB49	<0.10	<0.10
PCB52	<0.10	<0.10
PCB60	<0.10	<0.10
PCB66	<0.10	<0.10
PCB70	<0.10	<0.10
PCB74	<0.10	<0.10
PCB77	<0.10	<0.10
Pentachlorobiphenyls (µg/L)		
PCB82	<0.10	<0.10
PCB87	<0.10	<0.10
PCB99	<0.10	<0.10
PCB101	<0.10	<0.10
PCB105	<0.10	<0.10
PCB114	<0.10	<0.10
PCB118	<0.10	<0.10

PCB126	<0.10	<0.10
Hexachlorobiphenyls (µg/L)		
PCB128	<0.10	<0.10
PCB138 + 158	<0.10	<0.10
PCB153	<0.10	<0.10
PCB156	<0.10	<0.10
PCB166	<0.10	<0.10
PCB169	<0.10	<0.10
Estimated Total (µg/L)		
	<0.10	<0.10

Various international studies have investigated PCB contamination in water bodies, analysing their sources, concentrations, and compliance with regulatory standards such as those set by the World Health Organization (WHO), the European Union (EU), and the U.S. Environmental Protection Agency (EPA).

NIGERIA: A study by Iniaghe and Kpomah (2022) investigated the distribution, concentration, and risk assessment of polychlorinated biphenyls (PCBs) in water and sediments of the Udu River, found in the Niger Delta region of Nigeria. The Udu River is an important water source for local communities, agriculture, and fishing activities. However, it is exposed to various forms of pollution including petroleum related-activities industrial discharge, and urban runoff, which play roles in PCB contamination. Their study aimed to determine PCB levels and their compliance with local and international water quality standards, with respect to:

- Nigerian Water Quality Standards
- United States Environmental Protection Agency (U.S. EPA)
- World Health Organization (WHO)

The methodology used in the study employed a comprehensive sampling and analytical approach to assess PCB contamination levels in the Udu River. It involved the sampling of five sites along the Udu River as per their proximity to industrial zones and human settlements (Iniaghe and Kpomah 2022).

Liquid-liquid extraction of the water samples was performed using n-hexane and dichloromethane in a separatory funnel. Utilizing gas chromatography-mass spectrometry, the number of polychlorinated biphenyls (PCBs) congeners in the extracts was measured. Those analysed included: PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-153, and PCB-180 (Iniaghe and Kpomah, 2022). PCBs in the sampled water samples ranged in concentration between 0.008 µg/L and 0.215 µg/L (Iniaghe and Kpomah, 2022). The state of compliance of the of the test results vis-a-vis the regulatory standards is shown in Table 5 below.

Table 5: State of Compliance of the PCBs in Selected International Study as per Regulatory Standards (Iniaghe and Kpomah, 2022).

Pollutant	Detected Range in Water (µg/L)	WHO Limit (µg/L)	U.S. EPA Limit (µg/L)	Nigeria Standard (µg/L)	Compliance
PCB-28	0.012 - 0.098	0.01	0.01	0.01	Exceeded WHO & EPA Limits
PCB-52	0.015 - 0.134	0.01	0.01	0.01	Exceeded All Limits
PCB-101	0.017 - 0.135	0.01	0.01	0.01	Exceeded All Limits
PCB-118	0.008 - 0.132	0.02	0.02	0.01	Exceeded Nigerian Standard
PCB-138	0.025 - 0.215	0.01	0.01	0.01	Exceeded All Limits

The pollution was linked to industrial waste and petroleum activities (Iniaghe and Kpomah, 2022) and amongst others recommended, stricter enforcement of industrial waste disposal laws to prevent PCB contamination and the adoption of advanced filtration systems (e.g., activated carbon, chemical oxidation) to remove PCBs from drinking water.

ALGERIA: In their 2024 study, "Occurrence, Sources and Risk Assessment of 12 Dioxin-Like Polychlorinated Biphenyls (DL-PCBs) in Sediments from the Soummam River Protected Area, Algeria: A Potential Threat to the Mediterranean Sea," Bensadi et al. (2024) investigated the presence, origins, and potential risks of twelve dioxin-like polychlorinated biphenyls (DL-PCBs) in the sediments of the Soummam River, northeastern Algeria. Furthermore, the study evaluated the ecological and human health risks associated with DL-PCB exposure by calculating Toxic Equivalents (TEQs) and Total Lifetime Cancer Risk (TLCR), respectively (Bensadi et al., 2024).

Different sediment samples were collected from various locations along the Soummam to assess twelve specific DL-PCBs contamination levels. Gas chromatography techniques were used to quantify the concentrations of these compounds. The study utilized Principal Component Analysis (PCA), a statistical method that assists in determining the origins and patterns of pollutants with respect to their distribution and concentration profiles, in a view to identify potential sources of DL-PCBs (Bensadi et al., 2024).

The study on PCB levels in the Soummam River, total DL-PCBs concentrations ranging from 3.64 ng/g to 9.38 ng/g with PCB 118 and PCB 105 being the predominant congeners (Bensadi et al., 2024). Principal component analysis suggested that commercial mixtures and municipal waste incineration could be responsible for the presence of PCBs in the region. High PCB levels in sediments suggested persistent environmental pollution from industrial sources (Bensadi et al., 2024). Even though the focus of the study the study mainly was on sediment analysis, the findings have impacts on overall water quality. The detected levels of DL-PCBs in sediments suggest ongoing contamination, which could affect aquatic life and potentially violate environmental quality standards aimed at protecting ecosystems and human health. The need for continuous monitoring and implementation of pollution control measures to ensure

compliance with water quality guidelines and to safeguard both the environment and public health, becomes fundamental due to the presence of these toxic compounds.

BELGIUM: A notable study focusing on PCB contamination was conducted in the Samme River catchment in the Brabant region of Belgium. The study by Denis et al. (2014), employed a comprehensive approach to evaluate both sediment and contaminant transport within the Samme River watershed. The study aimed to develop operational tools for effective sediment management in Walloon waterways, addressing issues such as the mixing of recent and older sediments and the input from unnavigable waterways into larger navigable systems (Denis et al., 2014).

The methodology included the extended monitoring of sediment and pollutant fluxes where, various river sediment sampling techniques, including automatic samplers, turbidity sensors, and Time Integrated Samplers were used at the catchment outlet (Denis et al., 2014). It also involved the assessment of within-catchment sediment and pollutant transport which was used in identifying the sources of PCB contamination and the conducting of chemical analysis on the riverbed sediments along the Samme River and its main tributary (Denis et al., 2014).

The findings of the study revealed that the sediments in the Samme Riverbed exhibited high concentrations of PCBs with the polluted sediments being considered key contributors to the contamination seen in the Brussels-Charleroi canal (Denis et al., 2014). In Belgium, surface water quality monitoring is conducted by regional agencies. In the Flanders region, the Flemish Environmental Agency (VMM) oversees the monitoring program, which includes measuring parameters for which water quality objectives have been set, determining water quality indices and classes, identifying unknown discharges, comparing data with water quality standards, and compiling annual pollution loads per hydrographic basin (Kristensen and Bogestrand, 1996).

Internationally, the European Union has the Water Framework Directive (WFD) which are laid out directives to manage water quality, which aims for good qualitative and quantitative status of all water bodies (Directive, 1998). PCBs, being persistent organic pollutants, are subject to strict regulations under these directives. The findings from the Samme River study underscore the challenges in meeting both local and international water quality standards due to historical and ongoing PCB contamination.

4.3.3 Polyaromatic Hydrocarbons (PAHs) in Local and International Perspective

In their 2019 study titled "Levels of Polycyclic Aromatic Hydrocarbons in the Water and Sediment of Buffalo River Estuary, South Africa, and Their Health Risk Assessment," Adeniji et al. (2019) examined the Buffalo River Estuary, a heavily industrialized and polluted area in South Africa. The estuary is significantly affected by urban runoff, industrial waste, and its proximity to a large port. The researchers measured PAH concentrations in both water and sediment, identified likely pollution sources, and evaluated the related health risks. The study observed that PAH levels in the water varied, generally reaching higher concentrations during the dry season. This seasonal increase was attributed to reduced water flow, which limited dilution and resulted in PAH accumulation (Adeniji et al., 2019). The PAH concentrations in the water typically ranged from 1.4.9 to 206 µg/L, influenced by both seasonal changes and proximity to pollution sources. For this study PAHs were recorded at concentrations below 0.1 µg/L in both raw and treated water samples after testing with the GC-MS as depicted in Table 6. Polyaromatic Hydrocarbons constitutes a section of organic compounds that are primarily formed when organic materials such as fossil fuels are incompletely combusted. These pollutants can enter water bodies through industrial discharges, urban runoff, and atmospheric deposition (Abdel-Shafy and Mansour, 2016).

Table 6: Once-Off GC-MS Results for Polyaromatic Hydrocarbons on Raw and Treated Water from the Umzonyana DWTP Sourced from the Buffalo River (22.08.2024).

	Raw Water	Treated Water
Polyaromatic Hydrocarbons (µg/L)		
Napthalene	<0.10	<0.10
Acenaphthene	<2.00	<2.00
Acenaphthylene	<0.10	<0.10
Fluorene	<0.10	<0.10
Phenanthrene	<0.10	<0.10
Anthracene	<0.10	<0.10
Flouranthene	<0.10	<0.10

pyrene	<0.20	<0.20
Benzo(a)anthracene	<0.10	<0.10
Chrysene	<0.10	<0.10
Benzo(b+k)fluoranthene	<0.20	<0.20
Benzo(a)pyrene	<0.10	<0.10
Benzo(g,h,i)perylene	<0.20	<0.20
Dibenz(a,h)anthracene	<0.20	<0.20
Indeno(123-cd)pyrene	<0.20	<0.20

As in other cases, South Africa is not alone as several countries internationally have done some research to assess the PAH contamination in water bodies and their state of compliance with international water quality standards set by U.S. Environmental Protection Agency (EPA), the European Union (EU), and the World Health Organization (WHO).

BRAZIL: In a study in Brazil (Lima et al., 2005), the Amazon River Basin was found to have experienced PAH contamination due to crude oil extraction and biomass burning. Since the study was a review, the authors did not conduct new experimental research but rather analyzed and synthesized findings from previous studies. It included the review of literature on PAH formation, transport, and degradation. The study brought to the fore that many regions, especially urban and industrial areas, exceeded the regulatory limits due to persistent PAH pollution, and that PAH levels in sediments and fish exceeded Brazilian and WHO water quality standards, posing a threat to aquatic biodiversity and public health (Lima et al., 2005). They went on further to suggest that compliance monitoring should not focus only on water samples but also on sediment quality assessments Since PAHs accumulate in sediments (Lima et al., 2005). In conclusion, Lima et al. (2005) analysed PAHs derived from combustion and their environmental implications. While regulations exist to control PAH levels in water, many areas still experience non-compliance, particularly in highly industrialized regions. Their findings stress the need for better pollution control measures, enhanced monitoring strategies, and effective remediation techniques to mitigate PAH contamination in aquatic systems.

NIGERIA: Anyakora et al. (2005) conducted an analysis of 16 priority polynuclear aromatic hydrocarbons (PAHs) in fish, sediment, and water samples from a fishing settlement in Nigeria's Niger Delta region. The study was prompted by concerns over significant pollution, likely caused by seepages from oil discharge terminals. The 16 priority PAHs—including acenaphthene, fluorene, acenaphthylene, phenanthrene, naphthalene, anthracene, fluoranthene, benzo[a]pyrene, pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, dibenz[a,h]anthracene, benzo[k]fluoranthene, benzo[ghi]perylene, and indeno[1,2,3-cd] pyrene. The researchers compared the detected levels of PAHs in the study against established water quality standards to assess compliance. Regulatory bodies, such as the World Health Organization (WHO), have set guidelines for acceptable concentrations of PAHs in drinking water due to their potential health impacts (WHO, 2011)

The quantification and determination of PAHs in water, fish, and sediment samples were performed using GC–MS with isotopically labelled internal standards (Anyakora et al., 2005). This methodology aligns with standard procedures for PAH analysis, such as the EPA Method 610, which outlines protocols for detecting polynuclear aromatic hydrocarbons in environmental samples.

The research conducted by Anyakora et al. (2005) underscores the critical need for regular monitoring and remediation efforts in areas susceptible to PAH contamination. Implementing stricter pollution controls and adhering to established water quality regulations are essential steps to protect both environmental and public health.

ITALY: A study by Acquavita et al. (2014), titled "The PAH level, distribution and composition in surface sediments from a Mediterranean Lagoon: The Marano and Grado Lagoon (Northern Adriatic Sea, Italy)", investigated the concentration, spatial distribution, and potential sources of polycyclic aromatic hydrocarbons (PAHs) in surface sediments of the Marano and Grado Lagoon. The researchers analysed 16 priority PAHs, as identified by the U.S. Environmental Protection Agency (EPA), in sediment samples from various locations within the lagoon. PAH concentrations ranged from non-detectable levels to a maximum of 1056 ng/g (Acquavita et al., 2014). The highest contamination was observed near the Aussa-Corno River mouth, an area influenced by industrial discharges (Acquavita et al., 2014). Comparatively, the overall contamination levels in the lagoon were similar to those found in minimally polluted sites

across the Mediterranean and were lower than those reported in the adjacent Gulf of Trieste.

The methodology to assess PAH contamination included sample collection where surface sediment samples were collected from multiple sites within the lagoon, with particular attention to areas near potential pollution sources, such as river mouths and industrial zones (Acquavita et al., 2014). Thereafter, an analytical analysis was conducted, and the collected samples underwent extraction and purification processes to isolate PAH compounds. Subsequently, gas chromatography-mass spectrometry (GC-MS) was utilized to identify and quantify the individual PAH compounds present in the sediments (Acquavita et al., 2014). The detected PAH levels were evaluated against established sediment quality guidelines however, while specific PAH regulatory limits for sediments may vary by jurisdiction, the observed concentrations in the Marano and Grado Lagoon were generally low. The study suggests that, despite industrial activities, the lagoon remains one of the less polluted transitional environments in the Mediterranean region (Acquavita et al., 2014).

Acquavita et al. (2014) research provides valuable insights into the current state of PAH contamination in the Marano and Grado Lagoon. The findings highlight the importance of ongoing environmental monitoring and the implementation of effective pollution control measures to maintain the lagoon's ecological health. Despite localized contamination near industrial areas, the overall PAH levels suggest the lagoon is relatively unpolluted compared to other Mediterranean coastal environments.

4.4 Compliance with Water Quality Standards

4.4.1 South African National Standards (SANS)

South Africa's drinking water quality is regulated by the Department of Water and Sanitation under the South African National Standards (SABS, 2015), which sets maximum allowable concentrations for various chemical and microbiological parameters in drinking water. Organic compounds primarily contain carbon and generally dissolve in solution as whole molecules rather than as ions, and can be analysed either collectively through oxidation processes, individually as specific compounds, or as grouped compounds (Schutte and Focke, 2006).

The standard does not mention specific acceptable concentration of OCPs, PCBs, and PAHs in drinking water (Water, 2008; Ncube, 2010) but recommends that organic pollutants (Thalates and Phenols) be kept to levels below 0.01 µg/L. This omission has been noted in academic literature, highlighting that while SANS 241 addresses various chemical parameters, it lacks comprehensive coverage of these specific organic pollutants (Ncube, 2010).

The results of this study are thus in line with the SANS standards, with regards to treated water from the Umzonyana DWTP and local regulations for human consumption based on the levels of these pollutants. It is also consistent with recent water quality test done at the plant where the plant recorded a score of 91.03% (DWS, 2023). The results do not however suggest compliance since it is a once-off test. The plant's in-house laboratory tests for Total Organic Carbon in lieu of OCPs, PCBs and PAH.

In keeping with the recommendations by Schutte and Focke (2006) with regard to the size of the population the plant serves ten water quality tests are completed at the plant every month. While some research studies have made monthly measurements during their study periods, a regular, publicly available timetable for the ongoing monitoring of the water quality of the Buffalo River does not appear to exist. The frequency of the monitoring is likely determined by the objectives and available funds of the respective research studies or monitoring programs.

4.4.2 World Health Organization (WHO) Guidelines

The World Health Organization (WHO) provides guidelines for drinking water quality that are followed globally (WHO, 2022). These guidelines are often more stringent than national standards and are used as benchmarks for evaluating water safety. This is because WHO uses the precautionary principle. The precautionary principle means that when there is scientific uncertainty, stricter limits are preferred to protect public health, especially for vulnerable groups such as infants, the elderly, and immune-compromised individuals (WHO, 2022)

- ❖ **OCPs:** The WHO has set guideline values for specific OCPs, such as DDT (1 µg/L), aldrin/dieldrin (0.03 µg/L), and lindane (2 µg/L). The concentrations of OCPs detected in this study are below these guideline values, indicating that the levels

present in the treated water do not pose a significant risk to human health according to WHO standards.

- ❖ **PCBs:** The WHO does not provide a specific guideline value for PCBs in drinking water, but some international standards recommend keeping PCBs below 0.5 µg/L (Directive, 1998). The detected level of less than 0.2 µg/L in this study is below this threshold.
- ❖ **PAHs:** The WHO recommends a maximum concentration of 0.1 µg/L for benzo[a]pyrene, one of the most toxic PAHs (WHO, 1998). The PAH concentration recorded in this study is below this level, suggesting minimal risk from PAH contamination.

Overall, the concentrations of OCPs, PCBs, and PAHs in both raw and treated water samples from the Buffalo River are within regulatory limit. This outcome, observed in both the raw and treated water, is a prospective reflection of the quality of the water during the course of the testing; however, it requires regular examination on the basis of environmental survey and public health concerns. The WHO standards emphasises ongoing monitoring and risk management as contained in the WHO Guidelines for Drinking Water Quality 4th Edition (WHO, 2011), which emphasizes on the point that, compliance cannot be solely based on once-off sampling as in the case of this study, but on a detailed continuous process of risk assessment and management. Also as discussed earlier, the occurrence and concentration of POPs in aquatic environments could fluctuate arising from contaminants been affected by disturbance of contaminants, changes in agricultural activity or land use and, flooding or storm events. therefore, it does not follow that a once-off test with results indicating low concentrations or below detectable levels serve as a confirmation that future sampling will not exceed regulatory limits (Jones and De Voogt, 1999).

4.4.3 European Union (EC) Water Quality Standards

Under the European Union (EU) Drinking Water Directive (98/83/EC) and the Water Framework Directive (WFD), has established rigorous water quality standards which specify maximum allowable concentrations for various contaminants, including POPs (Directive, 1998).

- **OCPs:** The EU has set environmental quality standards (EQS) for priority substances such as aldrin, dieldrin, and endrin at 0.01 µg/L for inland waters including rivers lakes and groundwater (Kern, 2014) The OCP concentrations detected in this study are close to this threshold but remain compliant with drinking water and water standards.
- **PCBs:** Similar to WHO guidelines, the EU sets stringent limits for PCBs, below 0.2 µg/L for safe water use, in line with the levels detected in this study.
- **PAHs:** The EU's standard for benzo[a]pyrene in drinking water is 0.01 µg/L, a stricter threshold than both SANS and WHO guidelines. While the total PAH concentration is below 0.1 µg/L, further speciation analysis would be needed to confirm whether individual PAH compounds like benzo[a]pyrene remain below EU limits.

From the EU guidelines comparison with this study's results, the water quality in the Buffalo River complies with general safety thresholds for OCPs, PCBs, and PAHs. Table 7 incorporates the Australian Drinking Water Guideline (ADWG).

Table 7: Outline of Local and International Regulatory Standards on PAH, PCB and OCP.

Persistent Organic Pollutant	Regulatory Body	Standard µg/L	Comment
PAHs	WHO	0.7	For benzo[a]pyrene
	EU	0.10	Sum of concentrations of specified PAHs (E.U. 2020)
	SANS	0.01	For benzo[a]pyrene (SABS, 2014)
	ADWG	0.01	NHMRC, NHMMC (2011)
PCBs	WHO	Not Specified	WHO has not established a specific guideline value for

			PCBs in drinking water.
	EU	Not Specified	The EU Drinking Water Directive does not specify a limit for PCBs (E.U. 2020)
	SANS	Not Specified	No specific limit for PCBs in SANS 241 (SABS, 2014)
	ADWG	Not Specified	NHMRC, NHMMC (2011)
OCPs	WHO	Varies	For example, DDT: 1.0 µg/L; Lindane: 2.0 µg/L.
	EU	0.1	For individual pesticides; 0.50 µg/L total pesticides (E.U. 2020)
	SANS	Varies	For example, Aldrin and Dieldrin: 0.03 µg/L. (SABS, 2014)
	ADWG	Varies	NHMRC, NHMMC (2011)

4.5. Performance of the Umzonyana Drinking Water Treatment Plant

4.5.1 Effectiveness of the treatment process

The results indicated that these contaminants were below the limits of detection in both raw and treated water samples, suggesting a minimal presence in the source water and/or effective removal during treatment. The implications of the results below detection level could mean the following:

- That the Buffalo River may have minimal contamination from PAHs, PCBs, and OCPs due to limited agricultural runoff, industrial discharge, or other pollution sources.

- That the treatment methodologies of the Umzonyana Water Treatment Plant may have efficiently removed the said contaminants, thereby reducing their concentrations at levels below detectable levels.

When one takes into consideration the complexity of these pollutants, this could be a demonstration that the treatment methods used, such as coagulation, flocculation, filtration and chemical treatment, are capable of handling trace organic contaminants (Alexander et al., 2012). A recent by study by Tahraoui et al. (2024) provided a comprehensive assessment of how well aluminum sulfate (a coagulant) performs in treating surface water contaminated with a range of pollutants. Their study focused on the treatment of polluted surface water from a reservoir using coagulation–flocculation, a key step in conventional water treatment and amongst its key findings was the 80–90% removal of chemical oxygen demand (COD) and biochemical oxygen demand (BOD). hence indicating a strong ability to remove suspended solids and biodegradable organics.

The employment of advanced technologies such as Advanced Oxidation Processes (AOPs), Granular Activated Carbon (GAC) filtration, or membrane filtrations systems could further consolidate the removal of POPs like OCPs, PCBs, and PAHs. (Titchou et al., 2021) These methods have shown to be effective in adsorbing or breaking down lipophilic and hydrophobic organic compounds, which are often resistant to conventional water treatment processes. Teodosiu et al. (2018) evaluated advanced drinking water treatment methods for removing emerging pollutants by demonstrating that ozonation and activated carbon adsorption and advanced oxidation proved effective. The research demonstrates that improved pollutant removal occurs through these methods yet their environmental sustainability needs thorough evaluation to determine the best treatment options

The Umzonyana Drinking Water Treatment Plant could benefit immensely from incorporating Advanced Operation Processes Membrane Filtration and Granulated Activated Carbon (GAC) filtration. Even though the one-off test for PAHs, PCBs and OCPs from the raw and treated water from the Umzonyana Drinking Water Treatment Plant during this study recorded below detectable levels, it would still be prudent to incorporate Advanced Oxidation Processes (AOPs), Granular Activated Carbon (GAC) filtration, and membrane filtration systems.

This precautionary approach is necessary because the limited sampling frequency may not capture the temporal and spatial variability of persistent organic pollutants (POPs) in the Buffalo River, and previous studies have established POP pollution of the river.

4.6 Environmental implications and source analysis

4.6.1 Possible Sources of Contamination in the Buffalo River

The Buffalo River catchment area is subject to various pollution sources, including historical contamination, urban development, industrial discharges, and agricultural runoff (Osuolale and Okoh,, 2017). The following section examines the main pollution sources affecting the Buffalo River to understand the potential threats to both treatment system operations and public health.

- ❖ **Agriculture:** The widespread historical use of organochlorine pesticides in agriculture may contribute to the continued presence of OCPs in the river, particularly in areas where these chemicals were heavily used in the past. Pesticides can persist in soil and sediment for many years and may enter water bodies through surface runoff or groundwater flow (Yahaya et al., 2017).
- ❖ **Industrial Activities:** PCBs were used in a variety of industrial applications before their ban, and they can still be released into the environment through improper disposal of old equipment, leaks from landfills, or industrial accidents. Industries located along the river may also contribute PAHs through the combustion of fossil fuels, industrial waste disposal, or accidental spills (Patel et al., 2020).
- ❖ **Urban Runoff:** Urban areas around the Buffalo River may be contributing PAHs through vehicular emissions, stormwater runoff, and wastewater discharge. The incomplete combustion of organic materials, such as fuel from vehicles or coal from power plants, is a major source of PAH contamination in urban water bodies (Adeneji et al., 2019). The UDWTP is located around Mdantsane in the Eastern Cape of South Africa, as enclosed in the circle on the map in Figure 6 below. The location of the UDWTP reservoir brings it in close proximity to urban settlements and farms hence a potential urban run-off.

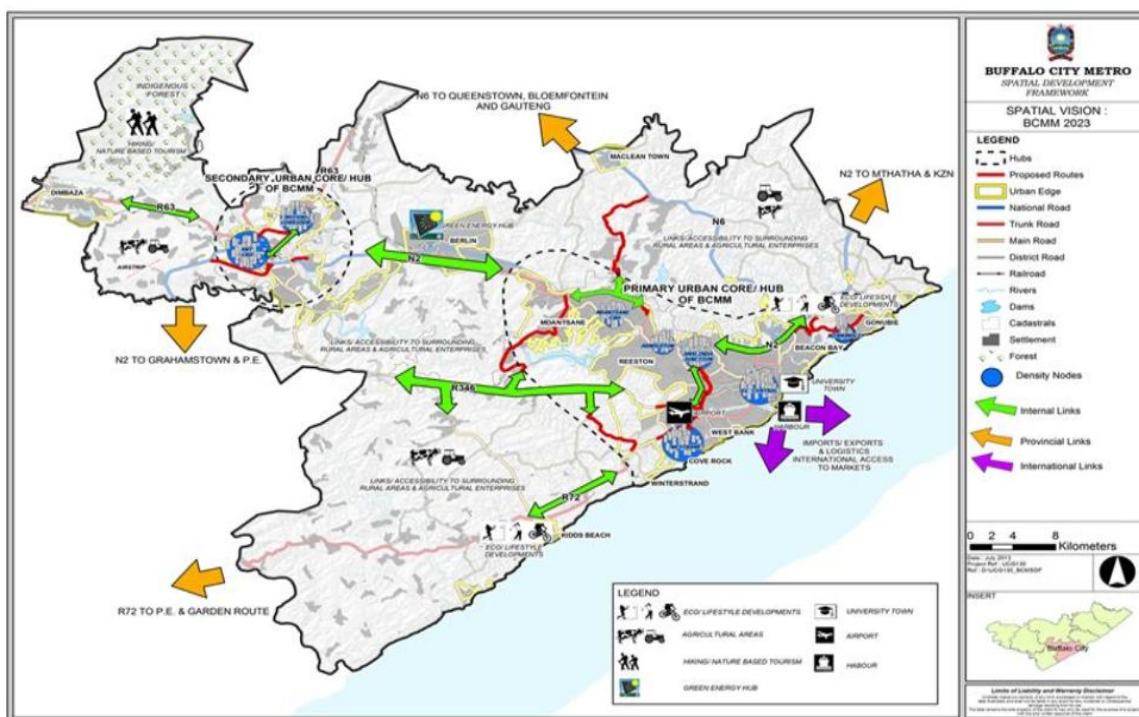


Figure 6: BCMM Spatial Development Map (Buffalo City Metropolitan Municipality, 2018) highlighting sources of POPs in the catchment.

4.7 Bioaccumulation and Ecological Risks

The likely presence of POPs like PCBs, PAHs and OCPs, in the Buffalo River poses ecological risks due to their potential for bioaccumulation in aquatic organisms. These compounds being lipophilic, has the potential to accumulate in the fatty tissues of organisms and can biomagnify up the food chain. Top predators, including fish and birds, are particularly vulnerable to the toxic effects of these pollutants, which can lead to reproductive harm, immune system suppression, and increased mortality rates. (Impellitteri et al., 2023)

Studies, for example, have shown notable bioaccumulation of PCBs and PAHs in fish species with varying concentrations across various tissues, including muscle, liver, spleen, and kidney (Rimayi et al., 2019). This emphasizes the possibility of these pollutants remaining in marine food webs. When one considers the complexity of these pollutants, this might be proof that the treatment techniques employed, including coagulation, flocculation, filtration, and chemical treatment, are able to manage trace organic pollutants.

The ecological risks linked to POPs are significant. The PAHs have been linked to carcinogenic and mutagenic properties in aquatic organisms, in addition to causing adverse effects on reproduction and development (Adeniji et al., 2019). Similarly, PCBs interfere with endocrine systems and impair immune function in wildlife populations. While organochlorine pesticides (OCPs) have been prohibited or restricted, they remain harmful due to their past use and long-lasting presence, which can cause water body contamination through leaching and surface runoff from previously treated soil (Yahaya et al., 2017).

Research within the Buffalo River in South Africa has detailed the occurrence and geographic location of numerous contaminants. Adeniji et al. (2019) have assessed the concentration levels of polycyclic aromatic hydrocarbons (PAHs) in the Buffalo River Estuary in South Africa, detailing the occurrence and geographic location of numerous contaminants. Adeniji et al. (2019) have assessed the concentration levels of polycyclic aromatic hydrocarbons (PAHs) in the Buffalo River Estuary, with records of concentrations within water and sediment samples raising serious ecological issues.

Whilst the initial results from this study may show the lack of measurable levels of PAHs, PCBs, and OCPs in the Buffalo River and treated water, the inherent characteristics of these persistent organic pollutants—namely their long-lasting nature and propensity to bioaccumulate—require constant vigilance and proactive management. Also the results below “detection levels” do not confirm absence because of these three factors:

- The sampling method failed to detect short-term contamination pulses which could still impact biological systems (Gilbreath and Mckee, 2015)
- Bioaccumulative POPs create chronic effects in living tissues even when aqueous concentrations remain low (Guo et al, 2019)
- The presence of POPs in water body sediments and fish tissues at low levels creates ongoing human exposure risks through fish consumption and additional exposure routes (Yahaya et al, 2017)

The employment of advanced water treatment techniques and the implementation of regular environmental assessments are critical steps toward reducing the potential ecological and human health risks posed by these pollutants. For instance, POPs can

be degraded by Advanced Oxidation Processes (AOPs) such as photocatalysis, ozonation, and Fenton reactions. The AOPs are reviewed by Gaur et al., (2022) as effective methods for breaking down POPs into less harmful substances, and the need for designing more efficient photocatalysts to enhance degradation processes is emphasized.

4.8 Responses from Umzonyana DWTP personnel

The role and responsibilities of the personnel interviewed are shown in the Table 8 below. A complete evaluation of the Umzonyana DWTP efficiency in removing PAHs, PCBs and OCPs from Buffalo River source water requires interviews with personnel at different levels of the plant. The treatment process reveals different aspects to staff members who work at various levels including plant superintendent and process controllers and lab technicians and mechanics. Managers supply details about policy and system upgrades and resource allocation while engineers explain treatment technology capabilities and limitations and operators explain daily operational practices and challenges and maintenance routines. The multi-level input provides complete understanding of plant operations while revealing knowledge gaps in protocol adherence and treatment strategy effectiveness against POPs.

Table 8: Role and responsibilities of UDWTP personnel interviewed.

Role	Responsibilities
Plant Superintendent (n = 1)	▪ Monitor continuous water demand ▪ Ensure that the infrastructure of the WTP or WTW and the equipment operate to specified standards ▪ Initiate and maintain communication with customers and stakeholders. ▪ Manage and supervise staff to achieve maximum productivity.
Process Controllers / Plant Operators (n = 4)	• Operate and maintain pumps, filters, storage tanks, and other equipment essential for water treatment and

	distribution. • Regularly collect and analyse water samples to ensure they meet quality standards • Identify and address equipment malfunctions, performing routine maintenance and making necessary repairs
Laboratory Technician (n = 2)	• Performing technical laboratory analysis • Collect and analyse water samples • Ensure treated water complies with relevant regulations.
Mechanic (n = 2)	• performs routine maintenance, repairs, and troubleshooting on equipment

Responses from ten Umzonyana DWTP personnel to the questionnaire as depicted in Figure 7, gave important insights about the staff's knowledge, experience, and perspectives on water treatment, particularly concerning POPs. Below is a breakdown and analysis of the responses.

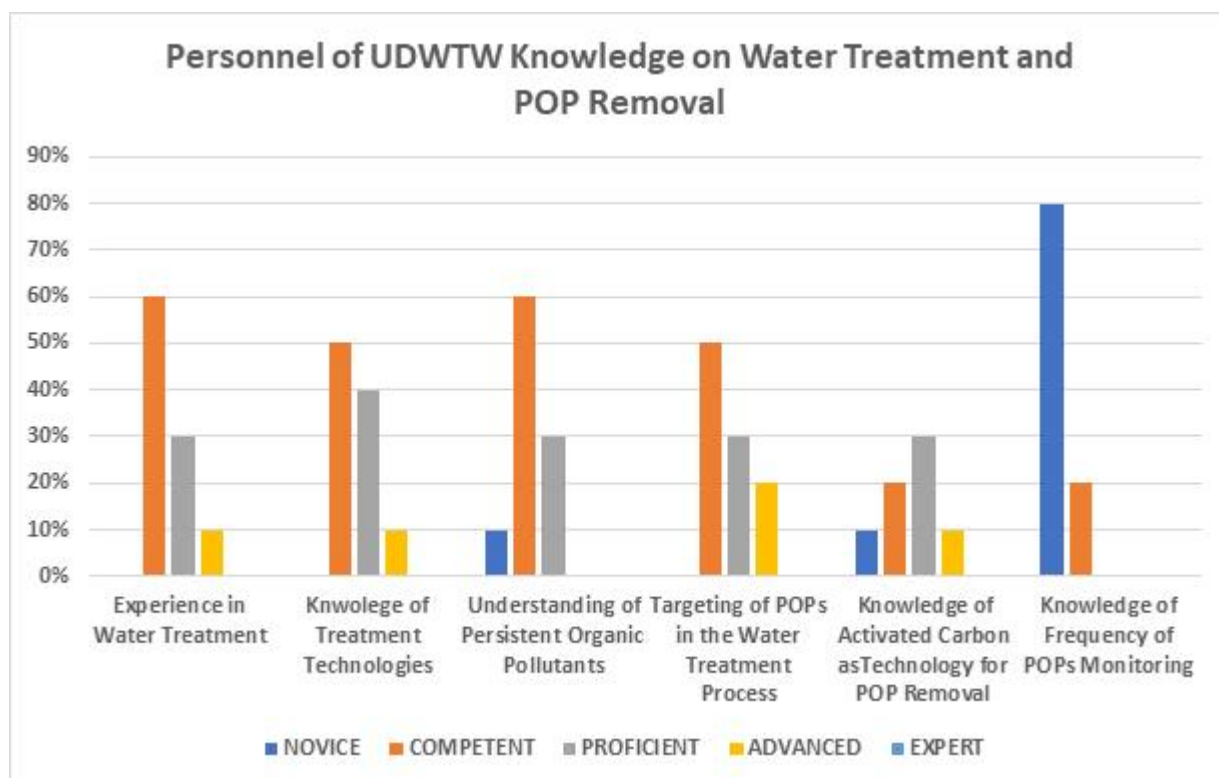


Figure 7: Knowledge of UDWTW personnel water treatment and POP removal.

Experience in water treatment:

The percentage of respondents with between 6 and 10 years of experience in water treatment amounted to 60%. This suggests that a majority of the personnel are moderately experienced, likely providing them with a solid understanding of treatment processes. This is key since, according to Momba et al. (2009), operators in treatment plants, especially in developing countries, lack the training required to remove POPs. This stance was further supported by Nefale et al, (2017), when measurement instruments were in use, experienced operators competently dosed chemicals and achieved better water clarity and safety

Knowledge of treatment technologies:

Also, 80% of respondents, aside from the mechanics, could accurately describe the basic technologies used in treatment at the plant. This response suggests a high level of familiarity among the personnel with the plant's processes, which is essential for maintaining effective operations. This is important when one relates it to research conducted by Stackelberg et al. (2004), which demonstrated that numerous pharmaceutical compounds survived standard water-treatment procedures and ended up in drinking water supplies. The research indicated that treatment plant staff must recognize the current process boundaries while understanding the necessity of implementing advanced treatment solutions to eliminate these contaminants effectively.

Upgrades to treatment processes:

All the personnel interviewed, representing 100%, stated that the treatment processes had not been upgraded in recent years. This could be a downside, suggesting the need for innovation or modernization in the future. This factor is key considering that modernization results in enhanced water quality and improved control of emerging contaminants and better operational efficiency (Przybylska and Pruss, 2022)

Understanding of persistent organic pollutants (POPs):

Regarding understanding the concept of POPs, 70% of the respondents were familiar. It could be inferred that most staff are aware of the environmental and health risks that the pollutant poses, though a minority may need further training. More so when POPs are considered emerging pollutants of concern.

Targeting POP removal in the treatment process

Interviews indicated 50% of respondents said that removing POPs was a specific target in the water treatment process. This suggests that POP removal is not a recognized priority, since half of those sampled might not fully grasp its importance, since it is not a parameter that conventional DWTP focuses on, or may not be involved in that aspect of the treatment process. Those who agreed lumped it up with the Total Organic Carbon that is removed by the treatment process. This stance is unsurprising since POPs are not a parameter on the SANS 241 or in the Blue Drop assessment.

Technologies for POP removal

In the interviews, 5 respondents out of 10 identified activated carbon treatment as the technology used for removing POPs, which is a widely recognized and effective method. 3 out of 10 respondents selected chemical precipitation, while 1 out of 10 chose "other" technologies. This indicates that activated carbon is the most widely acknowledged and favoured method, although some staff may hold different views or be aware of other techniques.

Frequency of POP monitoring:

In the interviews, 8 out of 10 respondents did not answer the question about the frequency of monitoring and evaluating POPs in raw water. The other two provided responses but without detail. They intimated that it was not part of their routine. This points to a possible knowledge gap or the absence of clear procedures for POP monitoring, highlighting an area that could benefit from improvement. The absence of knowledge on monitoring from the mechanics is understandable as against the technical staff. The research by Mandal et al. (2024) stands out as a significant study that demonstrates the need for regular monitoring of POPs in DWTPs. The research demonstrates the need for ongoing POPs monitoring especially for perfluorooctane sulfonic acid (PFOS) in water sources to guarantee drinking water safety. The authors emphasize that POP levels need to be monitored according to established limits for different water types including groundwater and drinking water to safeguard human health and environmental protection (Mandal et al., 2024).

Challenges in POP removal:

Six out of 10 respondents cited financial constraints as the main challenge in removing POPs from raw water, while three out of 10 attributed the challenge to technological limitations. This highlights that funding is a noteworthy impediment in the removal of POPs, irrespective of the fact that some staff also believe that upgrades or technological advancements could improve the situation.

Effectiveness of current systems:

In the interviews, 70% of respondents rated the current treatment system for removing POPs moderately effective, while 2 out of 10 rated it very effective. This indicates that while the staff generally considers the system to be working, there is still room for improvement in its performance and efficiency. Their perspective was however general and not exclusive to POPs.

Knowledge of POP origins

In the interviews, 6 out of 10 respondents were oblivious of the probable origins of POPs, while 4 out of 10 claimed to have some knowledge. This highlights a gap in understanding the sources of pollution, which could be fundamental for addressing the issue at its root. Currently, there is a lack of peer-reviewed literature that evaluates DWTPs personnel's understanding of POPs) sources, risks and removal techniques. Scientific literature contains many studies about POPs occurrence, risks and water treatment methods but there is a shortage of research about DWTP staff knowledge and comprehension. Mandal et al. (2024) present a detailed analysis of POPs in water through their discussion of classification, sources, potential risks, and treatment methods. The study fails to investigate the knowledge levels of DWTP personnel.

Operational challenges

Rather intriguing was the fact that none of the respondents provided any information regarding operational challenges at the DWTP. This could be interpreted either as a lack of perceived operational problems or a reluctance to discuss internal issues, but it is a significant omission. However, most DWTPs personnel face numerous challenges in removing POPs and other contaminants from raw water sources. These challenges

encompass technical, operational, and resource-related aspects, impacting the efficacy of water treatment processes (Membracon, 2022).

Conclusion

The staff at Umzonyana Water Treatment Plant are generally well-versed in water treatment technologies and have moderate experience, though additional education on POPs and their sources would be beneficial. Financial and technological constraints are viewed as the main obstacles to effectively removing POPs from the water. Gaps may exist in the monitoring and evaluation of POPs, as well as in understanding their sources, which could be improved with enhanced training and better resource allocation.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter provides the conclusions for the two research objectives: the presence of Persistent Organic Pollutants (POPs) in the Buffalo River and their removal by drinking water treatment plants, specifically the Umzonyana DWTP, and the evaluation of the Umzonyana DWTP staff's knowledge of the removal of POPs.

5.2 Conclusions

The study aimed to understand the removal or non-removal of POPs by DWTPs from the Buffalo River catchment. To that end it employed the use of Gas Chromatography-Mass Spectrometry (GC-MS) analysis to determine the concentrations of organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and Polycyclic aromatic hydrocarbons (PAHs) in raw and treated water samples.

Research Objective 1

This was to determine the first research objective of the study that had to do with the efficiency in the removal of possible POPs in raw water sourced from the Buffalo River by DWTPs, in this instance the Umzonyana DWTP.

The GC-MS results revealed that OCPs were $<0.1 \mu\text{g/L}$ in both raw and treated water, PCBs were $<0.1 \mu\text{g/L}$ in both raw and treated water, and PAHs were $<0.2 \mu\text{g/L}$ in both raw and treated water. The once-off sampling and subsequent GC-MS results indicated below detection level concentrations of OCPs, PCBs, and PAHs in both raw and treated water from the Buffalo River and Umzonyana Water Treatment Plant, respectively.

Although once-off results, the following conclusions can be made. The source water quality and findings show that the presence of PAHs, PCBs, and OCPs at concentrations below detection limits in the raw water sample suggests that the Buffalo River, at least for this single sampling activity, exhibited low levels of these persistent organic pollutants. The efficacy of the treatment process is further shown by the fact that UDWTP treated water meets water quality guideline limits for various parameters,

which corroborates the treatment efficiencies of the plant, even though POPs were not present in the source water.

Conventional treatment processes—usually consisting of coagulation, sedimentation, filtration, and disinfection—are most likely aimed at microbial and particulate removal. However, for already relatively high-quality raw water, these processes can leave behind or enhance the quality of water with respect to trace organic contaminants (Zhang et al., 2022).

Further uncertainty regarding the treatment efficiency is unfortunately still present since no POPs were identified in raw water, and therefore, the efficiency could not be conclusively established. The South Africa, SANS 241:2015 aligns with principles of the WHO, that emphasises the need for physical, microbiological and chemical monitoring. The EU Drinking Water Directive (2020/214) and the Australian Drinking Water Guideline just as the SANS 241:2015 requires the demonstration of compliance through the documentation and the verifying of monitoring programs against a once-off result.

Whilst it is a positive that the once-off test from the Buffalo River showed OCPs, PCBs and PAHs concentrations within regulatory limits, it does not satisfy the broad criteria with regards to compliance from the WHO standards. Satisfactory compliance demands frequent monitoring, a comprehensive risk management system and long-term assurance of safe water delivery.

However, the following acknowledgement of shortcomings and limitations can be made:

- I. Low concentrations of POPs in raw water may not accurately represent the plant's removal efficiency under higher contaminant loads.
- II. Single sampling event may not capture temporal variability in POPs concentrations.
- III. Limited scope: only OCPs, PCBs, and PAHs were analyzed, excluding other POPs. There are thousands of POPs and their congeners however the study limited itself to these three. For example, since the Buffalo River receives discharge from municipal wastewater treatment plant, it would be justified to analyse the source water for pharmaceuticals and personal care products (PPCP) in future studies.

IV. Lack of information on treatment plant operations, maintenance, and quality control measures in relation to PAH, PCB and OCP removal by treatment plants. The insufficient information about treatment plant operations and maintenance and quality control procedures particularly regarding POPs such as PAHs, PCBs, and OCPs stems from multiple interconnected factors:

❖ Limited monitoring capacity and resources

- The detection of POPs requires laboratory facilities with highly sensitive and expensive analytical instruments, including gas chromatography-mass spectrometry (GC-MS), which are often insufficient in many countries.
- Shortage of trained personnel to carry out routine POP-specific monitoring.
- The budgetary constraints focus on testing microbiological or conventional chemical contaminants (e.g., turbidity, nitrates, chlorine) instead of expensive POP analysis.

❖ Regulatory gaps and inconsistent reporting requirements

In many countries, including South Africa, water quality regulations focus on microbiological and conventional chemical standards, with limited or no legally mandated monitoring of POPs in drinking water.

- The testing of PAHs, PCBs, and OCPs is not standard unless there is a known contamination source or incident.
- Lack of harmonization with EU or WHO guidelines can result in inconsistent or voluntary monitoring.

❖ Data sensitivity and institutional reluctance

- Some treatment plant operators might avoid sharing data which could show operational or maintenance issues or water quality noncompliance problems.
- The fear of public backlash or reputational damage leads to restricted transparency and reporting on POPs.

Research Objective 2

The second research objective sought to evaluate the knowledge of staff of the Umzonyana DWTP in the removal of POPs from raw water. It solicited responses from

the Plant Manager, Water Treatment Plant Operators, Process Controllers, Laboratory Technicians and plant Mechanics. Notable findings from the analysis of responses from the questionnaire show that while the personnel demonstrated a solid understanding of general water treatment technologies, there are knowledge gaps concerning the identification, monitoring, and removal of POPs such as OCPs, PCBs, and PAHs. In addition to the above, the staff's awareness of the sources and health impacts of POPs was limited. The research identified inconsistencies in the application of best practices for monitoring of POPs in raw and treated water, which indicates the need for more regular training and structured procedures. Also, limitations bordering on finance and modern technology were identified as key barriers to the improvement and removal of POPs from drinking water. These constraints limit the ability to regularly monitor and assess POP levels, which is important in ensuring of effective water treatment.

Despite these limitations, this study contributes to the understanding of POPs removal by drinking water treatment plants and highlights the need for improved management and removal strategies in South Africa. The findings provide valuable insights for water treatment plant operators, policymakers, and researchers seeking to ensure safer drinking water.

5.3 Recommendations and areas of future research

Further monitoring and analysis of the feed water from the Buffalo River and the drinking water from the plant is hereby recommended using much more sensitive methodology to ensure that trace amounts of the said contaminant were within safe limits. Optical sensors are also being created as highly sensitive environmental monitoring instruments for POPs with quick and inexpensive detection (Caroleo et al., 2022). Spectroscopy-based methods have also been enhanced, facilitating improved trace analysis of persistent organic pollutants in water matrices that are complicated (Wang et al., 2019). Moreover, one analytical approach that combines various high-sensitivity methods has been proposed to ensure accurate detection in diverse environmental compartments (Avino & Russo, 2018).

The implementation of operational recommendations requires support from policy-level interventions. Standardization of procedures stands as an essential policy intervention. The implementation of national guidelines and standard operating procedures (SOPs)

for POPs monitoring and removal in drinking water treatment plants should follow WHO and SANS 241 standards. Standardized testing methods for raw and treated water POPs must exist in all municipalities to prevent testing discrepancies. The system requires scheduled audits and compliance checks to verify that water boards and municipalities follow POP monitoring protocols.

These developments reflect the growing effectiveness and selectivity of analytical methods in detecting POP pollution in aquatic ecosystems.

Future research should address these limitations by:

- a) **Conducting long-term monitoring of POPs concentrations.** The one-time POP analysis of raw and treated water from the Buffalo River and Umzonyana Drinking Water Treatment Plant in the current study found POP levels to be within regulatory limits. However, given historical contamination and pollution sources, regular periodic monitoring is necessary. Long-term monitoring ensures early detection of changes, minimizes the risk of cumulative exposure, and supports water safety plans. Advanced analytical techniques, such as GC-MS and membrane filtration, should be applied for increased sensitivity. Proactive monitoring safeguards water quality and public health resilience.
- b) **Analysing a broader range of POPs.** Regulatory compliance must not get mixed with assurance of ecological or human safety since untested POPs may pose risks. A broader study on a larger group of POPs, including recently discovered contaminants, must be conducted to analyse long-term exposure effects. Research from impacted catchments worldwide demonstrates that PFAS and PBDEs and dioxins and furans and SCCPs and PCP, HCBd and dicofol have become increasingly important POPs. These substances have gained recognition because they persist in the environment while being toxic and accumulating in living organisms and showing resistance to standard water treatment methods. The Buffalo River catchment requires attention to these additional POPs because their sources include industrial discharge and municipal waste as well as historical agricultural use in this area with mixed urban and industrial and agricultural activities. Future water quality assessments

and policy protection of human health and aquatic ecosystems require the inclusion of these additional POPs in monitoring strategies.

c) **Evaluating removal efficiency under varying raw water quality conditions.**

Raw water variability due to seasonal changes and contamination sources can impact efficiencies of removal processes (Mensah-Akutteh et al., 2022). Treatment performance under changing conditions needs to be assessed to guarantee long-term water supply security (WHO, 2017). The application of advanced monitoring methods and adaptable treatment processes may assist in more efficient elimination of contaminants (Gwenzi and Chaukura, 2018). Future studies should incorporate dynamic analyses to improve treatment system resilience and protect public health.

d) **Develop and validate new analytical methods for POPs detection.** The study analysed raw and treated water from the Buffalo River and Umzonyana Drinking Water Treatment Plant, detected persistent organic pollutants (POPs) within regulatory limits. However, these findings may not fully capture the presence of trace-level or emerging POPs due to limitations in current analytical methods. Traditional techniques, such as gas chromatography-mass spectrometry (GC-MS), may lack the sensitivity required for ultra-trace detection and often do not account for newly emerging POPs (Eppe and Galvin, 2024).

To overcome such challenges, the development and evaluation of advanced analytical methods become more increasingly vital. New methods, including stir bar sorptive extraction followed by thermal desorption and tandem mass spectrometry with gas chromatography (GC-MS/MS), have shown higher sensitivity and performance in the analysis of a broad range of persistent organic pollutants (POPs) in water samples. Such methods have achieved quantitation ranges between 0.14 and 10 ng/L with the strict standards regulated (Camino-Sanchez et al, 2012).

For South Africa, which could be faced with limited technical resources, it will be important to have in place alternative analytical techniques tailored to local conditions. Techniques have been reviewed such as two-dimensional gas chromatography-time of flight mass spectrometry for trace-level POPs analysis in

soil, and useful information on adaptable methods for water analysis (Rimayi and Madikizela, 2023)

With regards to staff of the Umzonyana Water Treatment Plant the following recommendations could be considered:

Enhanced Training Programs: comprehensive training programs is suggested to be developed and implemented to improve the staff's knowledge and understanding of POPs, including their, health impacts, sources and effective removal strategies. This could involve workshops, seminars, and certification courses in advanced water treatment and pollution control techniques.

Improved Monitoring and Evaluation Procedures: The plant should establish clearer protocols for the regular assessment of POPs in raw and treated water to address gaps in monitoring practices. The use of more precise detection methods should be standardized, ensuring that monitoring occurs frequently and accurately.

Investment in Technology and Infrastructure: Addressing the financial and technological barriers is crucial for enhancing the plant's ability to remove POPs effectively. Allocating more resources for modernizing treatment technology, especially those focused on POP removal, will improve the overall efficiency and reliability of the water treatment process.

Collaboration with Researchers and Policymakers: Strengthening relationships between water treatment managers, environmental scientists and policy makers is critical to addressing the challenges posed by POPs. Collaborative efforts can lead to better resource allocation, the development of stronger regulations on POPs, and the dissemination of best practices across the water treatment sector.

This research, comparing treated and untreated water samples both from the Umzonyana Drinking Water Treatment Plant and the Buffalo River, as well as the qualifications of the facility's employees, substantially advances the current knowledge base concerning water quality and public health. By comparing treated and untreated water samples, the research provides useful information on the effect of modern treatment methods on the removal of potential pathogens, heavy metals, and persistent organic pollutants (POPs). In addition, the analysis of employee qualifications

underscores the critical importance of human factors—training, technical competence, and operational supervision—in providing a stable source of drinking water.

The findings highlight the importance of continuous monitoring of water quality, including well past points and sources, into all treatment processes. In addition, they validate a need for continuous professional development and capacity building for all professionals who deal with water treatment operations. Overall, the findings support efforts towards improving water treatment methods, policy development that is relevant, and maintaining public health in communities with surface water resources. Overall, the study adds a comprehensive insight into the massive body of literature related to the management of water resources sustainably and providing drinking water in water-scarce regions.

The South African implementation of the Stockholm Convention on Persistent Organic Pollutants (POPs) has made policy strides, but its practical impact on water bodies like the Buffalo River remains limited. Despite national commitments to reduce POPs, the river continues to show contamination from industrial discharge, agricultural runoff, and poor wastewater treatment. This indicates a gap between policy and enforcement, highlighting the urgent need for stronger monitoring, upgraded treatment infrastructure, and better training of plant operators to align on-the-ground action with international obligations.

BIBLIOGRAPHY

- Abdel-Shafy, H.I. and Mansour, M.S., 2016. A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation. *Egyptian journal of petroleum*, 25(1), pp.107-123.
- Acar, Y.B. and Alshawabkeh, A.N. 1993 'Principles of electrokinetic remediation', *Environmental Science & Technology*, 27(13), pp. 2638–2647
- Achema, K.O. and Alhassan, C.J., 2022. Effect of Biodegradable Multiple Pesticides on Aquatic Biospecies. In *Insecticides-Impact and Benefits of Its Use for Humanity*. IntechOpen.
- Acquavita, A., Falomo, J., Predonzani, S., Tamberlich, F., Bettoso, N. and Mattassi, G., 2014. The PAH level, distribution and composition in surface sediments from a Mediterranean Lagoon: the Marano and Grado Lagoon (Northern Adriatic Sea, Italy). *Marine pollution bulletin*, 81(1), pp.234-241.
- Adeniji, A.O., Okoh, O.O. and Okoh, A.I., 2019. Levels of polycyclic aromatic hydrocarbons in the water and sediment of Buffalo River Estuary, South Africa and their health risk assessment. *Archives of environmental contamination and toxicology*, 76, pp.657-669.
- Alexander, J.T., Hai, F.I. and Al-Aboud, T.M., 2012. Chemical coagulation-based processes for trace organic contaminant removal: Current state and future potential. *Journal of environmental management*, 111, pp.195-207.
- Algaidy, N. and El Shrif, A. 2023. Numerical simulation of the laminar boundary layer flow over a flat plate. *Asmariya University Journal*. (4), 122-13 (8)
- Ali, I., Singh, P., Rawat, M.S.M. and Badoni, A., 2008. Analysis of organochlorine pesticides in the Hindon river water, India. *Journal of Environmental Protection Science*, 2, pp.47-53.
- Amdany, R., Chimuka, L., Cukrowska, E., Kukučka, P., Kohoutek, J., Tölgyessy, P. and Vrana, B., 2014a. Assessment of bioavailable fraction of POPS in surface water bodies

in Johannesburg City, South Africa, using passive samplers: an initial assessment. *Environmental monitoring and assessment*, 186, pp.5639-5653.

Amdany, R., Chimuka, L., Cukrowska, E., Kohoutek, J. and Vrana, B., 2014b. Investigating the temporal trends in PAH, PCB and OCP concentrations in Hartbeespoort Dam, South Africa, using semipermeable membrane devices (SPMDs). *Water SA*, 40(3), pp.425-436.

Anttila, P., Brorström-Lundén, E., Hansson, K., Hakola, H., Vestenius, M., 2016. Assessment of the spatial and temporal distribution of persistent organic pollutants (POPs) in the Nordic atmosphere. *Atmospheric Environment* 140, 22e33.

Anyakora, C., Ogbeche, A., Palmer, P. and Coker, H., 2005. Determination of polynuclear aromatic hydrocarbons in marine samples of Siokolo Fishing Settlement. *Journal of chromatography A*, 1073(1-2), pp.323-330.

ATSDR, T., 2002. Profile for DDT, DDE and DDD, US Department of Health and Human Services. Public Health Service, 497, pp.17-26.

Avino, P. and Russo, M.V., 2018. A comprehensive review of analytical methods for determining persistent organic pollutants in air, soil, water and waste. *Current Organic Chemistry*, 22(10), pp.939-953.

Aydin, M.E., Ozcan, S., Beduk, F. and Tor, A., 2013. Levels of organochlorine pesticides and heavy metals in surface waters of Konya Closed Basin, Turkey. *The Scientific World Journal*, 2013(1), p.849716.

Badawy, M.I., Ghaly, M.Y. and Gad-Allah, T.A., 2006. Advanced oxidation processes for the removal of organophosphorus pesticides from wastewater. *Desalination*, 194(1-3), pp.166-175.

Barletta, M., Lima, A.R. and Costa, M.F., 2019. Distribution, sources and consequences of nutrients, persistent organic pollutants, metals and microplastics in South American estuaries. *Science of the Total environment*, 651, pp.1199-1218.

Bensadi, L., Azzoug, M. and Benlaribi, R., 2024. Occurrence, sources and risk assessment of 12 dioxin-like polychlorinated biphenyls (DL-PCBs) in sediments from

the Soummam River protected area, Algeria: A potential threat to the Mediterranean Sea. *Marine Pollution Bulletin*, 208, p.117003.

Bergman, A. and Olsson, M., 1985. Pathology of Baltic grey seal and ringed seal females with special reference to adrenocortical hyperplasia: Is environmental pollution the cause of a widely distributed disease syndrome. *Finnish Game Res*, 44, pp.47-62.

Bratby, J., 2016. *Coagulation and flocculation in water and wastewater treatment*. 3rd ed. London: IWA Publishing.

Buffalo City Metropolitan Municipality. 2018. *Spatial Development Framework Map*. East London: Buffalo City Metropolitan Municipality.

Burkhard, L.P., Armstrong, D.E. and Andren, A.W., 1985. Partitioning behavior of polychlorinated biphenyls. *Chemosphere*, 14(11-12), pp.1703-1716.

Camino-Sánchez, F.J., Zafra-Gómez, A., Cantarero-Malagón, S. and Vílchez, J.L., 2012. Validation of a method for the analysis of 77 priority persistent organic pollutants in river water by stir bar sorptive extraction in compliance with the European Water Framework Directive. *Talanta*, 89, pp.322-334.

Caroleo, F., Magna, G., Naitana, M.L., Di Zazzo, L., Martini, R., Pizzoli, F., Muduganti, M., Lvova, L., Mandoj, F., Nardis, S. and Stefanelli, M., 2022. Advances in optical sensors for persistent organic pollutant environmental monitoring. *Sensors*, 22(7), p.2649.

CES. 2003 State of Environment Report: Amatole District. Report prepared for the Amatole District Municipality, PO Box 320, East London, April 2003. Available at: https://www.dws.gov.za/iwqs/rhp/state_of_rivers/ecape_04/BufRiverRepFnl.pdf
Accessed on 25/10/2024

Champeau, O., Ataria, J.M., Northcott, G.L., Kume, G., Barrick, A. and Tremblay, L.A., 2020. Assessment of the impacts of anthropogenic activities on a large river using longfin eel as a bioindicator. *Sustainability*, 12(20), p.8412.

Chigor, V.N., Sibanda, T. and Okoh, A.I., 2013. Variations in the physicochemical characteristics of the Buffalo River in the Eastern Cape Province of South Africa. *Environmental monitoring and assessment*, 185, pp.8733-8747.

Choi H, Al-Abed SR, Agarwal S. 2009. Catalytic role of palladium and relative reactivity of substituted chlorines during adsorption and treatment of PCBs on reactive activated carbon. *Environmental science & technology*. 2009; 43(19):7510-5.

Christiaan O, Maitland TS, Gabre K, Huibregt EP and Hugh-George E P .2015. An LC-MS/MS based survey of contaminants of emerging concern in drinking water in South Africa. *The South African Journal of Science*. 111 (9/10) 160-165.

Cousins, I. T., Gevao, B. & Jones, K. C. 1999. Measuring and modelling the vertical distribution of semivolatile organic compounds in soils. I: PCB and PAH soil core data. *Chemosphere*, 39, 2507-2518.

Creswell, J.W., Plano Clark, V.L., Gutmann, M.L. and Hanson, W.E., 2003. Advanced mixed methods research designs. *Handbook of mixed methods in social and behavioral research*, 209(240), pp.209-240.

Creswell, J.W. and Creswell, J.D., 2017. Research design: *Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Dai, W.J., Wu, P., Liu, D., Hu, J., Cao, Y., Liu, T.Z., Okoli, C.P., Wang, B. and Li, L., 2020. Adsorption of polycyclic aromatic hydrocarbons from aqueous solution by organic montmorillonite sodium alginate nanocomposites. *Chemosphere*, 251, p.126074.

Daramola, I.O. & Adebayo, M.A., 2022. Recent developments in the application of advanced oxidative processes for remediation of persistent organic pollutants from water. In: M.N. Rashed, ed. *Persistent organic pollutants (POPs) – monitoring, impact and treatment*. London: IntechOpen. Chapter 2, pp.1–24. <https://doi.org/10.5772/intechopen.101304>

Daughton, C.G. and Ternes, T.A., 1999. Pharmaceuticals and personal care products in the environment: agents of subtle change?. *Environmental health perspectives*, 107(suppl 6), pp.907-938.

Daughton, C.G., 2001. Pharmaceuticals and personal care products in the environment: overarching issues and overview.. *ACS Symposiums Series Vol 791*. Washington, DC: American Chemical Society, pp. 2–38.

Denis, A.C., Van Campenhout, J., Bouffieux, A., Houbrechts, G., Hallot, E., Bousmar, D., Veschkens, M. and Petit, F., 2014. Quantitative and qualitative evaluation of sediment and contaminant transport in the Samme river catchment (Brabant region-Belgium). In *4th International Symposium on Sediment Management*. Maggioli Editore è un marchio di Maggioli SpA.

Department of Environmental Affairs, 2012. *South Africa National Implementation Plan (NIP) for the Stockholm Convention on Persistent Organic Pollutants*. Pretoria: Department of Environmental Affairs.

Department of Water Affairs (DWA). 2015. *SANS 241-1 & 2: Drinking Water Specification*. Pretoria: South African Bureau of Standards.

Department of Water Affairs and Forestry (DWAf). 1996. *South African Water Quality Guidelines (2nd ed.). Volume 1: Domestic Use*. Pretoria: Department of Water Affairs and Forestry, Republic of South Africa.

Department of Water and Sanitation (DWS). 2004. The Ecological Health of the Buffalo River Poster. Available at: https://www.dws.gov.za/iwqs/rhp/state_of_rivers/posters/Bufferalo_Xhosa_English_poster_4.pdf Accessed on 25/10/2024

Department of Water and Sanitation (DWS). 2018. *National Water and Sanitation Master Plan*. Pretoria: Department of Water and Sanitation. Available at: https://www.gov.za/sites/default/files/gcis_document/201911/national-water-and-sanitation-master-plandf.pdf Accessed on 12/09/2025.

Department of Water and Sanitation (DWS). 2023. Blue Drop National Report. Available at: https://ws.dws.gov.za/iris/releases/BDN_2023_Report.pdf (accessed on 24/10/2024)

Department of Water and Sanitation (DWS). 2023. *National Water Resource Strategy III*. Pretoria: Department of Water and Sanitation. Available at: <https://www.dws.gov.za/Documents/Gazettes/Approved%20National%20Water%20Res>

[ource%20Strategy%20Third%20Edition%20\(NWRS3\)%202023.pdf](#) (accessed on 12/09/2025)

Directive, C., 1998. On the quality of water intended for human consumption. *Official Journal of the European Communities*, 330, pp.32-54.

Duan, J., Li, W., & colleagues. (2024). New solutions to keep drinking water safe as pesticide use increases worldwide. *University of South Australia*. Retrieved from <https://unisa.edu.au/media-centre/Releases/2024/new-solutions-to-keep-drinking-water-safe-as-pesticide-use-increases-worldwide/> Accessed on 25/10/2024

Duttagupta, S., Mukherjee, A., Bhattacharya, A. and Bhattacharya, J., 2020. Wide exposure of persistent organic pollutants (PoPs) in natural waters and sediments of the densely populated Western Bengal basin, India. *Science of the Total Environment*, 717, p.137187.

Edokpayi, J.N., Odiyo, J.O., and Durowoju, O.S., 2017. Impact of wastewater on surface water quality in developing countries: a case study of South Africa. *Water quality*, pp.401-416.

Eppe, G. & Galvin, R., 2024. *Improved Persistent Organic Pollutants Analysis for a Safer Global Environment*. Technology Networks, 6 March. Available at: <https://www.technologynetworks.com/applied-sciences/articles/improved-persistent-organic-pollutants-analysis-for-a-safer-global-environment-384495?utm> Accessed on 25/10/2024

Esplugas, S., Bila, D.M., Krause, L.G.T. and Dezotti, M., 2007. Ozonation and advanced oxidation technologies to remove endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs) in water effluents. *Journal of hazardous materials*, 149(3), pp.631-642.

European Union, 2020. *Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast)*. Official Journal of the European Union, L 435, pp.1-62. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32020L2184> [Accessed 01/04/2025].

Fatoki, O.S. and Awofolu, O.R., 2004. Levels of organochlorine pesticide residues in marine-, surface-, ground-and drinking waters from the Eastern Cape Province of South Africa. *Journal of Environmental Science and Health, Part B*, 39(1), pp.101-114.

Fischer, D., Costley, S., Moloi, M., Jila, X. and Khauoe, G., 2012. South Africa National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants. *Department of Environmental Affairs Pretoria, South Africa*.

Focazio, M.J., Kolpin, D.W., Barnes, K.K., Furlong, E.T., Meyer, M.T., Zaugg, S.D., Barber, L.B. and Thurman, M.E., 2008. A national reconnaissance for pharmaceuticals and other organic wastewater contaminants in the United States—II) Untreated drinking water sources. *Science of the total Environment*, 402(2-3), pp.201-216.

Fujii, S., Polprasert, C., Tanaka, S., Lien, H., Pham, N., Qiu, Y., 2007. New POPs in the water environment: distribution, bioaccumulation and treatment of perfluorinated compound sea review paper. *Journal of Water Supply: Research and Technology* 56 (5), 313e326.

Fujitani, T., Fujii, Y., & Harada, K. 2020. Levels of Octachlorostyrene in Mothers' Milk and Potential Exposure Among Infants in Sendai City, Japan 2012. *International Journal of Environmental Research and Public Health*, 17(9), 3064.

Gaur, N., Dutta, D., Singh, A., Dubey, R. and Kamboj, D.V., 2022. Recent advances in the elimination of persistent organic pollutants by photocatalysis. *Frontiers in Environmental Science*, 10, p.872514.

Gaurav, G.K., Mehmood, T., Kumar, M., Cheng, L., Sathishkumar, K., Kumar, A. and Yadav, D., 2021. Review on polycyclic aromatic hydrocarbons (PAHs) migration from wastewater. *Journal of Contaminant Hydrology*, 236, p.103715.

Geyer, H.J., Rimkus, G.G., Scheunert, I., Kaune, A., Schramm, K.W., Kettrup, A., et al., 2000. Bioaccumulation and occurrence of endocrine-disrupting chemicals (EDCs), persistent organic pollutants (POPs) and other organic compounds in fish and other organisms including humans. In: *Bioaccumulation New Aspects and Developments*. Springer, Berlin, Heidelberg, pp. 1e166.

Gilbreath, A.N. and McKee, L.J., 2015. Concentrations and loads of PCBs, dioxins, PAHs, PBDEs, OC pesticides and pyrethroids during storm and low flow conditions in a small urban semi-arid watershed. *Science of the Total Environment*, 526, pp.251-261.

Gilca, A.F., Teodosiu, C., Fiore, S. and Musteret, C.P., 2020. Emerging disinfection byproducts: A review on their occurrence and control in drinking water treatment processes. *Chemosphere*, 259, p.127476.

Girones, L., Oliva, A.L., Negrin, V.L., Marcovecchio, J.E. and Arias, A.H., 2021. Persistent organic pollutants (POPs) in coastal wetlands: A review of their occurrences, toxic effects, and biogeochemical cycling. *Marine Pollution Bulletin*, 172, p.112864.

Gregoraszczuk, E.L. and Ptak, A., 2013. Endocrine - disrupting chemicals: Some actions of POPs on female reproduction. *International journal of endocrinology*, 2013(1), p.828532.

Guo, W., Pan, B., Sakkiyah, S., Yavas, G., Ge, W., Zou, W., Tong, W. and Hong, H., 2019. Persistent organic pollutants in food: contamination sources, health effects and detection methods. *International journal of environmental research and public health*, 16(22), p.4361.

Gwenzi, W. and Chaukura, N., 2018. Organic contaminants in African aquatic systems: current knowledge, health risks, and future research directions. *Science of the Total Environment*, 619, pp.1493-1514.

Halling-Sørensen, B.N.N.S., Nielsen, S.N., Lanzky, P.F., Ingerslev, F., Lützhøft, H.H. and Jørgensen, S.E., 1998. Occurrence, fate and effects of pharmaceutical substances in the environment-A review. *Chemosphere*, 36(2), pp.357-393.

Hasan, H.A., Muhammad, M.H. and Ismail, N.I., 2020. A review of biological drinking water treatment technologies for contaminants removal from polluted water resources. *Journal of Water Process Engineering*, 33, p.101035.

Huang X, Liu Q, Yao S, Jiang G. 2017. Recent progress in the application of nanomaterials in the analysis of emerging chemical contaminants. *Analytical Methods*. 9(19):2768-83

Hung, H., Katsoyiannis, A.A., Brorström-Lundén, E., Olafsdottir, K., Aas, W., Breivik, K., Bohlin-Nizzetto, P., Sigurdsson, A., Hakola, H., Bossi, R. and Skov, H., 2016. Temporal trends of Persistent Organic Pollutants (POPs) in arctic air: 20 years of monitoring under the Arctic Monitoring and Assessment Programme (AMAP). *Environmental Pollution*, 217, pp.52-61.

Hung, H., Katsoyiannis, A.A. and Guardans, R., 2016. Ten years of global monitoring under the Stockholm Convention on Persistent Organic Pollutants (POPs): Trends, sources and transport modelling. *Environmental pollution*, 217, pp.1-3.

Impellitteri, F., Multisanti, C. R., Rusanova, P., Piccione, G., Falco, F., & Faggio, C. 2023. Exploring the Impact of Contaminants of Emerging Concern on Fish and Invertebrates Physiology in the Mediterranean Sea. *Biology*. <https://doi.org/10.3390/biology12060767>

Information on Multilateral Environmental Agreements (InforMEA). (2012) *South Africa – National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants*. Available at: <https://www.informea.org/en/content/legislation/south-africa-national-implementation-plan-nip-stockholm-convention-persistent> (Accessed: on 10/09/2025).

Infrastructurenews. 2013. Umzonyana WTW to receive R50million upgrade.available at: <https://infrastructurenews.co.za/2013/04/17/umzonyana-wtw-to-receive-r50million-upgrade/> (accessed on 25/08/2024)

Iniaghe, P. and Kpomah, E., 2022. Polychlorinated biphenyl (PCBs) in water and sediments along the Udu River, Niger Delta, Nigeria: concentration, distribution and risk assessment. *Environ Expo Assess*. Available at <http://dx.doi.org/10.20517/jeea.2022.19>

Innovatech Labs. n.d. The Beginner's Guide to Interpreting GC/MS Results. from <https://www.innovatechlabs.com/newsroom/1841/how-to-interpret-gas-chromatography-mass-spectrometry-results/> (accessed on 18/05/2025)

International Organization for Standardization (ISO). 2019. *ISO 5667-1:2019 Water quality — Sampling — Part 1: Guidance on the design of sampling programmes*. Geneva: ISO.

Jepson, P.D., and Law, R.J., 2016. Persistent pollutants, persistent threats. *Science* 352 (6292), 1388e1389.

John, W. and Trollip, D., 2009. National standards for drinking water treatment chemicals. Water Research Commission, Pretoria, South Africa, p.101.

Jones, K.C. and De Voogt, P., 1999. Persistent organic pollutants (POPs): state of the science. *Environmental pollution*, 100(1-3), pp.209-221.

Jones, K.C., 2021. Persistent organic pollutants (POPs) and related chemicals in the global environment: some personal reflections. *Environmental Science & Technology*, 55(14), pp.9400-9412.

Jonker, M.T. and Koelmans, A.A., 2002. Sorption of polycyclic aromatic hydrocarbons and polychlorinated biphenyls to soot and soot-like materials in the aqueous environment: mechanistic considerations. *Environmental science & technology*, 36(17), pp.3725-3734.

Jurado, E., Dachs, J., Marinov, D. & Zaldivar, J. M. 2007. Fate of persistent organic pollutants in the water column: does turbulent mixing matter? *Marine pollution bulletin*, 54, 441-451.

Kampire E, Rubidge, G and Adams JB. 2017. Characterization of polychlorinated biphenyls in surface sediments of the North End Lake, Port Elizabeth, South Africa. *Water SA* 43 (4) 646–654.

Kellerman, A.M., Hernes, P.J., McKenna, A.M., Clark, J.B., Edmund, A., Grunert, B., Mann, P.J., Mannino, A., Novak, M., Stubbins, A. and Tzortziou, M., 2023. Mixing behavior of dissolved organic matter at the Yukon and Kolyma land ocean interface. *Marine Chemistry*, 255, p.104281.

Kern, K., 2014. New standards for the chemical quality of water in Europe under the new Directive 2013/39/EU. *Journal for European Environmental & Planning Law*, 11(1), pp.31-48.

Koelble, T.A. and LiPuma, E. (2010) 'Institutional obstacles to service delivery in South Africa', *Social Dynamics*, 36(3), pp. 565–589

Kouras, A., Zouboulis, A., Samara, C. and Kouimtzis, T., 1998. Removal of pesticides from aqueous solutions by combined physicochemical processes—the behaviour of lindane. *Environmental pollution*, 103(2-3), pp.193-202.

Krasner, S.W., Westerhoff, P., Chen, B., Rittmann, B.E. and Amy, G., 2009. Occurrence of disinfection byproducts in United States wastewater treatment plant effluents. *Environmental science & technology*, 43(21), pp.8320-8325.

Kristensen, P. and Bøgestrand, J., 1996. *Surface water quality monitoring*. European Environment Agency.

Krithiga, T., Sathish, S., Renita, A.A., Prabu, D., Lokesh, S., Geetha, R., Namasivayam, S.K.R. and Sillanpaa, M., 2022. Persistent organic pollutants in water resources: Fate, occurrence, characterization and risk analysis. *Science of The Total Environment*, 831, p.154808.

Kumar, R., Sharma, P., Verma, A., Jha, P.K., Singh, P., Gupta, P.K., Chandra, R. and Prasad, P.V., 2021. Effect of physical characteristics and hydrodynamic conditions on transport and deposition of microplastics in riverine ecosystem. *Water*, 13(19), p.2710.

Lammel, G., Meixner, F.X., Vrana, B., Efstathiou, C.I., Kohoutek, J., Kukucka, P., et al., 2016. Bidirectional air-sea exchange and accumulation of POPs (PAHs, PCBs, OCPs and PBDEs) in the nocturnal marine boundary layer. *Atmospheric Chemistry and Physics* 16 (10), 6381e6393.

LeChevallier M.W, Evans T.M, Seidler R.J., 1981. Effect of turbidity on chlorination efficiency and bacterial persistence in drinking water. *Applied and environmental microbiology*, 42(1), pp159–67.

Li, S., Luo, J., Hang, X., Zhao, S. and Wan, Y., 2019. Removal of polycyclic aromatic hydrocarbons by nanofiltration membranes: Rejection and fouling mechanisms. *Journal of membrane science*, 582, pp.264-273.

Li, W., Zhu, N., Shen, Y. and Yuan, H., 2021. Towards efficient elimination of polycyclic aromatic hydrocarbons (PAHs) from waste activated sludge by ozonation. *Environmental Research*, 195, p.110783.

Lima, A.L.C., Farrington, J.W. and Reddy, C.M., 2005. Combustion-derived polycyclic aromatic hydrocarbons in the environment—a review. *Environmental forensics*, 6(2), pp.109-131.

Lohmann, R., Brevik, K., Dachs, J. & Muir, D. 2007. Global fate of POPs: Current and future research directions. *Environmental pollution*, 150, 150-165

Lohmann, R., MacFarlane, J. K. & Gschwend, P. M. 2005. Importance of black carbon to sorption of native PAHs, PCBs, and PCDDs in Boston and New York Harbor sediment. *Environmental science & technology*, 39, 141-148.

Lu JY, Du X, Lipscomb G. Cleaning membranes with focused ultrasound beams for drinking water treatment. In 2009 IEEE International Ultrasonics Symposium 2009, 1195-1198 IEEE.

Mandal, A., Senthil Kumar, P., Poorva, C.S., Srinivasa Raju, L., Balasubramani, S.R. and Rangasamy, G., 2024. Research progress of persistent organic pollutants in water: classification, sources, potential risks, and treatment approaches. *Water Practice & Technology*, 19(3), pp.937-959.

Meffe, R. and de Bustamante, I., 2014. Emerging organic contaminants in surface water and groundwater: a first overview of the situation in Italy. *Science of the Total Environment*, 481, pp.280-295.

Membracon, 2022. The 5 Most Common Problems In Water Treatment. [online] Available at: <https://www.membracon.co.uk/blog/5-common-problems-water-treatment/> [Accessed 19 May 2025].

Mensah-Akutteh, H., Buamah, R., Wiafe, S. and Nyarko, K.B., 2022. Raw water quality variations and its effect on the water treatment processes. *Cogent Engineering*, 9(1), p.2122152. Available at: <https://doi.org/10.1080/23311916.2022.2122152>

Metcalfe, C., Miao, X.S., Hua, W., Letcher, R. and Servos, M., 2004. Pharmaceuticals in the Canadian environment. In *Pharmaceuticals in the environment: sources, fate, effects and risks* (pp. 67-90). Berlin, Heidelberg: Springer Berlin Heidelberg.

Michałowicz, J. and Duda, W., 2007. Phenols--Sources and Toxicity. *Polish Journal of Environmental Studies*, 16(3).

Momba, M.N.B., Obi, C.L. and Thompson, P., 2009. Survey of disinfection efficiency of small drinking water treatment plants: Challenges facing small water treatment plants in South Africa. *Water Sa*, 35(4).

Moodley, B., Birungi, G. and Ndungu, P., 2016. *Detection and Quantification of Emerging Organic Pollutants in the Umgeni and Msunduzi Rivers*. WRC Report No. 2215/1/16. Pretoria: Water Research Commission. Available at: <https://www.wrc.org.za/wp-content/uploads/mdocs/2215-1-16.pdf> (Accessed: 07/09/2025).

Mukhopadhyay, A., Duttagupta, S. and Mukherjee, A., 2022. Emerging organic contaminants in global community drinking water sources and supply: A review of occurrence, processes and remediation. *Journal of Environmental Chemical Engineering*, 10(3), p.107560. [HTML]

Muñoz-Arnanz, J., Roscales, J.L., Ros, M., Vicente, A., Jiménez, B., 2016. Towards the implementation of the Stockholm Convention in Spain: five-year monitoring (2008e2013) of POPs in air based on passive sampling. *Environmental Pollution* 217, 107e113

Mwakalapa, E.B., Mmochi, A.J., Müller, M.H.B., Mdegela, R.H., Lyche, J.L., Polder, A., 2018. Occurrence and levels of persistent organic pollutants (POPs) in farmed and wild marine fish from Tanzania. A pilot study. *Chemosphere* 191, 438e449.

Nair, HT and Perumal S. 2022. Trophic transfer and accumulation of microplastics in freshwater ecosystem: Risk to food security and human health. *International Journal of Ecology - Wiley Online Library*.

Ncube, E.J., 2010. Selection and prioritization of organic contaminants for monitoring in the drinking water value chain (Doctoral dissertation, University of Pretoria).

Ncube, E.J., Voyi, K. and Du Preez, H., 2012. Implementing a protocol for selection and prioritisation of organic contaminants in the drinking water value chain: Case study of Rand Water, South Africa. *Water SA*, 38(4), pp.487-504.

Ndunda, E.N., Madadi, V.O. and Wandiga, S.O., 2018. Organochlorine pesticide residues in sediment and water from Nairobi River, Kenya: levels, distribution, and ecological risk assessment. *Environmental Science and Pollution Research*, 25, pp.34510-34518.

Nefale, A.D., Kamika, I., Obi, C.L. and Momba, M.N., 2017. The limpopo non-metropolitan drinking water supplier response to a diagnostic tool for technical compliance. *International journal of environmental research and public health*, 14(7), p.810.

Nelson, P., 2003. *Index to EPA test methods*. United States Environmental Protection Agency, Region I.

Netshithothole, R., Managa, M., Botha, T.L. and Madikizel, L.M., 2024. Occurrence of selected pharmaceuticals in wastewater and sludge samples from wastewater treatment plants in Eastern Cape province of South Africa. *South African Journal of Chemistry*, 78, pp.7-14.

Nghiem, L.D., Boussouga, Y.A.Imbrogno, A., and Schäfer, A.I., 2021. Trace Contaminant Removal by Nanofiltration. *Nanofiltration: Principles, Applications, and New Materials*, 2, pp.805-887.

NHMRC, NRMCC. 2011. Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

Nordberg, M., Templeton, D.M., Andersen, O. and Duffus, J.H., 2009. Glossary of terms used in ecotoxicology (IUPAC Recommendations 2009). *Pure and Applied Chemistry*, 81(5), pp.829-970.

Norra, G.-F. & Radjenovic, J., 2021. Removal of persistent organic contaminants from wastewater using a hybrid electrochemical-granular activated carbon (GAC) system. *Journal of Hazardous Materials*, 415, p.125557. Available at: <https://doi.org/10.1016/j.jhazmat.2021.125557>

Odabasi, M., Dumanoglu, Y., Falay, E.O., Tuna, G., Altioek, H., Kara, M., et al., 2016. Investigation of spatial distributions and sources of persistent organic pollutants (POPs)

in a heavily polluted industrial region using tree components. *Chemosphere* 160, 114e125

Olaniyan, L.W. and Okoh, A.I., 2020. Determination and ecological risk assessment of two endocrine disruptors from River Buffalo, South Africa. *Environmental Monitoring and Assessment*, 192(12), p.750.

Osuolale, O. and Okoh, A., 2017. Human enteric bacteria and viruses in five wastewater treatment plants in the Eastern Cape, South Africa. *Journal of infection and public health*, 10(5), pp.541-547.

O'Keefe J.H., van Ginkel C.E., Hughes D.A., Hill T.R. and Ashton P.J. 1996. A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape, with special emphasis on the impacts of low cost, high-density urban development on water quality. Water Research Commission Report No. 405/1/96. WRC PO Box 824 Pretoria 0001. Available at: https://www.dws.gov.za/iwqs/rhp/state_of_rivers/ecape_04/BufRiverRepFnl.pdf

Palmer, R.W. and O'Keeffe, J.H., 1990. Downstream effects of impoundments on the water chemistry of the Buffalo River (Eastern Cape), South Africa. *Hydrobiologia*, 202, pp.71-83.

Patel, A.B., Shaikh, S., Jain, K.R., Desai, C. and Madamwar, D., 2020. Polycyclic aromatic hydrocarbons: sources, toxicity, and remediation approaches. *Front Microbiol* 11: 562813 [online]

Persson, N.J., Gustafsson, Ö., Bucheli, T.D., Ishaq, R., Naes, K. and Broman, D., 2002. Soot-carbon influenced distribution of PCDD/Fs in the marine environment of the Grenlandsfjords, Norway. *Environmental Science & Technology*, 36(23), pp.4968-4974.

Przybylska, A. and Pruss, A., 2022. The impact of modernization of the water treatment plant on improving the quality of water directed to recipients. *Journal of Ecological Engineering*, 23(11), pp.11-17.

Qu, C. 2017. Persistent organic pollutants in a multimedia environment and associated human health risks: Case studies in the region of Campania, Italy, and south-central China. Available at: <https://doi.org/10.6093/UNINA/FEDOA/11531>

Ren, X., Zeng, G., Tang, L., Wang, J., Wan, J., Liu, Y., et al., 2018. Sorption, transport and biodegradation: an insight into bioavailability of persistent organic pollutants in soil. *The Science of the Total Environment* 610, 1154-1163

Republic of South Africa. 1997. *Water Services Act, No. 108 of 1997*. Pretoria: Government Gazette.

Republic of South Africa. 1998. *National Water Act, No. 36 of 1998*. Pretoria: Government Gazette.

Rimayi, C. 2011. Influence of Matrix Effect on Selected Organochlorine Pesticide Residues in Water from the Jukskei River Catchment: Gauteng, South Africa. Available at: <https://digiresearch.vut.ac.za/bitstreams/7d10815f-f0de-464a-a2e4-d70a6d66c216/download> (accessed on 16/10/2024)

Rimayi, C., Chimuka, L., Gravell, A., Fones, G.R. and Mills, G.A., 2019. Use of the Chemcatcher® passive sampler and time-of-flight mass spectrometry to screen for emerging pollutants in rivers in Gauteng Province of South Africa. *Environmental Monitoring and Assessment*, 191(6), p.388.

Rimayi, C. and Madikizela, L.M., 2023. Utility of an alternative method (to USEPA Method 1613) for analysis of priority persistent organic pollutants in soil from mixed industrial–suburban areas of Durban, South Africa. *Integrated Environmental Assessment and Management*, 19(3), pp.749-762.

Ritter, L., Solomon, K.R., Forget, J., Stemmeroff, M. and O'Leary, C., 1995. Persistent organic pollutants: an assessment report on: DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, hexachlorobenzene, mirex, toxaphene, polychlorinated biphenyls, dioxins and furans. *International Programme on Chemical Safety (IPCS)*.

River Health Programme (RHP). 2004. State-of-rivers report: Buffalo River system. Pretoria: Department of Water Affairs and Forestry.

Roos, C., Pieters, R., Genthe, B. and Bouwman, H., 2011. Persistent organic pollutants (POPs) in the water environment. *Water Res. Comm. Rpt*, 1561(1), p.11.

Sahmarani, R., Net, S., Chbib, C., Baroudi, M. and Ouddane, B., 2021. Elimination of organochlorine pesticides from water by a new activated carbon prepared from Phoenix dactylifera date stones. *Environmental Science and Pollution Research*, 28, pp.10140-10154.

Said, T.O. and El Zokm, G.M., 2024. Persistent Organic Pollutants in Aquatic Systems. *Classification, Toxicity, Remediation and Future Springer*, 1.

Sasakova, N., Gregova, G., Takacova, D., Mojzisova, J., Papajova, I., Venglovsky, J., Szaboova, T., and Kovacova, S., 2018. Pollution of surface and groundwater by sources related to agricultural activities. *Frontiers in sustainable food systems*, 2, pp.1-42.

Schutte, F. and Focke, W., 2006. Handbook for the operation of water treatment works. *The Water Research Commission, The Water Institute of Southern Africa, TT265/06*.

Shah, S., Wong, S., Bearer, C. and Brumberg, H., 2017. Environmental health reform in a synthetic world. *Pediatric research*, 82(3), pp.373-375.

Sharp, E.L., Parsons, S.A. and Jefferson, B., 2006. Seasonal variations in natural organic matter and its impact on coagulation in water treatment. *Science of the Total Environment*, 363(1-3), pp.183-194.

Shabeer, T.P.A., Saha, A., Gajbhiye, V.T., Gupta, S. & Manjaiah, K.M., 2014. Simultaneous removal of multiple pesticides from water: Effect of organically modified clays as coagulant aid and adsorbent in coagulation–flocculation process. *Environmental Technology*, 35(20), pp. 2619–2627.
<https://doi.org/10.1080/09593330.2014.9145>

Sil, A., Ghosh, D., Barman, M., Bhattacharyya, K., Das, S., Horijan, B. and Lohara, S., 2020. Strategies for mitigation of polychlorinated biphenyls (PCBs): A review. *International Journal of Chemical Studies*, 8(4), pp.1700-1708.

Sillanpää, M., Ncibi, M.C. and Matilainen, A., 2018. Advanced oxidation processes for the removal of natural organic matter from drinking water sources: A comprehensive review. *Journal of environmental management*, 208, pp.56-76.

- Smol, M. and Włodarczyk-Makula, M., 2017. The effectiveness in the removal of PAHs from aqueous solutions in physical and chemical processes: a review. *Polycyclic Aromatic Compounds*, 37(4), pp.292-313.
- Sorlini, S. Collivignarelli M.S. Castagnola, F. Crotti B.M. and Raboni, M., 2015. The methodological approach for the optimization of drinking water treatment plants' operation: a case study, *Water science and technology*, 71(4), pp. 597-604
- South African Bureau of Standards (SABS), 2014. *South African National Standard (SANS 241:2014) – Drinking Water Quality*. Pretoria: SABS
- South African Bureau of Standards (SABS), 2015. *SANS 241-1:2015 Drinking Water – Part 1: Microbiological, Physical, Aesthetic and Chemical Determinants*. Pretoria: SABS Standards Division
- Spurgeon, D., Wilkinson, H., Civil, W., Hutt, L., Armenise, E., Kieboom, N., Sims, K. and Besien, T., 2022. Worst-case ranking of organic chemicals detected in groundwaters and surface waters in England. *Science of The Total Environment*, 835, p.155101.
- Stackelberg, P.E., Furlong, E.T., Meyer, M.T., Zaugg, S.D., Henderson, A.K. & Reissman, D.B. 2006. *Persistence of pharmaceutical compounds and other organic wastewater contaminants in a conventional drinking-water-treatment plant*, *Science of the Total Environment*, 329(1-3), pp. 99–113. doi:10.1016/j.scitotenv.2004.12.044.
- Tahraoui, H., Toumi, S., Boudoukhani, M., Touzout, N., Sid, A.N.E.H., Amrane, A., Belhadj, A.E., Hadjadj, M., Laichi, Y., Aboumustapha, M. and Kebir, M., 2024. Evaluating the effectiveness of coagulation–flocculation treatment using aluminum sulfate on a polluted surface water source: A year-long study. *Water*, 16(3), p.400.
- Taiwo, A.M., 2019. A review of environmental and health effects of organochlorine pesticide residues in Africa. *Chemosphere*, 220, pp.1126-1140.
- Tata and Howard, Inc. (2015). *Water Treatment and Wastewater Treatment Infographic*. [image] Available at: <https://tataandhoward.com> [Accessed 12 May 2025].
- Teodosiu, C., Gilca, A.F., Barjoveanu, G. and Fiore, S., 2018. Emerging pollutants removal through advanced drinking water treatment: A review on processes and

environmental performances assessment. *Journal of cleaner production*, 197, pp.1210-1221.

Thakur, M. and Pathania, D., 2020. Environmental fate of organic pollutants and effect on human health. In *Abatement of Environmental Pollutants* (pp. 245-262). Elsevier.

Titchou, F.E., Zazou, H., Afanga, H., El Gaayda, J., Akbour, R.A. and Hamdani, M., 2021. Removal of persistent organic pollutants (POPs) from water and wastewater by adsorption and electrocoagulation process. *Groundwater for Sustainable Development*, 13, p.100575.

Tsai, J.H., Chen, S.J., Huang, K.L., Chang-Chien, G.P., Lin, W.Y., Feng, C.W., et al., 2016. Characteristics of persistent organic pollutant emissions from a diesel-engine generator fueled using blends of waste cooking oil-based biodiesel and fossil diesel. *Aerosol and Air Quality Research* 16, 2048e2058.

Ugranli, T., Gungormus, E., Kavcar, P., Demircioglu, E., Odabasi, M., Sofuoglu, S.C., et al., 2016. POPs in a major conurbation in Turkey: ambient air concentrations, seasonal variation, inhalation and dermal exposure, and associated carcinogenic risks. *Environmental Science and Pollution Research* 23 (22), 22500e22512

United Nations Environment Programme (UNEP). 2009 Stockholm Convention on Persistent Organic Pollutants (POPs) as amended in 2009: Text and Annexes. Available at: <https://wedocs.unep.org/20.500/11822/27568> (Accessed: 10 March 2024)

United States Environmental Protection Agency (USEPA). 2019. Method 3500C: Organic Compounds in Water by GC/MS. In *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (SW-846).

United States Environmental Protection Agency (USEPA). 2019. Method 3510C: Separatory Funnel Liquid-Liquid Extraction. In *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (SW-846)

United States Environmental Protection Agency (USEPA). 2019. Method 3520C: pH Adjustment. In *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (SW-846).

United States Environmental Protection Agency (USEPA). 2019. Method 3535A: Extraction of Organic Compounds from Water Using a Solvent. In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846). available at: https://www.nemi.gov/methods/method_summary/9187/

United States Environmental Protection Agency (USEPA). 2019. Method 3630C: Solid-Phase Extraction. In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846).

United States Environmental Protection Agency (USEPA). 2019. Method 3650C: Silica Gel Cleanup. In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846).

United States Environmental Protection Agency (USEPA). 2019. Method 3690C: Data Analysis and Reporting. In Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846).

U.S. Environmental Protection Agency (EPA). n.d. Public Health Statement: Polychlorinated Biphenyls (PCBs). Retrieved April 1, 2025, from <https://semspub.epa.gov/work/03/2256618.pdf>

Vasseghian, Y., Khataee, A., Dragoi, E.-N., Moradi, M., Nabavifard, S., Oliveri Conti, G., et al., 2020. Pollutants degradation and power generation by photocatalytic fuel cells: a comprehensive review. *Arab. J. Chem.* 13, 8458–8480.

Verlicchi, P. and Grillini, V., 2020. Surface water and groundwater quality in South Africa and mozambique—Analysis of the Most critical pollutants for drinking purposes and challenges in water treatment selection. *Water*, 12(1), p.305.

Verma, S., Daverey, A. and Sharma, A., 2017. Slow sand filtration for water and wastewater treatment—a review. *Environmental Technology Reviews*, 6(1), pp.47-58.

Villanueva, C.M., Kogevinas, M., Cordier, S., Templeton, M.R., Vermeulen, R., Nuckols, J.R., Nieuwenhuijsen, M.J. and Levallois, P., 2014. Assessing exposure and health

consequences of chemicals in drinking water: current state of knowledge and research needs. *Environmental health perspectives*, 122(3), pp.213-221.

Walsh, M.E., Zhao, N., Gora, S.L. and Gagnon, G.A., 2009. Effect of coagulation and flocculation conditions on water quality in an immersed ultrafiltration process. *Environmental Technology*, 30(9), pp.927-938.

Wang, F., Gao, B., Yue, Q., Bu, F. and Shen, X., 2017. Effects of ozonation, powdered activated carbon adsorption, and coagulation on the removal of disinfection by-product precursors in reservoir water. *Environmental Science and Pollution Research*, 24, pp.17945-17954.

Wang, L., Pang, S. and Zhou, G., 2019. Recent advances in spectroscopy technology for trace analysis of persistent organic pollutants. *Applied Sciences*, 9(17), p.3439.

Water, S.D., 2008. Standards under the microscope. *The Water Wheel*.

Wood TP, Duvenage CSJ and Rohwer E. 2015. The occurrence of anti-retroviral compounds used for HIV treatment in South African surface water. *Environmental Pollution* 199 235-243.

World Health Organization (WHO), 1998. Polynuclear aromatic hydrocarbons. *Guidelines for drinking water quality*, pp.123-52.

World Health Organization (WHO). 2011. Guidelines for Drinking-Water Quality. WHO Press.

World Health Organization (WHO), 2011. *Guidelines for Drinking-Water Quality*. 4th ed. Geneva: WHO Press. Available at: <https://www.who.int/publications/i/item/9789241548151> (Accessed: 10/09/2025)

World Health Organization (WHO). 2017. *Guidelines for drinking-water quality: Fourth edition incorporating the first addendum*. Geneva: WHO. Available at: <https://www.who.int/publications/i/item/9789241549950> (Accessed: 8 July 2025).

World Health Organization (WHO), 2017. Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. World Health Organization

World Health Organization (WHO), 2022. *Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda*. Geneva: WHO. Available at: <https://www.who.int/publications/i/item/9789241549950> (Accessed: on 02/04/2025)

Yahaya, A., Okoh, O.O., Okoh, A.I. and Adeniji, A.O., 2017. Occurrences of organochlorine pesticides along the course of the Buffalo River in the Eastern Cape of South Africa and its health implications. *International Journal of Environmental Research and Public Health*, 14(11), p.1372.

Yahaya, A., Adeniji, O.A., Okoh, O.O., Songca, S.P. and Okoh, A.I., 2018. Distribution of polychlorinated biphenyl along the course of the Buffalo River, Eastern Cape Province, South Africa, and possible health risks. *Water SA*, 44(4), pp.601-611.

Yahaya, A., Okoh, O.O., Agunbiade, F.O. and Okoh, A.I., 2019. Occurrence of phenolic derivatives in Buffalo River of Eastern Cape South Africa: exposure risk evaluation. *Ecotoxicology and Environmental Safety*, 171, pp.887-893.

Yin, R.K., 2014. Case study research: Design and methods (Vol. 6). sage.

Zamxaka, M., G. Pironcheva, and NYO_ Muyima. "Microbiological and physico-chemical assessment of the quality of domestic water sources in selected rural communities of the Eastern Cape Province, South Africa." *Water Sa* 30, no. 3 (2004): 333-340.

Zhang, K., Chang, S., Wang, E., Zhang, Q., Fan, Y., Bai, Y., Zhang, M., Fu, Q. and Jia, W., 2022. Occurrence, health risk, and removal efficiency assessment of volatile organic compounds in drinking water treatment plants (DWTPs): An investigation of seven major river basins across China. *Journal of Cleaner Production*, 372, p.133762.

ANNEXURE A

Questionnaire On the Operation of a Drinking Water Treatment Plant and Removal of Persistent Organic Pollutants (POPs)

Instructions for Completion:

Please answer all questions to the best of your ability. If unsure about a question, please choose "Unsure" or provide your best estimate. Your responses are crucial in helping us understand and improve our water treatment processes, especially concerning the removal of persistent organic pollutants. Thank you for your participation.

Demographic Information

1. Position at the Plant:

☐ Operator

☐ Supervisor

☐ Manager

☐ Other (Please specify): _____

2. Years of Experience in Water Treatment:

☐ Less than 1 year

☐ 1-5 years

☐ 6-10 years

☐ More than 10 years

General Operation

3. Please briefly describe your daily responsibilities at the water treatment plant.

4. What type of water treatment technologies are currently implemented at your plant?

☐ Coagulation and Flocculation

☐ Sedimentation

☐ Filtration

☐ Disinfection

☐ Advanced Oxidation Processes

☐ Membrane Processes

☐ Other (Please specify): _____

5. Has there been any recent upgrade or modification to the treatment processes? If yes, please specify the nature of these upgrades.

Capacity to Remove POPs

6. Is the removal of Persistent Organic Pollutants (POPs) a specific target in your water treatment processes?

☐ Yes

☐ No

7. If yes, which technologies are employed to specifically target and remove POPs?

☐ Activated Carbon Treatment

☐ Advanced Oxidation

☐ Membrane Filtration

☐ Chemical Precipitation

☐ Biological Treatment

☐ Other (Please specify): _____

8. What are the challenges faced in removing POPs from the water supply?

☐ Technological limitations

☐ Financial constraints

☐ Lack of skilled workforce

☐ Regulatory challenges

☐ Other (Please specify): _____

9. How frequently is the effectiveness of POP removal monitored and evaluated?

☐ Daily

☐ Weekly

☐ Monthly

☐ Annually

☐ Other (Please specify): _____

10. In your experience, how effective is the current system in removing POPs from the drinking water?

☐ Very effective

☐ Moderately effective

☐ Slightly effective

☐ Not effective at all

☐ Unsure

11. Please provide any suggestions or feedback on improving POP removal capabilities at the plant.

Closing

12. Do you have any additional comments or insights you would like to share about the operations or environmental challenges at the plant?

ANNEXURE B



NORTH-WEST UNIVERSITY
YUNIBESITHI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Private Bag X6001, Potchefstroom

South Africa, 2520

Tel: +27 18 299 - 1111/2222

Web: <http://www.nwu.ac.za>

28th April, 2024

ATTN: The Plant Manager/Superintendent
Plant Operator
Process Controller
Lab Technician

Dear Sir/Madam,

RE: INVITATION TO PARTICIPATE IN RESEARCH STUDY

Introduction

You are being invited to participate in a research study conducted by Mr Benjamin Addey with Student #: 44285086 under the supervision of Prof Wynand Malherbe for a Masters in Ecological Water Requirements in Environmental Management at the North-West University. The study is entitled "Persistent Organic Pollutants (POPs) removal by Drinking Water Treatment Plants (DWTPs): A case study of the Buffalo River Catchment" and aims to investigate the removal of potential Persistent Organic Pollutants of raw water from the Buffalo River by the KWT DWTP. You were **purposively** selected as a possible participant in this study because of your management/operational responsibility at the DWTP. The research will form part of a master's dissertation which will be submitted in partial fulfillment of the requirements for the degree Masters in Ecological Water Requirements in Environmental Management at the North-West University.

Interview procedure

If you agree to participate in this study, you would be requested to do the following:

- Indicate a time and date when you will be available for an interview. The interview should take no more than 10 minutes of your time.
- Indicate whether you would prefer to be interviewed in person, telephonically or via a technology such as Zoom or Skype.
- Agree to the recording (audio only) of the interview to ensure that it can be accurately transcribed. The recording will be deleted as soon as it has been transcribed. You will have the right to review and edit the audio recording if you so choose.
- Read through this consent form which is to be signed on the day of the interview.

Confidentiality

The records from this study will be kept as confidential as possible. No individual identities will be used in any reports or publications resulting from the study. All transcripts will be given codes (e.g. Participant 1) and stored separately from any names or other direct identification of participants. The information obtained through the interview will be used exclusively for this study and for no other purpose.

Potential risks and discomforts

No risks or discomforts are foreseen. In the event that a risk is identified, or discomfort is experienced, the interview will be stopped. You further have the right to end the interview at any time and for any reason.

Potential benefits to the interviewee and/or society in general

The study will contribute to existing knowledge on the pollution of the Buffalo River by POPs and the role of DWTPs. It will further provide insights on possible recommendations on optimization of the DWTP and routine monitoring of POPs

Compensation

No compensation can be offered for participation in the research.

Withdrawal

You may withdraw from the study at any time and do not have to provide a reason.

Ethical clearance

This research has obtained ethical clearance with ethics #: NWU-01210-24-A9 from the Senate Committee for Research Ethics. If you have any concerns or questions in this regard, please contact Prof. Roelof Burger (roelof.burger@nwu.ac.za).

Contact details of researcher

If you have any questions or concerns about the research, please feel free to contact Benjamin Addey on 071 789 9247 / 44285086@nwu.ac.za or Prof Wynand Malherbe on Wynand.Malherbe@nwu.ac.za

INTERVIEWEE CONSENT

I _____ confirm that the above information was explained to me in a language and in manner that I understood. I further confirm that I am older than 18 years of age and hereby volunteer to take part in the study.

Signature_____Place_____Date_____

RESEARCHER CONFIRMATION

I _____ hereby confirm that the contents of this document was explained to the participant in a language and manner that he / she could understand.

Signature_____Place_____Date_____

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the **Faculty of Natural and Agricultural Sciences Ethics Committee (FNAS-REC)**, the Faculty of Natural and Agricultural Sciences Ethics Committee hereby **approves** your study as indicated below. This implies that the North-West University Senate Committee for Research Ethics (NWU-SCRE) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: Persistent Organic Pollutants (POPs) Removal by Drinking Water Treatment Plants. (DWTPs): A Case Study of the Buffalo River Catchment

Study Leader/Supervisor: Prof W Malherbe

Student: BT Addey

Ethics number:

N	W	U	-	0	1	2	1	0	-	2	4	-	A	9
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Institution

Study Number

Year

Status

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application type: Single

Risk Category:

Minimal

Commencement date: 22/02/2024

Expiry date: 22/05/2025

Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.

Special in process conditions of the research for approval (if applicable):

- The following documentation are archived by FNASREC and should be complete and kept up to date:
 - Research proposal
 - Signed approval from the scientific committee indicating the proposed risk category
- All researchers involved in the study should submit signed NWU code of conduct statements annually.
- All researchers of low risk studies should submit proof of relevant ethics training every two years.
- All researchers that take part in activities that pose a safety and security threat to the researchers or the environment should submit a risk assessment form annually.
- All research involving human interaction should follow best ethical practise and keep documents as proof. This includes informed consent, questionnaires, incorporation of risk-benefit, and responsible data management.
- Any research at governmental or private institutions, permission must still be obtained from relevant authorities and provided to the FNASREC. Ethics approval is required BEFORE approval can be obtained from these authorities.

Special conditions:

The best practices with regards to interviews should be implemented, including proper negotiation of access to participants; representative sampling; documented informed consent that includes the important elements; alignment of information collected with research questions; anonymization of collected information, ensuring the integrity and security of all data collected.

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:

- *The study leader/supervisor (principle investigator)/researcher must report in the prescribed format to the FNASREC:*
 - *annually (or as otherwise requested) on the monitoring of the study, whereby a letter of continuation will be provided, and upon completion of the study; and*
 - *without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.*
- *The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the study leader/researcher must apply for approval of these amendments at the FNASREC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.*
- *Annually a number of studies may be randomly selected for an external audit.*
- *The date of approval indicates the first date that the study may be started.*
- *In the interest of ethical responsibility, the NWU-SCRE and FNASREC reserves the right to:*
 - *request access to any information or data at any time during the course or after completion of the study;*
 - *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;*
 - *withdraw or postpone approval if:*
 - * *any unethical principles or practices of the study are revealed or suspected;*
 - * *it becomes apparent that any relevant information was withheld from the FNASREC or that information has been false or misrepresented;*
 - * *submission of the annual (or otherwise stipulated) monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and / or*
 - * *new institutional rules, national legislation or international conventions deem it.*
- *FNAS-REC can be contacted for further information or any report templates via Roelof.Burger@nwu.ac.za 018 299 4269*

The FNASREC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the FNASREC or the NWU-SCRE for any further enquiries or requests for assistance.

Yours sincerely,



Prof Roelof Burger
Chairperson Faculty of Natural and Agricultural Sciences Ethics Committee (FNASREC)

Buffalo City Metropolitan Municipality

East London | Bisho | King Williams Town
Province of the Eastern Cape
South Africa

Website: www.buffalocity.gov.za



**BUFFALO CITY
METROPOLITAN MUNICIPALITY**

Office of the City Manager
10th Floor Trust Centre
Cnr Oxford and North street
East London
5201

Tel: 043 705 1045
Email: Kholekas@buffalocity.gov.za

Date: 03 JUNE 2024

TO WHOM IT MAY CONCERN

**RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH IN BCMM:
MR. BENJAMIN ADDEY**

Dear Sir/Madam

IT IS HEREBY ACKNOWLEDGED THAT MR. BENJAMIN ADDEY IS AN MASTERS OF ENVIRONMENTAL MANAGEMENT CANDIDATE AT NORTH-WEST UNIVERSITY AND WILL BE CONDUCTING RESEARCH PROJECT ON "PERSISTENT ORGANIC POLLUTANTS REMOVAL BY DRINKING WATER TREATMENT PLANTS: A CASE STUDY OF THE BUFFALO RIVER CATCHMENT".

He has met the prerequisites for conducting data collection at Buffalo City Metropolitan Municipality (BCMM) for partial fulfillment of his research.

WITH REFERENCE TO THE LETTER TO THE CITY MANAGER DATED 03 JUNE 2024, PERMISSION WAS REQUESTED TO CONDUCT RESEARCH AT BCMM FOR HIS RESEARCH REPORT, ENTITLED "PERSISTENT ORGANIC POLLUTANTS REMOVAL BY DRINKING WATER TREATMENT PLANTS: A CASE STUDY OF THE BUFFALO RIVER CATCHMENT".



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This request was scrutinized by the Information and Knowledge Management, Research and Policy Unit for further assistance, and approved in accordance with national and international research ethical and legal norms, standards, and guidelines.

Mr. BENJAMIN ADDEY was asked to provide the Unit with the necessary documentation, which he subsequently did.

BCMM officials contact details will be provided to him and he will be informed to contact them directly for assistance.

We wish **MR. BENJAMIN ADDEY** good luck in his research at Buffalo City Metropolitan Municipality.

MR. GCOBANI MSINDWANA

.....
HEAD: IKM, RESEARCH AND POLICY

MR MXOLISI YAWA

.....
CITY MANAGER

APPROVED

NOT-APPROVED



BUFFALO CITY METROPOLITAN MUNICIPALITY

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