A TIME SERIES ANALYSIS OF FRESH WATER QUALITY IN THE GREATER PLETTENBERG BAY MUNICIPALITY, WESTERN CAPE PROVINCE

BY

ZOVUYO KOLWAPI

A MINI DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE
MASTER OF ENVIRONMENTAL MANAGEMENT

IN THE

FACULTY OF APPLIED SCIENCES

Department of Environmental and Occupational Studies

CAPE PENINSULA UNIVERSITY OF TECHNOLOGY

CAPE TOWN

Supervisor: Dr Solomon Eghosa Uhunamure

Co-Supervisor: Prof Karabo Shale

District Six Campus

Date Submitted**:**

APRIL 2023

DECLARATION

I, **Zovuyo Kolwapi**, declare that the dissertation which I hereby submit, for the degree of Master of Environmental Sciences at the Cape Peninsula University of Technology, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature: **Date: 2023 April 05**

Zovuyo Kolwapi

ABSTRACT

This study aimed to analyse the variation of recreational water quality in Plettenberg Bay in an attempt to comprehend the effects of pollution on the environment, and more specifically the potential impacts on the quality of surface water used for recreational activities. Plettenberg Bay is a major destination for tourists in South Africa, with recreational water activities representing an important attraction and contributor to the local economy. The study analysed the specific water quality parameters and their variation over five years. Water and its recreational use have a paramount importance for the economy and ecology, and this requires the solid implication of authorities and the community to conserve its quality for the benefit of all. Therefore, the importance of constant monitoring and analysis of water quality cannot be overemphasised if water must be kept clean and well-managed.

For this study, data were obtained from Bitou Municipality, the local authority in charge of the water monitoring program in Plettenberg Bay. The selected datasets contained water quality data collected by the Bintou Municipality waterworks department in three sampling sites in Plettenberg Bay. The samples were tested for six water quality parameters namely, Ammonia, Suspended Solids, Conductivity, Nitrates/Nitrites, pH, and *E coli*. Microsoft Excel was used extensively to analyse and present the data. Furthermore, published literature was used to identify how chemicals react in surface waterbodies and how their behaviour has impacted the overall quality of water. To ensure that water quality is safe enough for full-contact recreational activities, drinking water standards prescribed by The South African National Standards (SANS 241:2015) were used as the standard of reference in the analysis of data. Although this study focused on recreational water, using drinking water quality standards allowed for a better-quality control in this study.

The general trends observed showed a certain level of stability over the five years. Although the concentration of some parameters varied throughout the years, it was noted that most of them did not exceed permissible values, with only a few chemicals showing a more erratic trend in their concentration levels. In all, it is recommended that the Bintou Municipality increase the sampling frequency to allow a clearer understanding of water quality variation and to minimise potential uncertainties.

DEDICATION

To my Lord and saviour, for giving me wisdom and the power to do all things through Him who strengthens me.

To my amazing mother who has always inspired me and pushed me to realize my full potential, without you I simply wouldn't be me.

To the rest of my family and friends, who have been amazing support systems all throughout.

To my best friend Teboho Letseli, who has been my number one cheerleader and my eternal guiding light. Continue resting in peace, my angel.

ACKNOWLEDGEMENTS

- To my amazing supervisor Professor Karabo Shale, who without, none of this would be possible. Thank you for all your dedication and hard work over the years.

- Dr Solomon Eghosa Uhunamure, I cannot thank you enough for your dedication and for ensuring that we reach this stage.

- To all my lecturers who have made worthwhile contributions to my academics thank you all so much, without you all, I would not be where I am today.

- Water Works Department of Bitou Municipality, the data I received from the Municipality played a pivotal role in my entire study and thank you for all the assistance and patience.

CONTENTS

TABLE OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATION

Abbreviation	**Description**
APEs:	Alkylphenol Ethoxylates
BM	Bitou Municipality
CFU:	Colony Forming Units
DWAF:	Department of Water Affairs and Forestry
E. coli	*Escherichia coli*
EC:	Electric Conductivity
EPA:	Environmental Protection Agency
ISE:	Ionic Specific Electrode
NEMA:	National Environmental Management Act
PAEs:	Phthalic Acid Esters
SANS:	South African National Standards
SS:	Suspended Solids
TDS	Total Dissolved Solids
TSS:	Total Suspended Solids
UV:	Ultraviolet
VOCs:	Volatile Organic Compounds
WHO:	World Health Organization

DEFINITION OF TERMS

Term	**Definition**
Chelating Agents:	Organic compounds capable of linking together metal ions to form complex ring-like structures called chelates (Gupta, 2020).
Dioxins:	Mainly by-products of industrial practices. They are produced through a variety of incineration processes, including improper municipal waste incineration and the burning of trash, and can be released into the air during natural processes, such as forest fires and volcanic activity (Sciences, 2019).
Effluent:	Liquid waste or sewage discharged into a river or the sea.
Endocrine disruptors:	Chemicals that may interfere with the body's endocrine system and produce adverse developmental, reproductive, neurological and immune effects in both humans and wildlife (Sciences, 2019).
Ground-level Ozone:	A colourless and highly irritating gas that forms just above the earth's surface. It is called a secondary pollutant because it is produced when two primary pollutants react in sunlight and stagnant air (Canada, 2016).
pH:	A figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acidic and higher values are more alkaline.
Photochemical smog:	A type of smog produced when ultraviolet light from the sun reacts with nitrogen oxides in the atmosphere. It is visible as a brown haze and is most prominent during the morning and afternoon (Bethel Afework, 2018).

Pollutant: Any substance or energy introduced into the environment that has undesired effects or adversely affects the usefulness of a resource.

Smog: A noxious mixture of gasses and particles that often appears as a haze in the air and has been linked to a number of adverse effects on health and the environment (Canada, 2016).

Surfactant: A chemical substance that alters interfacial properties by absorbing the boundary between two immiscible phases (Y. Yamashita, 2017).

Volatile Organic Compounds: Defined by the US Environmental Protection Agency as any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbide or carbonates and ammonium carbonate, which participates in atmospheric photochemical reactions (Robert Tisserand, 2014).

Wastewater: Water that has been used in the home, in a business or as part of an industrial process.

CHAPTER 1 : INTRODUCTION

1.1. Background of study

Water is an important substance for human and all organism on the planet especially for our biochemical development, although its usage cover other aspects such as human recreational needs (Meride and Ayenew, 2016; Kılıç, 2020). Keeping the recreational quality up to the best environmental standards is necessary for public health (Department of Water Affairs and Forestry, 1996)**,** as every deterioration of the environment, including water, can result in devastating effects on those who are exposed to it. Throughout the year, tourists come in numbers to enjoy the unique and natural beauty of the Western Cape Province in south Africa, and Plettenberg Bay receives a considerable of these tourists who engage in water activities for leisure. Therefore, the quality of recreational water should be maintained for both residents' and tourists' interests.

The National Environmental Management Act 107 Of 1998 defines the environment as the surroundings in which humans exist which are inclusive of the land, water, and the atmosphere, and taking into account the interrelationships, combinations, properties, and conditions of all organisms that exist within the surroundings. Yigitcanlar (2015) suggest that since the mid-20th century, the main threat to the sustainability of natural resources has been globalisation and human population growth. This threat has been observed in the apparent change in the structure and functioning of the environment through various human activities.

Globalisation on the other hand is the process by which people and communities come to experience an increasingly common economic, social, and cultural environment (International Federation of Social Workers, 2012). From this definition, the process affects everybody throughout the world. As a result of globalisation, the world experiences vast amounts of overconsumption, overproduction, waste disposal, and international travel which in turn puts a strain on the environment. The same can be seen with the overproduction and consumption of household cleaning chemicals, the raw materials needed to manufacture these chemicals, the processes involved in manufacturing them and their ultimate disposal put a strain on the environment. In many areas such as the Plettenberg Bay area municipal; wastewater is disposed of in surface waters and this water usually contains the raw materials used to manufacture household cleaning chemicals, and this influences the quality of water parameters over a period (Opere et al., 2020).

Globalisation also influences and increases international travel, especially for tourism purposes, where tourists travel to different parts of the world. Globalisation also has a visible impact on Plettenberg Bay as it is a huge tourist destination. Tourism has also formed one of Plettenberg Bay's key economic corner stones (Statistics South Africa, 2018). During holiday seasons the town is host to a significant number of holiday makers who enjoy engaging in a number of recreational activities, both on land and in water. One of the major tourist attractions for holiday makers is water activities as Plettenberg Bay has three Blue Flag status beaches. Tourists enjoy swimming, boating, whale watching, and many other recreational activities, maintaining a pollution-free environment for the enjoyment of tourists and community members is very important. If the overall water quality of recreational water in Plettenberg Bay is degraded it will have a negative impact on the economy of Plettenberg Bay as tourists will prefer to go elsewhere.

With overconsumption and overproduction due to globalisation, there arises a negative impact on water quality in Plettenberg Bay, especially in the overconsumption and overproduction of household cleaning chemicals. These chemicals amongst others are not commonly regarded as pollutants since they are mostly used within confined spaces such as one's home, office, and classroom to make them acceptable and safe for human habitation. However, some of the most commonly used household cleaning chemicals pose a great threat to the health of the environment by contributing to the formation of smog and reducing the quality of water.

These pollutants come in various forms depending on their intended use; sprays, gels, aerosols, and foam, they rely on chemicals to propel them out of a container or as a medium to convey an active ingredient, which is considered a pollutant (Opere et al., 2020). Polakovic (2003) states that approximately 90% of the contents of an aerosol can constitute chemical propellants that contribute to smog. Today, most of the smog we see is photochemical smog. Photochemical smog is produced when sunlight reacts with nitrogen oxides and at least one volatile organic compound (VOC) in the atmosphere. Nitrogen oxides come from car exhaust, coal power plants, and factory emissions. VOCs are released from gasoline, paints, and many cleaning solvents.

When sunlight hits these chemicals, they form airborne particles and ground-level ozone or smog (National Geographic, 2019).

Most household cleaning chemicals are often poured down drains and are carried away by sewage systems to wastewater treatment plants where they undergo a series of treatments before being discharged as effluent into water bodies which are also used for recreational purposes. According to Edokpayi (2017), wastewater effluents are major contributors to a variety of water pollution problems. Most cities in developing countries generate on average 30–70 m^3 of wastewater per person per year. The poor quality of wastewater effluents is responsible for the degradation of the receiving surface water body. Wastewater effluent should be treated efficiently to avoid adverse health risks to humans and the aquatic ecosystem.

1.2. Problem Statement

The area of Plettenberg Bay is a tourist destination, and the local economy relies heavily on recreational activities such as swimming. Engaging in recreational activities in water that is contaminated represents a considerable risk to public and ecological health. In the case of recreational water, for example, allowing contamination may lead to severe damage to the reputation of a tourist attraction such as Plettenberg. Such an event will have ripple economic effects on areas of Plettenberg Bay which depends heavily on tourism and reactional water activities. Therefore, it is important to analyse the water quality within the area as it relates to the recreational activities' guidelines and standards. The monitoring and analysis of the quality of recreational water will provide a comprehensive characterization of the water quality which will assist to determine the potential impacts of contaminated recreational on tourism.

Various chemicals are released into the environment and once they enter the surface waters, they breakdown to form toxic substances, and some react with other chemicals to form more toxic substances which harm human health from recreational activities and the overall quality of water within an area. With tourism being one of the town's key economic cornerstones, it is very important to ensure that the town remains a tourist destination by conserving and protecting the environment. Plettenberg Bay is not the only tourist town. However, it has very specific activities that tourists can only enjoy in this town. Such activities involve visiting the indigenous forests, hiking the Robberg Peninsula, and taking a swim in any of the six Blue Flag status beaches. If the recreational water quality in the area is not monitored, the quality will begin to decline to a point that it will not be possible to do any water activities and tourists will gradually start to visit less if they cannot do the activities they desire, and as a result of that the economy will take a huge knock. Once contaminants enter waterbodies understanding their characteristics is imperative as it will assist in their remediation and decrease their impact on the overall quality of recreational water within the area.

1.3. Rationale of the Study

Yehia (2019) argues that tourism is vital for the success of many economies around the world and especially for economies of host destinations. Plettenberg Bay, being a host destination, relies heavily on tourism to boost its local economy. Cultural exchange, development of infrastructure, job creation and boosting the revenue of the economy can all be achieved through tourism. According to Stats SA (2018), the tourism sector directly contributed 2.9% of South African gross domestic product in 2016, making it a larger contributor than the agriculture sector. In a South African context, tourism can be seen to be one of the great contributors to the economic upliftment of poorer regions (such as townships and informal settlement areas) through job creation.

Tourism has been one of the biggest catalysts in growing and developing the town of Plettenberg Bay as tourists demand a higher and better standard of experiences during the holiday season. This means that the infrastructure must be well maintained, the quality of services provided must be top tier and the environment must remain pristine. Most of the tourists that visit Plettenberg Bay always want to do water activities as Plettenberg Bay boasts six Blue Flag status beaches, it is important to ensure that the water quality meets or exceeds the standards prescribed in Volume 2 of the South African Water Quality Guidelines for recreational water use.

Since Plettenberg Bay is a tourist destination is important to analyse the variations in water quality and asses how these variations may in turn impact tourism. If water quality continues to decline, so will the population of aquatic organisms which is one of the main tourist attractions in Plettenberg Bay, the more polluted waters become the less aesthetically pleasing they will be for tourists and ultimately, tourists will choose to vacation elsewhere and the market to visit Plettenberg Bay will begin to dry up. This will in turn negatively impact the economy of the town and its livelihood, and the household incomes of many families in Plettenberg Bay who rely on the arrival and spending trends of tourists to make a living.

1.4. Significance of the Study

The study will help to reduce further environmental degradation by informing decision-makers and key policymakers on the environmental risks associated with recreational water quality degradation and ultimately its impact on tourism and the economic growth of the town. The study will also contribute to the general body of knowledge. The study will work as a tool to better formulate regulations and policies that will conserve and protect the environment sustainably.

1.5. Purpose of Study

The purpose of this study is to evaluate the surface water quality of the greater Plettenberg Bay area and to ensure that the surface water quality is compliant with the standards prescribed by The Department of Water Affairs and Forestry in Volume 2 of the South African Water Quality Guidelines as it relates to recreational water use.

1.6. Research Questions

1. How have the proximate parameters of (Ammonia, Suspended Solids, Conductivity, Nitrates/Nitrites and pH) surface water in the greater Plettenberg Bay changed over a period of five years?

2. How has the microbial water quality (*E. coli)* of the greater Plettenberg Bay changed over a period of five years?

3. What are the efficient remediation methods to reduce the impact of the possibly polluted waters?

1.7. Aims and Objectives

The goal of this study is to analyse the variations in water quality for a period of five years in an attempt to comprehend the effects of pollution in the environment of Plettenberg Bay, more specifically in surface waters in order to further investigate the impact the presence of these chemicals will have on recreational activities and tourisms.

The specific objectives are:

- To assess the proximate parameters of (Ammonia, Suspended Solids, Conductivity, Nitrates/Nitrites and pH) water in the greater Plettenberg Bay.

- To assess the microbial water quality by analysing the *E. coli* levels.

- Provide a possible solution to reduce the impact of possibly polluted recreational waters in the Plettenberg Bay area.

1.8. Delineation of Study

This study focuses on the water quality parameters of the greater Plettenberg Bay area namely, Ammonia, Suspended Solids, Conductivity, Nitrates/Nitrites, pH, and *E. coli* and their impact on the quality of recreational water, more specifically contact recreational water. Two samples are obtained at the wastewater treatment plant, one sample is taken from the untreated raw wastewater and the second sample is taken from the treated final effluent just before it is discharged. The other three samples are taken from The Gans River, The Old Nick, and The Goose Valley Golf Estate. This study will only focus on contact recreational water quality and will only consider the water quality standards prescribed by The Department of Water Affairs and Forestry in Volume 2 of the South African Water Quality Guidelines for recreational water use.

1.9. Layout of Chapters

Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Research Methodology

Chapter 4: Results and Discussion

Chapter 5: Conclusion

Chapter 6: Recommendations

1.10. Summary

Globalisation has resulted in worldwide overconsumption and overproduction of chemicals that are classified as environmental pollutants. Most of these chemicals are in the products that are used daily. The understanding of the characteristics of these pollutants is pivotal in the efficient management and use, to decrease, reverse or stop further environmental degradation. Understanding the characteristics of pollutants found in surface waters of the Plettenberg Bay area will also assist in identifying the impacts of these pollutants on tourism activities, and human and wildlife health which is one of the main aims of this research. This will also allow for the findings of this research to have an impact on the regulations of water quality monitoring programs for the Bitou Municipality. It can also be used as an informative tool or aid during decision-making processes.

CHAPTER 2 : LITERATURE REVIEW

2.1. Introduction

In areas closest to urban areas, water quality is often degraded by anthropogenic activities such as the discharge of chemical products from domestic activities (Lin *et al.*, 2022). Cleaning has become one of the human activities that are carried out daily, it is done to maintain a healthy, safe, and aesthetically pleasing environment. According to Sabharwal (2015), cleaning agents are a complex mixture of chemicals that are used to remove dirt including dust, stains, bad smells, and grime on surfaces. Cleaning and disinfecting agents have the same role in combating infections. Cleaning and disinfecting agents are commonly used in most households, and they eventually end up in water bodies, surface waters, storm waters, and wastewater (Sabharwal, 2015).

2.2. The behaviour of various household cleaning chemicals in waterbodies

When Sodium Hypochlorite is added to water the pH of water increases due to the presence of caustic soda (sodium hydroxide) and the formation of two other substances takes place. The two substances formed are Hypochlorous acid (HOCl) and the less reactive Hypochlorite ion (OCl^-) (LENNTECH, 2019). Once the wastewater containing these two substances is flushed down sewage pipes it ultimately ends up being discharged into natural waterbodies as effluent, the substances undergo chemical reactions with other elements and minerals to form other toxic substances such as dioxins which are known to be persistent organic pollutants as they tend to linger for years in the environment. Beach (2019) claims dioxins are one of the most harmful chemicals as they can cause endocrine disruptions in aquatic animals. This wastewater may also alter the pH levels of natural water bodies by making them more acidic, the decrease in pH will also result in an increase in temperature. Areas such as Plettenberg Bay are known for their dynamic range of aquatic organisms, it is one of the main reasons tourists come from all over the world to do activities such as whale and dolphin watching, fishing and scuba diving (King, 202; Hempel & Flemming, 2021). Therefore, the quality of water must not be degraded to a point where aquatic organisms are not able to survive as this would also have potentially negative impacts on the local economy.

The U.S Environmental Protection Agency (1997) has identified chemicals such as phosphorus, nitrogen, ammonia, and chemicals known to be Volatile Organic Compounds as the worst environmental hazards in household cleaners. It has become imperative to fully understand the characteristics of these chemicals, their sources, persistence, toxicity, fate, bioaccumulation, releases, and transport (David & Niculescu, 2021).

According to (Sholl, 2011) 2-butoxyethanol ($C_6H_{14}O_2$) is one of the key ingredients to many household window cleaners, whiteboard cleaners, liquid soaps, and dry-cleaning solutions. It acts as a solvent which breaks down both water-soluble and hydrophobic substances making it much easier to remove them.

Phthalates also known as phthalate esters are esters of phthalic acid and they are mainly used as plasticizers. However, Sholl (2011) suggests that they may be found in fragranced household cleaning chemicals such as air fresheners, dish soap and some toilet paper. Due to proprietary laws companies do not have to disclose what is in their scents, therefore it may not appear on many product labels. Sopheak *et al.* (2015) Phthalatic Acid Esters (PAEs) can easily be released into the environment directly and/or indirectly, during manufacture, use, and disposal. This makes them ubiquitous in the various matrices of the environment; specifically, river and marine waters/sediments and recreational water.

Sopheak *et al.* (2015) argue some PAEs are endocrine-disrupting chemicals, and their environmental behaviour has attracted considerable attention due to their potential impact on ecosystem functioning and public health. As a direct result, PAEs have been listed amongst other chemicals on the priority pollutant list, to stress the importance of closely monitoring their concentrations in recreational waters and drinking water as these waterbodies have many users such as humans and aquatic organisms. PAEs can be deposited into waterbodies in a number of different processes such as atmospheric deposition, leaching, and drainage. Ultraviolet B Rays can penetrate surface water and induce photolysis of PAEs either directly by direct absorption of radiation or indirectly by the oxidation reactions of reactive chemical species that might be present in a waterbody (Sopheak *et al.,* 2015).

Ammonia (NH_3) is a colourless gas with a very distinct smell, when dissolved in water it produces a strongly alkaline solution. Ammonia may be used on its own or as an ingredient in household cleaning chemicals to clean tiles, sinks, kitchen and bathroom countertops and tubs (National Center for Biotechnology Information, 2023). It is very effective in removing household stains, grime and grease, it may also be found in window cleaners; because ammonia evaporates quickly which helps in avoiding streaking on glass windows.

Once ammonia enters a water environment it reacts with the water to form two substances, according to Oram (2014) the term ammonia refers to two chemical species which are in equilibrium in water (NH_3, un-ionized and NH_4^+, ionized). However, only the un-ionized (NH_3) form is responsible for toxicity in water.

The chemical formula of the reaction that occurs between water (H_2O) and ammonia (NH_3) is as follows; **$NH_3 + H_2O \Leftrightarrow NH_4^+ + OH^-$.** Oram (2014) further elaborates to say that in the equation it can be said that one molecule of ammonia will react with one molecule of water to form one ammonium ion and one hydroxyl ion, the presence of the arrow suggests that the reaction can go either way, especially under favourable conditions. This reaction is highly dependent on the temperature and pH of the water, to this fact, Oram (2014) states that as the pH of the water increases; the water becomes more alkaline due to an increase in hydroxyl ions, this extra presence of hydroxyl ions will push the equilibrium to the left and more of the unionized species of ammonia is formed. It can be said that at any given time both species of ammonia will be present in water, however, the quantities of each species' presence in a waterbody will vary depending on temperature and pH.

Phosphates are one of the many prominent mineral compounds that can be found in surface water, according to Oram (2014) Phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate, each compound contains phosphorous in a different chemical arrangement. The sources of these types of phosphates are predominantly living or decaying plants and animals, Oram (2014) further suggests that these types of phosphates can also occur as free ions or weakly chemically bounded in aqueous systems, chemically bonded to sediments and soils, or as mineralized compounds in soil, rocks, and sediments.

Orthophosphates occur as a result of natural processes and in many instances, they also occur as a result of anthropogenic processes namely, partially treated, and untreated sewage, run-off due to agricultural activity and any use of fertilizers on lawns or plantations. Orthophosphates are typically found in very low concentrations in unpolluted surface waters. Polyphosphates are normally used for treating boiler waters and are also used in household detergents, Oram (2014) states that in water, they are transformed into orthophosphate and available for plant uptake. On the other hand, organic phosphate can be said to be a type of phosphate that is bound up in the tissue of plants, waste solids and other organic material. As soon as decomposition has taken place, this organic phosphate is converted to orthophosphate.

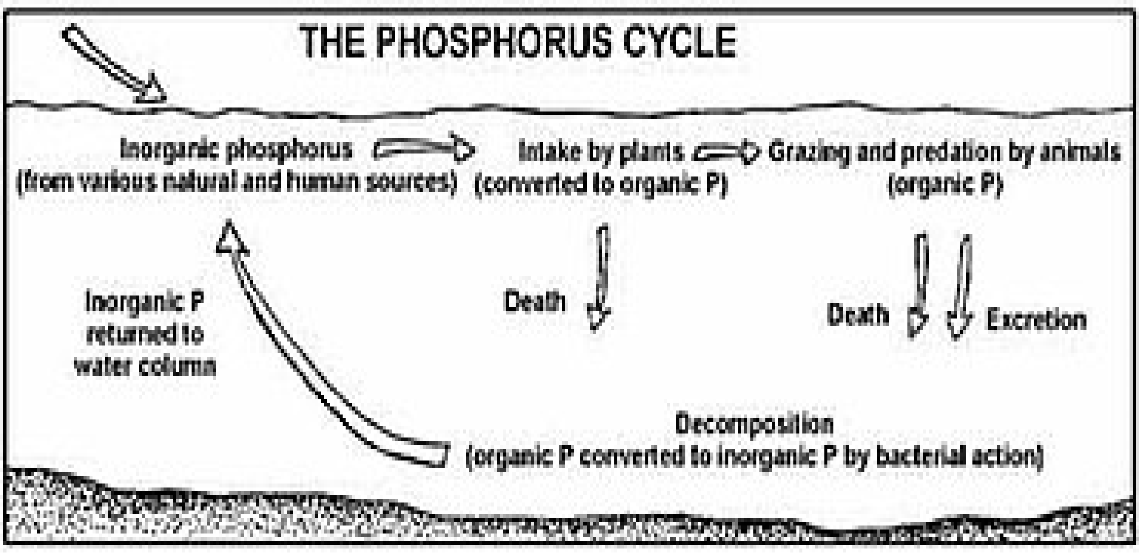


Figure 1 the aquatic phosphorous cycle

The phosphorous cycle (figure 1) can be used to illustrate just how phosphorous is cycled throughout the environment and more specifically in surface waters and how it changes forms at each stage in a water environment. The United States Environmental Protection Agency (1997) breaks down the aquatic phosphorous cycle as follows; aquatic plants take in dissolved inorganic phosphorus which they then convert to organic phosphorus which then becomes part of their tissues. Animals get the organic phosphorus they need by eating either aquatic plants, or other animals, or by decomposing plant and animal material.

In some instances when animals and plants excrete wastes or die, the organic phosphate that has formed part of their tissue is released and sinks to the bottom of the waterbody where it is then transformed by aquatic bacterial decomposers from its organic form to an inorganic form. The inorganic phosphorous at the bottom is then stirred back into the water column; both dissolved and attached to particles for intake by plants and animals when currents, chemical interactions, aquatic animals, and human activity disturb the waters and the begins again.

In a stream system, the phosphorus cycle tends to move phosphorus downstream as the current carries decomposing plant and animal tissue and dissolved phosphorus. It becomes stationary only when it is taken up by plants or is bound to particles that settle at the bottom of pools (United States Environmental Protection Agency, 1997).

The United States Environmental Protection Agency (1997) defines Nitrates as a form of nitrogen which is found in several different forms in terrestrial and aquatic ecosystems, these forms include Ammonia (NH_3), Nitrates (NO_3) and Nitrites (NO_2). Oram (2014) states that nitrogen is essential for all living organisms as it is a component of protein. However, the United States Environmental Protection Agency (1997) argues that Nitrates together with Phosphorous in excess can accelerate the eutrophication process. Oram (2014) also argues that excessive concentrations of nitrate-nitrogen or nitrite-nitrogen in water can be hazardous to health, especially for infants and pregnant women. Both authors state the importance of the presence of nitrogen in the environment (specifically surface waters), on the other hand, both authors stress the negative impact of having nitrogen in excess amounts in the environment, this is why it is imperative to constantly monitor the levels of nitrogen in a waterbody at any given time.

The United States Environmental Protection Agency (1997) argues that Nitrates from various land sources reach surface waters much faster than other nutrients such as Phosphorous and this is due to the fact that Nitrates have a larger affinity for water particles than they do for soil particles and as a result, they will dissolve more readily in water than other nutrients.

Water that is polluted with nitrogen-rich organic matter might show low nitrates. Decomposition of the organic matter lowers the dissolved oxygen level, which in turn slows the rate at which ammonia is oxidized to nitrite (NO_2) and then to nitrate (NO_3). Under such circumstances, it might be necessary to also monitor for nitrites or ammonia, which are considerably more toxic to aquatic life than nitrate (United States Environmental Protection Agency, 1997). This is why it is important to closely monitor levels of all the various forms of Nitrogen as a specific form might only appear to be present at very low concentrations giving the illusion that the water quality is compliant. On the other hand, the other forms of nitrogen might be present in very high concentrations which could cause health issues but that could be overlooked if only one form of nitrogen is being monitored and the others are left unmonitored.

2.3. Environmental impact of cleaning chemicals

Nearly all used cleaning products and wastewater are disposed into municipal sewers. Many cleaning agents released into the environment, biodegrade slowly or incompletely thus posing a risk of water supply contamination and/or impact on wildlife (Sabharwal, 2015).

There are potential environmental impacts associated with cleaning chemicals and active ingredients contained in the product considered to be essential for the cleaning effectiveness of the product (Sholl, 2011). There has been increasing scientific evidence which links developmental endocrine disruptions in wildlife to cleaning agents (Chaturvedi, 2013; Sabharwal, 2015; Aldous, 2018). Once household cleaning water has been disposed of in drains, it is treated with various chemicals in municipal treatment plants along with other wastewater and sewage, then it is discharged into nearby waterbodies. Most ingredients in the cleaning agents break down during treatment or soon afterwards, which then alters the water quality for human consumption and other wildlife. Alkylphenol ethoxylates (APES) are surface active agents which are key ingredients in some household laundry detergents, disinfectants, stain removers and degreasers. They are a cause for concern due to their ability to cause endocrine disruptions by mimicking the hormone oestrogen in aquatic animals once it has entered the water.

The presence of APES in waterbodies negatively impacts the reproduction and survival of aquatic animals. Ismail (2018) suggests that even though metabolites of APES are classified as hazardous substances, they continue to be released into the environment from a variety of sources and are not usually monitored. Warhurst (1995) states that Oestradiol is a hormone that influences the development and maintenance of female sex characteristics, and the maturation and function of accessory sex organs. Chokwe (2017) further elaborates those studies have demonstrated that APES compete for the binding site of natural oestrogen receptors in vertebrates and can elicit a variety of responses, including stimulation of vitellogenin, an egg-yolk protein in males; modification of testicular structure and decreased sperm counts thus leading to both intersex fish and altered sex ratios in populations, and induction of both liver damage and mortality.

On treatment APES also breakdown into molecules which are more toxic and not readily biodegradable. They breakdown and attach themselves to other present elements where they form larger and more toxic substances. Once they undergo this process, they are termed chelating agents where they are specifically characterised by their ability to attach themselves to a metal atom by two or more bonds.

Phthalate acid esters (PAEs) have a variety of uses in the industry and as a result, it has become a highly produced chemical, characterising it as a potential risk to humans and the environment at large. According to Zheng *et al.* (2020), PAEs form a strong chemical bond to the matrices of polymers making them persistent, which means they can be found in almost all environments. Zheng *et al.* (2020) further argue that various pieces of evidence show the carcinogenic, teratogenic, and estrogenic effects of PAEs making them high potential risks to human and animal health as stated before.

The most common nutrient pollutants in water systems are considered to be compounds of nitrogen and phosphorous. The gradual or sudden increase of nutrient levels in water systems can be caused by anthropogenic activities such as the disposal of wastewater into a surface water system or natural events such as forest fires or flooding. Aldous (2018) states that Nitrogen compounds include Ammonia (NH_3), Nitrate (NO_3) and Nitrite (NO_2) all of which are, in sufficient concentrations, directly toxic to aquatic life. Wasielesky (2016) argues that Nitrite is the intermediate compound in the bacterial nitrification of ammonia to nitrate in oxidizing environments and the product of the denitrification of nitrate in reducing environments, as a result of the increased accumulation of Nitrite in water, the water quality becomes degraded and Wasielesky (2016) further argues that this degradation increases the consumption of oxygen in the water and excretion of ammonia by aquatic organisms, which then reduces animal growth and may lead to mortality. Wasielesky (2016) further elaborates how on how nitrite binds to hemocyanin, occupying the active site in place of oxygen and causing a transformation to meta-hemocyanin, which is unable to transfer oxygen to the tissues. For this reason, nitrite decreases the amount of oxygen available for tissue oxygenation, resulting in hypoxia and hypoxia-related mortality.

Ammonia (NH_3) can be characterised as having both direct and indirect biotic effects, with the direct effects focusing more so on individual mortality, impairment in reproduction and reduced growth rate. On the other hand, the indirect effects focus on the possible alteration of ecosystems and nutritional regimes or other physical parameters.

Craig (2003) argues that negative effects on ecosystems usually take the form of shifts in dominant organisms, usually to ones more capable of exploiting the nutritional regime or withstanding altered physical parameters. In these cases, toxicity to organisms comes about indirectly but is still ultimately traceable to the deposition of ammonia in some form. However, Craig (2003) further argues that under favourable conditions; with pH ranging between 7-8 and surface water temperature measuring at 20^{o}C, the total ammonia concentration in natural waters is typically below 0.1 ml/L. Any concentrations higher than 0.1 ml/L would serve as an indication of anthropogenic input and organic pollution. Craig (2003) further discusses how not all exposure leads to lethal effects, there also may be various sublethal effects on freshwater organisms.

The author argues that exposure to concentrations above 0.1 ml/L over extended periods may have an impact on the population of species and community characteristics. The most evident responses are integrative and are exhibited by reductions in growth (length or weight) or are related to reproductive success (egg production, hatching, larval survival). Craig (2003) continues to describe other effects such as species' behavioural responses, tissue damage (e.g., pathological changes in the tissue of the gills, liver, and kidney of fish) or biochemical or physiological changes, which can affect the individual but in most cases are reversible and will not necessarily change the character of the community.

As mentioned before, ammonia not only has direct ecological effects but indirect effects too which mainly focus on entire ecosystems. Craig (2003) identifies two major ecological effects, acidification of soft waters and eutrophication of aquatic and terrestrial ecosystems. The author further elaborates that nutrients are essential in lakes as they play an important role in the aquatic ecosystem. Nutrients are the raw materials needed for algal growth which works as a food source for zooplankton and the zooplankton in turn are a source of food for fish. Without the introduction of nutrients such as ammonia in natural waters, there would be negative effects on the various aquatic trophic levels. According to Craig (2003) the excessive input of nutrients like ammonia and dissolved phosphorus results in large standing crops of algae and plants, the oxygen concentration in the water is also significantly reduced due to the high respiration demand of phytoplankton. During the inevitable die-off of the algal blooms and plants, there is an increase in bacterial populations and toxins and as a direct result of this, the dissolved oxygen content is significantly decreased to the point where fish can no longer survive in the water. Over the long term, elevated eutrophic rates can alter the biological community towards organisms more tolerant of shaded, oxygen-deficient waters (Craig, 2003).

Craig (2003) suggests that natural waters that receive ammonia and phosphorous inputs; usually from wastewater treatment facilities, may have the favourable conditions required for eutrophication to take place throughout the summer season, with visible lush algal blooms and rooted plants. However, during the autumn season, the excessive plant growth dies offs and creates a toxic oxygen-deficient environment in that fish can no longer survive. On the other hand, water systems that only receive ammonia input will not undergo eutrophication due to the lack of phosphorous. However, the concentration levels of ammonia and nitrates in these water systems could very well continue to rise to toxic levels due to the nitrification process which would still result in oxygen depletion.

Suspended solids impact aquatic organisms through abrasion, scouring and reducing light penetration through the water column (Aldous, 2018). Once sediments enter surface waters, they become harmful to aquatic organisms as they have the potential to smother them and negatively impact their habitats. Aldous (2018) further states that it is broadly accepted that as the concentration of suspended particles (sediments) increases in water so does its impact on aquatic ecosystems. However, it is worth noting that several various factors may have a role in the impact of these suspended solids in aquatic ecosystems, factors such as the duration of exposure, particle size and distribution and the chemical composition of the suspended solids. Aquatic ecosystems are usually considered to be teeming with various microorganisms and it is imperative to understand the impact that suspended solids will have on the ecosystem as a whole, especially in areas such as Plettenberg Bay that are considered to be international tourist destination spots and wildlife sanctuaries. These suspended solids have adverse impacts on macrophytes, once they enter surface waters, they cloud the waters which in turn reduces the amount of light that can penetrate through the water, and this subsequently limits the rate of photosynthesis. Sedimentation can result in the smothering of submerged flora, drastically reducing the rate of photosynthesis (Aldous, 2018).

Suspended solids also pose adverse effects on macroinvertebrates, as they come into contact with these solids, they may cause abrasions to external respiratory organs making it very difficult for them to breathe or subject to predation through the dislodgement of these external organs. Aldous (2018) argues that the suspended solids can clog feeding structures, and this will in effect reduce species' growth rates, and increase stress levels and mortality rates as they cannot feed efficiently.

High levels of suspended solids may disrupt the natural behaviour of fish populations, especially fish such as Pike (*Esox luscious*), Perch (*Perca fluviatilis*) and Brown Trout (*Salmo trutta*) (Aldous, 2018). These types of fish that are sensitive to environments will high levels of suspended solids will display strong avoidance behaviour. On the other hand, fish that have adapted to turbid environments will experience issues such as clogged or damaged gills, and susceptibility to diseases and parasites. In instances where the fish ingest the sediments, they are like to become exposed to toxins and pathogens, Aldous (2018) argues that even if the exposure does not kill the fish, it may still very well alter the fish's blood chemistry and impair its growth. Sedimentation can destroy fish habitats and spawning beds and kill fish eggs that can become buried by the sediment. Sediment deposition can reduce egg and embryo survival by reducing the oxygen supply and coating the egg, preventing the embryo from escaping (Aldous, 2018).

Much like suspended solids, the total dissolved solids are essentially all the suspended solids in water but in their dissolved state. Ayenew (2016) states and elaborates that water can dissolve a wide range of inorganic and organic minerals or salts such as potassium, calcium, sodium, bicarbonates, chlorides, magnesium, and sulphates. Ayenew (2016) also argues that high TDS concentrations may result in the alteration of the taste, colour and odour of water. High TDS concentrations also indicate high mineralization in a water body. However, it does not pose significant health risks to humans, except for persons that suffer from kidney and heart diseases, where it can be seen to have a laxative or constipation effect. According to Rusydi (2018) conductivity or electrical conductivity (EC) and total dissolved solids (TDS) are frequently used as water quality parameters. Furthermore, EC is defined by Rusydi

(2018) as the ability of a liquid to conduct an electric charge and how this ability is dependent upon dissolved ion concentrations. This then implies that there exists a relationship between the concentration of total dissolved solids and EC measurements. One can then conclude that, the higher the conductivity of water, the higher the concentration of ions in water and vice versa (Saalidong et al., 2022).

According to Radke (2006), pH can be defined as a measure of acidity or alkalinity of water on a log scale from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline). The author further states that hydrogen ions are found in high concentrations in surface waters with a pH below 7 and hydroxyl ions are found in high concentrations in surface waters with a pH well above 7. The pH of a waterbody is susceptible to change (fluctuations), these changes can often be attributed to a variety of influential factors such as temperature and hydrogen ion concentration (Saalidong et al., 2022). The pH measurement of a water body must be regularly monitored. Radke (2006) argues that most aquatic organisms and some bacterial processes require a pH in a specified range for their optimum functioning and to contribute to the overall health of a water system. For example, the activity of nitrifying bacteria is optimal over a narrow pH range from 7 to 8.5. If pH changes above or below the preferred range of an organism (including microbes), physiological processes may be adversely affected.

Both Radke (2006) and Fondriest Environmental (2013) state that when pH is below optimal levels, fish become susceptible to fungal infections such as red spot disease and other physical damage to gills, eyes, and skin. As the pH of water drops, the solubility of calcium carbonate is reduced, inhibiting shell growth in aquatic organisms (Fondriest Environmental, 2013). On the other hand, Fondriest Environmental (2013) also argues that low pH levels can encourage the solubility of heavy metals. As the level of hydrogen ions increases, metal cations such as aluminium, lead, copper and cadmium are released into the water instead of being absorbed into the sediment. Radke (2006) further argues that an increase in pH can also cause the electrostatic forces that bind viruses to particles to be broken, thus enabling their release to the water column.

Phosphorous is considered to be an essential element for all life forms, Oram (2014) states that phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate each compound contains phosphorous in a different chemical arrangement. According to Fadiran (2008) in natural and wastewater, phosphorus occurs almost solely as dissolved phosphate and it is the most significant form of phosphorus in natural water. This study will mainly focus on the orthophosphate form of phosphates, and this is due to the fact that Fadiran (2008) argues that orthophosphate is the most thermodynamically stable form of phosphate, and is the form commonly identified in laboratory analysis and also used by plants. Furthermore, polyphosphates in water are unstable and eventually convert to orthophosphate. However, excessive phosphorous in surface water bodies can lead to eutrophication as revealed by Shock (2003), and factors that limit algal growth include available forms of nitrogen and phosphorus, sunlight, and temperature. Oram (2014) further elaborates those phosphates stimulate the growth of plankton and aquatic plants which are food sources in aquatic ecosystems. Furthermore, this increase in productivity will also result in an increase in the fish population and overall biological diversity of the system, as there are more food sources available.

On the other hand, as more nutrients such as phosphates and nitrogen are deposited into the water body, this productivity will ultimately cause an imbalance in the nutrient and material cycling processes. Oram (2014) also describes eutrophication as the enhanced production of primary producers resulting in reduced stability of the ecosystem. Once the aquatic system becomes overwhelmed with the excessive input of nutrients, Fadiran (2008) suggests that algal production will be accelerated to extreme quantities until they die off. Furthermore, the bacteria responsible for their decomposition use up and hence deplete the dissolved oxygen concentration in the water bodies to such levels that can result in fish kills due to eutrophication and algal bloom (Fardiran, 2008). These algal blooms are a specific nuisance in surface waters as they can accumulate as scum right on the surface of a water body which may be used for recreational activities. Fadiran (2008) suggests that this accumulation of algal blooms can result in clogged pipelines, restricted recreation, and foul odours when they eventually decay.

Various pathogenic bacteria may be present in water bodies, and they must be closely monitored as they are associated with serious health risks. This study will closely examine *Escherichia coli* (*E. coli*) as a water quality indicator of surface water used for recreational activities. According to Jang *et al.* (2017), the presence of *E. coli* in surface water has always been considered an indicator of recent water pollution from faecal contamination. However, with recent advancements in the field, various studies have shown that some specific strains of *E. coli* can survive for long periods, and potentially reproduce, in extraintestinal environments. With that being said, the presence of *E. coli* in a water body will not always be an indicator of recent contamination, the strain must be thoroughly analysed before any conclusion can be reached. Similarly, Ishii (2008) argues that until relatively recently *E. coli* was believed to survive poorly in the environment and not grow in secondary habitats such as water, sediment, and soil. *E. coli* has a number of limiting factors in the environment and Jang *et al.* (2017) draw a relationship between the survival rate of *E. coli* in the environment and required abiotic and biotic conditions. Abiotic factors include temperature, water and nutrient availability, pH, and solar radiation. Biotic factors include the presence of other micro-organisms, and the ability of *E. coli* to acquire nutrients, compete with other micro-organisms and form biofilms in natural environments (Jang *et al. 2017).*

Elsas *et al.* (2011) suggest that *E. coli* from contaminated water bodies may attach themselves to the surfaces of nearby plants, this can be attributed to their ability to produce filamentous structures that extend from the cell surface and help cells to attach to surfaces, where they colonize the plant from its roots. *E. coli* cells cannot be easily washed from plant parts or be killed and removed by disinfectants and washing. Thus, from infested consumable products, the organism can further spread to uncontaminated products during food processing and packaging, resulting in dissemination in the food production chain (Elsas *et al.* 2011). Therefore, *E. coli* contamination in the environment poses a serious threat to food security. It is also usually recommended that humans refrain from making use of water and irrigation water that exceeds the acceptable levels of *E. coli* present in water as it may lead to diseases when ingested and skin irritation when in contact with the skin.

2.4. Various human health effects of chemicals in waterbodies

2.4.1. Ammonia

Humans are exposed daily to ammonia. However, the exposure is at very low levels. Humans are exposed to ammonia in the very air that they breathe, the food that they consume and the water that they drink (David & Niculescu, 2021). Ammonia is also produced by the human body in the digestion and use of proteins. Department of Human Services (2000) states that humans are less sensitive to ammonia in water, but long-term ingestion of water containing more than 1 mg/l (ppm) ammonia may be damaging to internal organ systems and solutions having concentrations greater than

1000 mg/l (ppm) can cause severe burns and scarring of sensitive skin and mucous membranes. Furthermore, household cleaning solutions usually contain between 3% and 30% ammonia and pose a severe hazard if ingested (National Center for Biotechnology Information, 2023).

2.4.2. Conductivity

The conductivity of a waterbody refers to its ability to carry and electric charge and it is also used as an indicator of dissolved ionic solid concentration and salinity (Cotruvo, 2019). Conductivity does not pose a direct human health threat. However, Jones (2020) argues that dissolved ionisable solids may cause frustrating water hardness or alkalinity and therefore impact consumer satisfaction.

2.4.3. Nitrates

According to the Minnesota Department of Health (2018) consuming water with an excessive amount of nitrates may cause a medical condition known as methemoglobinemia, otherwise referred to as blue baby syndrome; causing the skin of babies to turn a bluish colour. This condition may in some extreme cases result in serious illness or death for infants under the age of sic months. Furthermore, other symptoms associated with methemoglobinemia are increased heart rate, nausea, headaches, and abdominal cramps (Fewtrell, 2004).

2.4.4. pH

The South African National Standards 241:2015 recommends that the acceptable pH range for drinking water should lie between 5.0-9.7 and anything outside of the recommended range may result in gastrointestinal irritation for humans. In the case of contact recreational use water, the Department of Water Affairs and Forestry (1996) recommends that the target water quality range should be 6.8-8.5 units. Measurements outside of this range may cause skin, eyes, nose, and mouth irritation in humans (Saalidong et al., 2022).

2.4.5. *E. coli*

Excessive levels of *E. coli* in contact with recreational water pose a health threat to humans, once contaminated water is ingested it may result in gastrointestinal illnesses for humans (Boehm & Soller, 2020).

2.4.6. How cleaning chemicals from various sources enter water bodies

According to Chaturvedi (2013) after use, residual (Surfactant) detergents are discharged into sewage systems directly or indirectly into the surface water and most of them end up dispersed into the different environment compartments, soil, and water.

Clayton (2004) also argues that with the use of chemicals in homes and gardens, where some of these chemicals are considered to be cleaning agents and detergents, may be discharged directly and legitimately to the drains and hence enter water bodies. Others such as paints, solvents or pesticides may be disposed of with little consideration for the environment and enter water bodies after diffusing through the soil or via surface water drains.

Both authors make the argument that household cleaning chemicals are disposed of in household drainage systems where they then enter water bodies and cause environmental concerns. Clayton (2004) states that other chemicals such as solvents, paints and pesticides may be present in water bodies, however, this literature review will mainly focus on the presence of household cleaning chemicals in the environment and more specifically in water bodies and environmental concerns associated with their presence.

Sabharwal (2015) argues that once household wastewater is discharged into drainage systems it is treated along with sewage and most other wastewater at municipal treatment plants, and then discharged into a nearby water body. Most ingredients in the cleaning agents break down during or soon after treatment, altering the water quality for human consumption and other wildlife. Sabharwal (2015) further suggests that bioaccumulation in plants and animals subsequently affecting the food chain is also some of the impacts of cleaning agents on the environment.

Clayton (2004) raises a similar concern where the author further elaborates that domestic treated sewage is dilute wastewater when compared to industrial effluents, many of the household chemicals are sufficiently diluted to ensure that they are not acutely toxic; their concentrations are mostly below the level at which they are immediately toxic. However, the discharge of treated sewage is normally a continuous process, even if the small quantities of toxic substances in the sewage are degraded in the environment there may be constant long-term exposure to them. Furthermore, if there is any tendency to bioaccumulate, continuous exposure to small concentrations may in the long-term result in potential risks.

Clayton (2004) and Sabharwal (2015) both suggest that even after treatment, wastewater discharged into water bodies may still pose a threat to the environment as some chemicals may have the tendency to bioaccumulate and may be persistent. Therefore, their effects on the environment may not be seen immediately but may have a chronic toxicity effect.

One of the many environmental concerns that arise from the disposal or presence of household cleaning chemicals in water bodies is eutrophication. Olaniran (2014) further elaborates that excessive nutrient loading can lead to eutrophication and temporary oxygen deficiencies that ultimately alter the energy relationship and water balance, disrupting biotic community structure and function. Clayton (2004) also states that various household cleaning chemicals contain phosphates, which can usually be removed by a means of biological wastewater treatment processes, but there is always a residual quantity in the discharge.

In the case of nitrogen compounds such as Ammonia (NH_3), Nitrate (NO_3) and Nitrite (NO_2) Aldous (2018) points out that the accumulation of these compounds in surface waters can be due to anthropogenic activities such as wastewater treatment facilities, industrial waste, and agriculture as they are responsible for disposing wastewater into nearby surface water bodies and as stated by Clayton (2004) these wastewaters always have residual quantities of nitrogen compounds and other contaminants. Besides anthropogenic activities, there are natural events that may also cause the increase of nitrogen compound quantities in surface waters. These natural events including flooding, where nitrogen compounds are directly deposited into nearby water bodies and forest fires. Nitrogen compounds and Phosphorous are often examined together as they are considered to be significant limiting factors in algal growth in surface waters. However, they do not necessarily have the same sources and modes of transportation. As argued by Fadiran (2008) in natural and wastewaters, phosphorus occurs almost solely as dissolved phosphate and orthophosphates are the form that is common in laboratory analysis due to the fact that it is the most thermodynamically stable in water. Much like nitrogen compounds, the sources of phosphorous in surface waters are also anthropogenic and natural. According to Fadiran (2008), the natural sources are considered to be atmospheric deposition, natural decomposition of rocks and minerals, weathering of soluble inorganic materials, decaying biomass, runoff, and sedimentation. The anthropogenic sources include fertilizers, wastewater and septic system effluent, animal wastes, detergents, industrial discharge, phosphate mining, water treatment, forest fires, and synthetic material development surface (Fadiran, 2008).

Alkalinity and pH are water quality parameters that have been observed to be closely related, such that one affects the other. However, there are distinct differences between the two water quality parameters and according to Fondriest Environmental (2013), alkalinity is a measurement of water's ability to resist changes in pH. Many factors may be considered to be sources of increased pH levels in surface waters, both natural and anthropogenic sources. Fondriest Environmental (2013) suggests that increased pH levels can be due to a result of interactions with surrounding rock (particularly carbonate forms) and other materials, pH can also fluctuate with precipitation (especially acid rain), wastewater or mining discharges and carbon dioxide concentrations.

Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) are water quality parameters that have a slight distinction. According to DataStream (2021), the distinction can be made as follows, TDS and TSS are measurements of small particles floating in surface water, these particles or solids can be divided into two types by passing the water through a filter. The particles that are large enough to be held back by the filter are called total suspended solids (TSS), while the particles that pass through the filter are called total dissolved solids (TDS). Oram (2014) argues that in studies conducted in the United States of America, it was observed that elevated TDS has been due to natural environmental features such as mineral springs, carbonate deposits, salt deposits, and sea water intrusion, but other sources may include: salts used for road de-icing, anti-skid materials, water treatment chemicals, stormwater, and agricultural runoff, and point/non-point wastewater discharges. On the other hand, Hudson-Edwards (2003) points out that the composition of TSS may include sand, silt, clay, mineral precipitates, and biological matter. TSS formation primarily depends on physical processes driven by hydrology. Processes that generate TSS in streams include erosion of adjacent surface soils and stream banks, scouring of the streambed, and aggregation of dissolved organic matter or chemical precipitation of inorganic solids within the water column.

E. coli is also considered to be a significant water quality parameter, most strains are harmless and live in the intestines of healthy humans and animals. *E. coli* may be found in water sources, such as private wells, that have been contaminated with faeces from infected humans or animals. Waste can enter the water through different ways, including sewage overflows, sewage systems that are not working properly, polluted storm water runoff, and agricultural runoff. Wells may be more vulnerable to such contamination after flooding, particularly if the wells are shallow, have been dug or bored, or have been submerged by floodwater for long periods of time (Centres for Disease Control and Prevention, 2015).

CHAPTER 3 : RESEARCH METHODOLOGY

4.3. Introduction

This chapter presents the research design and methodology used in this study. Furthermore, the study explains in detail the approach and methodological steps for data collection and analysis. It outlines the research procedures and data sources. The following section gives a presentation of the study area for this research.

4.4. Study area

Plettenberg Bay is situated along the Garden Route of the Southern Cape Coast. According to Smith (2005), it is bounded on the South-Western side by a rocky headland and the Robberg Peninsula. Four estuaries are present, namely, the Keurbooms estuary which is formed by the confluence of the Bitou and Keurbooms rivers, the Piesang estuary, the Sout River estuary, and the Groot River estuary. The local vegetation predominantly consists of Cape Fynbos and indigenous forests.

Plettenberg Bay has a population of 59,157 people according to the community survey in 2016. Tourism is one of the main sources of economic growth in Plettenberg Bay as it contributes significantly to the local economy. Plettenberg Bay is a well-known tourist destination, people travel from all over the world to spend their holidays in Plettenberg Bay which allows for various employment and business opportunities for the local people.

Figure 2 Local map of Plettenberg Bay

The Bitou Municipality forms part of the Garden Route District Municipality's water quality control programme, where the water quality monitoring programme strives to provide accurate and consistent information to the public on water quality performance per specific water supply system. The microbial, chemical and physical quality of water is determined through sampling at different sources towards a "catchment to consumer" monitoring approach. Sources of sampling include boreholes, rivers, dams, reservoirs, water purification works and taps.

3.1 Research design and approach

This research adopts a desktop study approach with the use of secondary quantitative data elicited from the waterworks department of Plettenberg Bay's Bitou Municipality. The study is supported by existing scientific literature related to the selected water quality parameters and their variations in recreational water in the Plettenberg Bay area. This study also addressed its objectives using an integrated quantitative method and desktop study approach. Field work was not conducted for this study, data were sourced from existing datasets available at the Bitou Municipality waterworks department. The municipality has an extensive monitoring programme through which water quality data are collected every month.

3.5. Data source

Secondary data were used for this research, which was obtained from the Bitou municipality's waterworks department. The data were collected by the municipality for an interval period of five years on a monthly and seasonal basis. Each sample was compared to identify any similarities and trends that may arise thereof. The study focused on six specific water quality parameters as they are considered to be major indicators of the quality of a water body. They are Ammonia, Suspended Solids, Conductivity, Nitrates/Nitrites, pH, and *E. coli*.

The water quality parameters that are being specifically considered in each sample are:

- Ammonia can be measured using ammonia sensors or ion-specific electrodes (ISE).

- Suspended Solids are commonly measured through filtration and weighing of a water sample.

- Conductivity is usually measured using the 2-AC Bipolar method, where the current that passes through a solution between a pair of electrodes is measured.

- Nitrates/Nitrites are commonly measured using ion-specific sensors (ISE) that can detect the nitrate activity in a water sample.

- pH which is measured through the colourimetric method; colourimetric paper is dipped in a water sample and the obtained colour is computed to find a respective value.

- *E. coli* is measured through an EPA-approved method known as Colilert, the water sample is mixed with a reagent powder and incubated for 24 hours, after 24 hours the sample is held under UV light to check for fluorescence.

3.2 Sampling sites

The Bitou Municipality is the local authority within the Plettenberg Bay region and as such, they are in charge and responsible for overseeing all water sampling and monitoring programmes to ensure compliance with water quality standards prescribed in Volume 2 of the South African Water Quality Guidelines as it relates to recreational water use.

The municipality's waterworks department collects samples from five various points within the Plettenberg Bay area. Two samples are collected at the water purification plants, sample one is collected from the raw wastewater before treatment and sample two is collected from the final effluent post-treatment. Sample three is collected from The Old Nick which serves as a market and shopping area. Sample four is collected from The Goose Valley Golf Estate which serves as a residential area and sample five is collected from The Gans River which is where the final effluent is discharged after treatment.

Figure 3 Old Nick sites

Figure 4 The Goose Valley Golf Estate sampling site

3.3 Sample collection

As stated above, data sampling for this study was not done directly by the researcher. However, the metadata obtained from Bitou Municipality was inspected to ascertain the validity and reliability of sample collection methods used by the Bitou Municipality's waterworks department. The procedure followed for sampling in the study is as follows: A total of 100 samples were collected using 500 ml glass storage container bottles that have been sterilised in an autoclave were used in collecting the water samples. Samples were transported in an ice cooler box to the municipal lab and immediately underwent a bacteriological analysis for any bacteria that may be present.

3.6. Data analysis

In this study, data on water quality in the Plettenberg Bay region obtained from the Bitou municipality's waterworks department are analysed against the guidelines for drinking water. The Department of Water Affairs and Forestry (1996) explains there are no recommended universal indicator organisms for recreational water quality as too many variables are involved. While the focus of this study is on recreational water, water used for all human purposes must protect health. Therefore, this research used the guidelines for drinking water to assess the water quality in the study area based on the highest standards of drinking water quality. This choice is also motivated by recreational water users who often ingest or come in full contact with water. The results are presented as descriptive statistics using graphs and tables.

3.7. Water quality guidelines

Access to safe-recreational water for all has become a very important component of basic human rights and an effective policy for tourism protection. Safe water has been a huge point of discussion in various international policy forums. During these forums a number of guidelines, management systems and frameworks have been synthesized in order to ensure that every single tourist on earth has access to safe water, all the nations are also usually encouraged to comply and adopt these policies to the best of their abilities (Glavan, 2018). Some tourists may ingest water during the activities it's important to consider

The World Health Organization (WHO) (2006) suggests that access to safe water is important as a health and development issue at a national, regional, and local level. Therefore, it is imperative that municipalities even at a local level can provide community members with safe water and this directly applies to the Bitou Municipality as well. as indicated in Table 1, the Bitou municipality follows the strict water quality standards prescribed by The South African National Standards (SANS 241:2015) for drinking water, which have been incorporated into the municipality's by-laws. SANS 241 gives the exact acceptable quantities of each parameter in drinking water, and it also clearly states the possible risks associated with quantities above acceptable limits, with risks varying from aesthetic, operational, acute, and chronic health.

Table 3-1: Drinking Water Guidelines (SANS 241: 2015)

Parameter	Unit	Risk	Standard Limit
pH	pH Unit	Operational	≥5.0 - ≤9.7
Total Dissolved Solids remove	mg/L	Aesthetic	1200
Suspended Solids	mg/L	Aesthetic	1200
Alkalinity remove	mg/L	Operational	20-200
E.coli (<1 taken as 0)	cfu/100mL	Acute Health	0
Ammonia	mg/L	Aesthetic	1.5
Nitrate	mg/L	Acute Health	11
Conductivity (25^{0}C)	mS/m	Aesthetic	170

Table 1 shows each parameter unit of measurement, risk, and standard limit. For pH, the standard limit ranges between 5.0 and 9.7, where the pH level cannot exceed 9.7 and cannot go below 5.0. Should the measurement fall anywhere outside of the standard limit, the risks associated with that are operational. According to the WHO (2006), the pH is very important in determining the corrosivity of water, a high pH value will result in high levels of corrosion. Humans exposed to waters with high pH values will result in eyes, skin, and gastrointestinal irritation.

The total dissolved solids, as indicated in table 1, shows a standard limit of 1200 mg/L and the risk associated with the level that exceeds the standard limit is aesthetic. Aesthetics play an important role in the public's perception of such as in recreational water, total dissolved solids in surface water may alter or degrade the water quality and this will affect the water's desirability to the public. Dissolved solids may also cause the water to appear different in colour and odour, which contributes negatively to the overall aesthetic of the surface water body. Much like total dissolves solids, suspended solids have a standard limit of 1200 mg/L and the risk associated with levels higher than 1200 mg/L is aesthetic, which is the same as that of total dissolved solids. Suspended solids in the water will cause it to be aesthetically undesirable to the public.

Alkalinity is measured in mg/L and the standard limit is 20-200, any levels that fall outside of the standard limit range are like to cause operational risks. Much like pH, alkalinity also has operational risks and should the standard limit be exceeded the water will be generally classified as hard. According to Cortruvo *et al.* (2011) depending on various interactions with factors such as pH and alkalinity, hard water can cause increased soap consumption and scale deposition in water distribution systems, as well as in heated water applications where insoluble metal carbonates are formed, coating surfaces, and reducing the efficiency of heat exchangers. Furthermore, soft waters if not stabilised can cause corrosion of metal surfaces and pipes. This corrosion may result in the presence of heavy metals such as cadmium, zinc, and copper in water.

For drinking water purposes, Table 1 shows that the standard limit for *E.coli* is 0 (where any measurement below 1 is taken as 0). *E. coli* is measured in colony-forming units (cfu) per 100 mL of water, the risk associated with levels that exceed the standard limit is acute health risks. Being exposed to water with high *E. coli* levels poses a significant risk to human health, as these waters can cause gastrointestinal illnesses. Even in agricultural use, such waters would pose a serious risk to food security (production and consumption). Hence, for recreational purposes involving full contact with water, it can only be suggested that *E. coli* limits conform to drinking water quality standards for maximum protection.

Ammonia and Nitrate are the most common forms of nitrogen in water bodies that are often used for recreational activities such as along beaches. Table 1 shows that the standard limit for ammonia is 1.5 mg/L and for nitrate, it is 11 mg/L. The risks associated with excessive ammonia quantities are aesthetic and the risks for excessive nitrates are acute health risks.

The last water quality parameter in Table 1 is conductivity, which is measured in micro-Siemen per meter. The standard limit for conductivity in water at 25^{0}C is 170 mS/m. Risks associated with high conductivity levels in water are aesthetic, similar to that of total dissolved solids and suspended solids. Pure water cannot conduct a current. However, waters with a high mineral and salt content can conduct a current. Therefore, high conductivity in water would mean there are minerals and salts present in the water. Hence, the aesthetic risks associated with conductivity exceed the standard limit as proposed in Table 1.

With the final effluent being discharged into the Gans River it is important to ensure that it meets recreational use water quality standards, it must specifically meet contact recreational use. Plettenberg Bay is a huge tourist attraction and destination area, with the use of coastal marine waters for activities such as swimming, boating, scuba diving, canoeing and many more water activities. The Bitou Municipality makes use of the South African Water Quality Guidelines, Volume 2: Recreational Use to determine recreational water compliance.

According to The Department of Water Affairs and Forestry (1996), a water quality guideline is a set of information provided for a specific water quality constituent. Volume 2 of the South African Water Quality Guidelines provides all the different target water quality ranges for various constituents in recreational water. Most target water quality ranges are qualitative as there are no specific quantitative measurements given for some constituents. However, there are general principles that need to be adhered to when considering the presence of various constituents in water.

The Department of Water Affairs and Forestry (1996) makes use of the general term Chemical Irritants, which is defined as; chemical compounds that exert toxic or irritant effects and occur in water mainly as a result of human activities. For chemical irritants in the case of full-contact recreational water the guidelines state that waters should not contain chemicals in such concentrations as to be toxic to humans if small quantities of water are ingested or absorbed through the skin and if this guideline cannot be adhered to, warning notices must be posted near the water body.

Furthermore, recreational water can be characterized as having low or high clarity and The Department of Water Affairs and Forestry (1996) defines the clarity of a body of water as the depth to which light can penetrate and this is often associated with turbidity. Ideally, contact recreational water should have high clarity as there are possible human health risks associated with low-clarity water bodies due to the presence of micro-organisms either as suspended or dissolved particulate matter in the water. Clarity is measured quantitatively in Secchi Disk visibility in meters. The guideline for clarity states that the acceptable target water quality range is 3.0-1.0 Secchi Disk Depth (m), at this range users will still find the water acceptable for swimming and risks of disease transmission by micro-organisms associated with particulate matter is still very low, with the water still appearing to be aesthetically pleasing.

Eden (2014) defines indicator organisms as organisms that are used as a sign of quality or hygienic status in food, water, or the environment. This study will only consider *E. coli* as an indicator organism and according to the guidelines it is measured quantitatively in counts per 100 mL for full contact recreational water use. The target water quality range is 0-130 counts per 100 mL, this range is deemed acceptable for full contact use and there are extremely low human health risks associated with this range.

However, any measurements that exceed 400 counts per mL are deemed unacceptable for full contact use and the water can most likely cause gastrointestinal illnesses in humans. The Department of Water Affairs and Forestry (1996) argues that contact with water of extreme pH can cause discomfort and irritation to the eyes, ears, skin and mucous membranes of the nose and mouth. Therefore, the target water quality range for pH is 6.5-8.5 units and any measurement outside of this range may cause skin, eyes, nose, and mouth irritation to humans and may have adverse aesthetic taste effects if swallowed.

CHAPTER 4 : RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents and discusses water quality data obtained from the analysis of water samples taken in the greater Plettenberg Bay area by the Bitou Municipality's water works department. Presentation and discussion of obtained data will result in identifying any patterns or trends that may arise over a five-year period (2016-2020) in the water quality of recreational water in the greater Plettenberg Bay area.

4.2. Ammonia

Table 2 shows the ammonia concentrations that were measured every month for five years (2016-2020). Moreover, Table 2.1 reflect descriptive statistics data. In table 2, each month has a total of five entries, representing the average concentration of ammonia for each year. An overall yearly average of these entries was calculated and used to figure 5. The bar chart gives a clearer visual depiction of the overall trend of ammonia over the five-year period, with the plotting of the overall yearly averages on the y-axis and the years on the x-axis.

From observing table 2 and figure 5, one can see the general trend that ammonia follows, where in 2016 the concentration measured slightly above 4 mg/L and between 2017 and 2019 the concentration decreases to exactly 2.54 mg/L. It is worth noting that in September of 2017, there was a significant increase of up to 8.80 mg/L in the concentration of ammonia, this was almost four times August's concentration and at least eight times October's concentration, making it a significant anomaly. This anomaly can be attributed to the presence of residual nitrogen compounds post-purification as stated by Clayton (2004). Ammonia concentrations were steadily decreasing until the year 2020 when there was a slight increase of exactly 0.88 mg/L from the year 2019. Humans are less sensitive to ammonia in water, but long-term exposure to water containing more than 1 mg/L can cause internal organ damage and any solution with a concentration greater than 1000 mg/L can cause severe burns and scarring to sensitive skin. (Oregon Department of Human Services, 2000). Ammonia's impact on recreational activities

Table 4-1: ammonia concentration 2018-2020

Month	2016	2017	2018	2019	2020
Jan	4,35	4,32	0,37	2,44	4,07
Feb	5,07	4,57	2,46	2,71	3,44
Mar	2,07	3,92	3,00	3,22	2,79
Apr	0,95	5,30	0,78	1,61	4,31
May	5,62	4,16	2,65	4,29	4,38
Jun	5,28	3,68	2,41	2,20	2,95
Jul	3,83	3,89	3,47	1,38	3,90
Aug	4,01	2,15	3,42	0,76	2,46
Sep	3,68	8,80	4,83	1,34	1,34
Oct	5,56	1,29	4,45	2,80	2,80
Nov	4,77	3,81	2,28	2,65	3,78
Dec	5,15	3,50	4,32	5,07	4,80
Yearly Average	**4,19**	**4,12**	**2,87**	**2,54**	**3,42**

Table 4-2: Descriptive statistics for Ammonia data

Ammonia	2016	2017	2018	2019	2020
Nbr. of observations	12	12,000	12,000	12,000	12,000
Minimum	0,950	1,290	0,370	0,760	1,340
Maximum	5,620	8,800	4,830	5,070	4,800
1st Quartile	3,793	3,635	2,378	1,553	2,798
Median	4,560	3,905	2,825	2,545	3,610
3rd Quartile	5,183	4,383	3,683	2,905	4,130
Mean	4,195	4,116	2,870	2,539	3,418
Variance (n)	1,882	3,016	1,710	1,415	0,888
Variance (n-1)	2,053	3,290	1,865	1,544	0,968
Standard deviation (n)	1,372	1,737	1,307	1,189	0,942
Standard deviation (n-1)	1,433	1,814	1,366	1,242	0,984
Skewness (Pearson)	-1,146	1,177	-0,381	0,602	-0,575
Kurtosis (Pearson)	0,339	2,151	-0,606	-0,282	-0,331
Standard error of the mean	0,414	0,524	0,394	0,359	0,284
Standard error of the variance	0,875	1,403	0,795	0,658	0,413

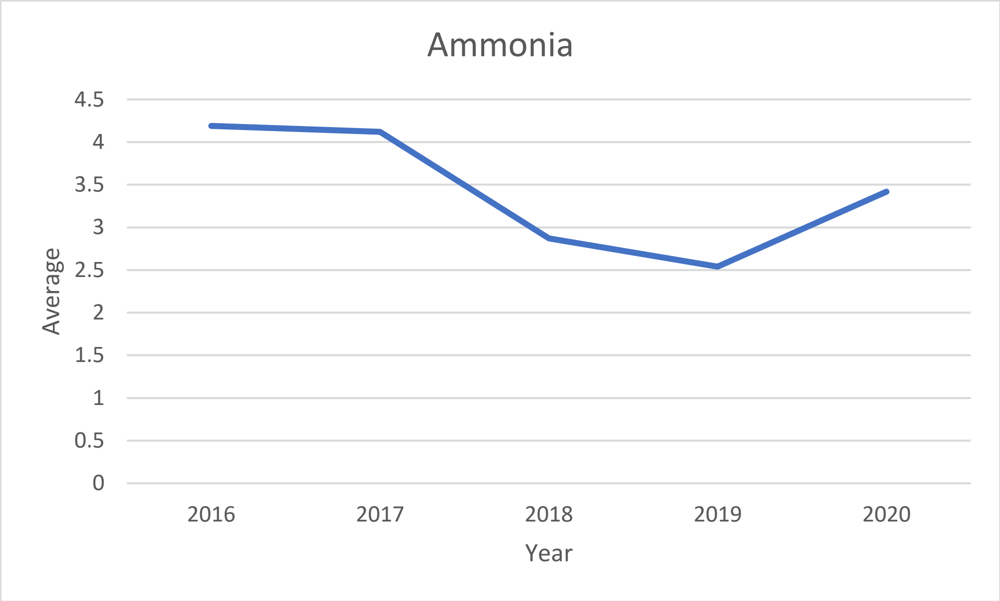


Figure 5 Graph depicting trends in Ammonia concentrations 2016-2020

4.3. Total Suspended Solids (TSS)

Table 3 shows the suspended solids concentrations that were measured every month for five years (2016-2020). Additionally, Table 3.1 shows descriptive statistical data. In table 3, each month has a total of five entries, representing the average concentration of suspended solids for each year. An overall yearly average of these entries was calculated and used to produce the graph in figure 6. The graph gives a clearer visual depiction of the overall trend of suspended solids over the five-year period, with the plotting of the overall yearly averages on the y-axis and the years on the x-axis.

Table 3 shows the highest ever measured concentration of suspended solids in the final effluent was 24.42 mg/L and that was in April of 2018. This was a significant increase in concentration compared to March and May 2018, according to Hudson-Edwards (2003) this anomaly can be attributed to various factors and some of the leading factors may be the aggregation of dissolved organic matter or chemical precipitation of inorganic solids within the water column. Lin *et al.* (2022) detail how various chemical substances behave once they enter a waterbody, some of them may undergo chemical reactions with other elements or minerals to form new less toxic or more toxic substances.

Table 4-3: Suspended Solids concentration 2016-2020

Month	2016	2017	2018	2019	2020
Jan	15,62	17,93	15,33	9,75	15,36
Feb	9,92	13.09	7,18	9,67	14,17
Mar	13,92	10.20	9,92	10,54	13,77
Apr	8,46	13.36	24.42	8,15	12,00
May	7,67	9.23	10,31	7,57	9,85
Jun	7,17	6.85	11,45	7,64	7,54
Jul	7,83	7.83	10,38	5,57	7,83
Aug	11,42	4,92	6,64	7,23	10,38
Sep	10,92	6,69	7,55	6,62	5,57
Oct	14,69	6,33	10,36	7,31	7,52
Nov	16,42	9,08	11,54	6,91	7,31
Dec	16,50	10,92	11,69	8,85	8,85
Yearly Average	**11,71**	**9,71**	**11,40**	**7,98**	**10,01**

Table 4-4: Descriptive statistics data for suspended solids

Suspended solids	2016	2017	2018	2019	2020
Nbr. of observations	12	12,000	12,000	12,000	12,000
Minimum	7,170	4,920	6,640	5,570	5,570
Maximum	16,500	17,930	24,420	10,540	15,360
1st Quartile	8,303	6,810	9,328	7,150	7,535
Median	11,170	9,155	10,370	7,605	9,350
3rd Quartile	14,923	11,463	11,578	9,055	12,443
Mean	11,712	9,703	11,398	7,984	10,013
Variance (n)	11,720	12,487	20,488	1,952	9,133
Variance (n-1)	12,786	13,623	22,351	2,130	9,963
Standard deviation (n)	3,423	3,534	4,526	1,397	3,022
Standard deviation (n-1)	3,576	3,691	4,728	1,459	3,156
Skewness (Pearson)	0,108	0,834	1,818	0,273	0,410
Kurtosis (Pearson)	-1,547	0,051	2,966	-0,805	-1,127
Standard error of the mean	1,032	1,065	1,365	0,421	0,911
Standard error of the variance	5,452	5,809	9,530	0,908	4,248

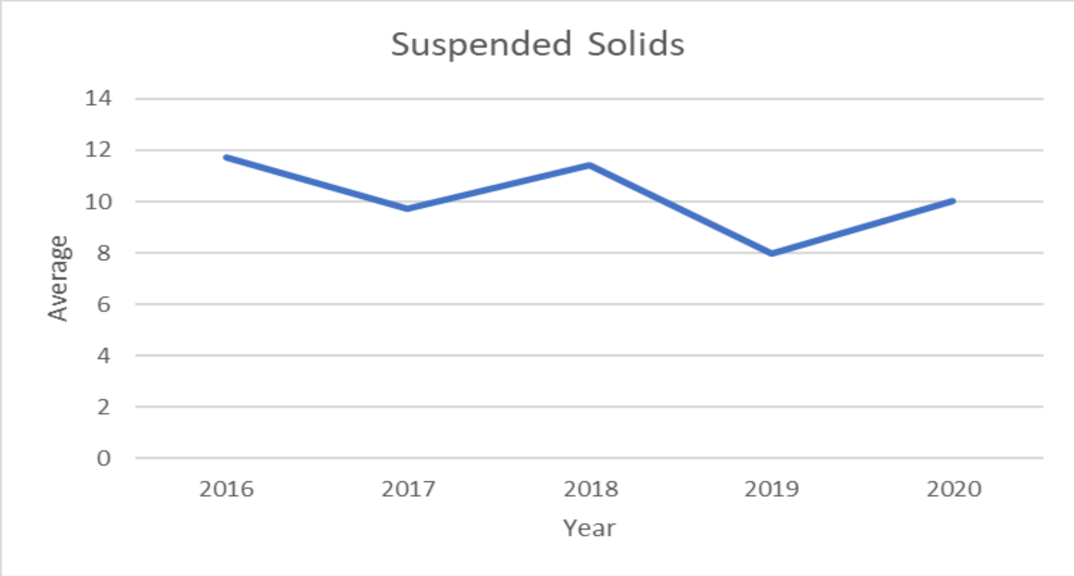


Figure 6: Graph depicting trends in Suspended Solids concentration 2016-2020

4.3. Electrical conductivity (EC)

Table 4 shows the measurement of conductivity that was measured every month for five years (2016-2020). Table 4.1 reflect descriptive statistical data. In table 4, each month has a total of five entries, representing the average measurement of conductivity for each year. An overall yearly average of these entries was calculated and used to produce the graph in figure 7. The graph gives a clearer visual depiction of the overall trend of conductivity over the five-year period, with the plotting of the overall yearly averages on the y-axis and the years on the x-axis.

According to Rusydi (2018), the total amount of dissolved ions in a body of water influences the water's overall EC, drawing a relationship between ion concentration and conductivity. Table 4 shows the increase in the measurement of conductivity starting in 2017, 2018 and 2019. This trend is also expressed in the yearly averages in figure 7 and this further proves the existing relationship pointed out by Rusydi (2018) in the literature review section, as one can observe how the increased suspended solids concentration of 2018 in table 3 and figure 6 resulted in an increase in the conductivity measurement in table 4 and figure 7 expressed as a yearly average.

Table 4-5 : Conductivity measurement 2016-2020

Month	2016	2017	2018	2019	2020
Jan	96,58	102,47	109,83	90,85	87,02
Feb	70,09	73,42	74,95	73,99	75,51
Mar	73,28	77,69	74,22	74,86	73,82
Apr	69,10	80,65,	69,28	76,85	69,68
May	75,43	72,97	69,38	77,86	71,01
Jun	71,65	73,31	69,28	79,13	68,79
Jul	66,68	70,83	65,99	74,50	66,68
Aug	55,25	67,59	71,61	84,22	55,25
Sep	70,08	76,38	82,67	84,35	70,44
Oct	78,44	66,46	82,16	84,39	78,53
Nov	86,68	69,15	86,82	76,77	69,55
Dec	87,14	83,37	83,85	79,14	65.23
Yearly Average	**75,03**	**76,19**	**78,34**	**79,74**	**70,96**

Table 4-6: Descriptive statistical data for conductivity.

Conductivity	2016	2017	2018	2019	2020
Nbr. of observations	12	12,000	12,000	12,000	12,000
Minimum	55,250	66,460	65,990	73,990	55,250
Maximum	96,580	102,470	109,830	90,850	87,020
1st Quartile	69,835	70,410	69,355	76,293	68,263
Median	72,465	73,365	74,585	78,495	70,060
3rd Quartile	80,500	78,430	82,965	84,253	74,243
Mean	75,033	76,191	78,337	79,743	70,959
Variance (n)	109,841	86,469	133,164	24,346	54,223
Variance (n-1)	119,827	94,330	145,269	26,559	59,152
Standard deviation (n)	10,481	9,299	11,540	4,934	7,364
Standard deviation (n-1)	10,947	9,712	12,053	5,154	7,691
Skewness (Pearson)	0,331	1,707	1,500	0,798	0,112
Kurtosis (Pearson)	-0,125	2,550	1,869	-0,312	0,760
Standard error of the mean	3,160	2,804	3,479	1,488	2,220
Standard error of the variance	51,094	40,222	61,943	11,325	25,223

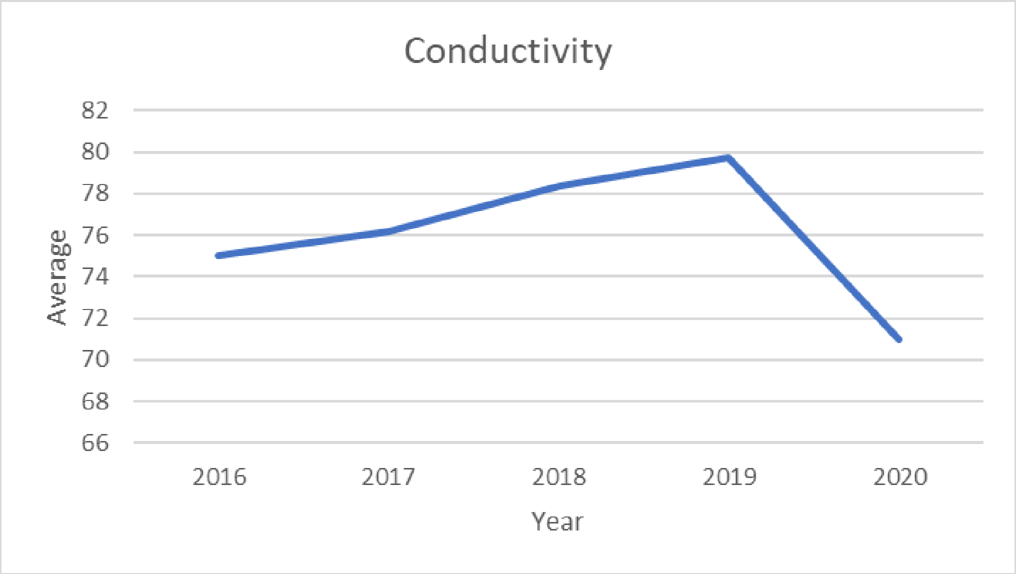


Figure 7: Graph depicting trends in conductivity measurements 2016-2020

4.4. Nitrates

Figure 3 shows the concentration of Nitrates/Nitrites that was measured every month for five years (2016-2020). In table 5, each month has a total of five entries, representing the average concentration of nitrates/nitrites for each year. An overall yearly average of these entries was calculated and used to produce the graph in figure 14. Table 5.1 further shows descriptive statistical data. The graph gives a clearer visual depiction of the overall trend of the concentration of nitrates/nitrites over the five-year period, with the plotting of the overall yearly averages on the y-axis and the years on the x-axis. The concentration for nitrates and nitrites presented a more erratic trend, where the concentration decreased from 2.24 mg/L in 2016 to 1.58 mg/L in 2017 and in 2018 the concentration of nitrates and nitrites in the effluent doubled and was measured at an all-time high of 3.18 mg/L. However, from 2019 to 2020 the concentration decreased, as can be seen in figure 14. Aldous (2018) argues that the accumulation of nitrogen compounds such as nitrates and nitrites in waterbodies may be a result of anthropogenic activities such as wastewater treatment facilities. Concurrently, Clayton (2004) argues that wastewater effluents always contain residual quantities of nitrogen compounds.

Table 4-7: Nitrates/Nitrites concentrations 2016-2020

Month	2016	2017	2018	2019	2020
Jan	1,52	0,89	1,58	1,54	1,11
Feb	1,65	0,92	2,33	0,68	1,19
Mar	2,53	0,77	1,70	0,87	0,76
Apr	2,92	0,91	1,83	1,67	0,90
May	1,27	1,12	2,17	2,09	0,95
Jun	3,10	4,99	3,79	1,10	1,79
Jul	2,09	1,89	5,88	3,84	2,53
Aug	4,84	1,66	2,07	2,25	2,40
Sep	2,99	2,46	12,46	2,92	1,97
Oct	0,95	2,00	1,95	3,09	2,10
Nov	1,26	0,64	1,17	3,20	1,85
Dec	1,72	0,65	1,21	1,19	1,27
Yearly Average	**2,24**	**1,58**	**3,18**	**2,04**	**1,57**

Table 4-8: descriptive statistical data for Nitrates/Nitrites.

Nitrates/Nitrites	2016	2017	2018	2019	2020
Nbr. of observations	12	12,000	12,000	12,000	12,000
Minimum	0,950	0,640	1,170	0,680	0,760
Maximum	4,840	4,990	12,460	3,840	2,530
1st Quartile	1,458	0,860	1,670	1,168	1,070
Median	1,905	1,020	2,010	1,880	1,530
3rd Quartile	2,938	1,918	2,695	2,963	2,003
Mean	2,237	1,575	3,178	2,037	1,568
Variance (n)	1,111	1,388	9,397	0,977	0,343
Variance (n-1)	1,212	1,514	10,251	1,065	0,374
Standard deviation (n)	1,054	1,178	3,065	0,988	0,585
Standard deviation (n-1)	1,101	1,231	3,202	1,032	0,612
Skewness (Pearson)	1,023	1,911	2,283	0,313	0,196
Kurtosis (Pearson)	0,511	3,021	4,103	-1,178	-1,374
Standard error of the mean	0,318	0,355	0,924	0,298	0,177
Standard error of the variance	0,517	0,646	4,371	0,454	0,159

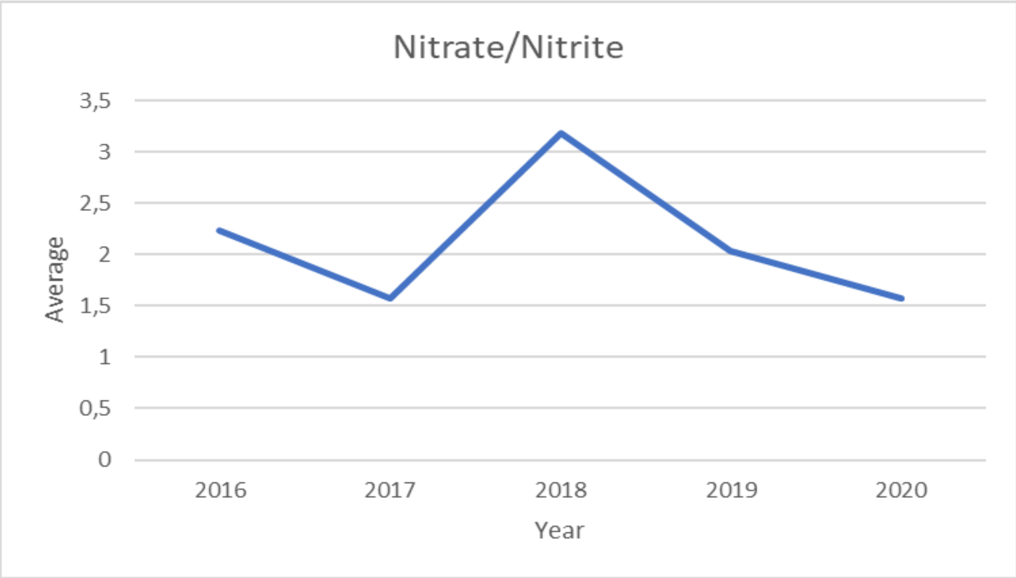


Figure 8: Graph depicting trends in Nitrates/Nitrites concentrations 2016-2020

4.5. pH

Table 6 shows the pH levels that were measured every month for five years (2016-2020). Table 6.1 further reflects descriptive statistical data. In table 6, each month has a total of five entries, representing the average measurement of pH for each year. An overall yearly average of these entries was calculated and used to produce figure 9. The graph gives a clearer visual depiction of the overall trend of pH over the five-year period, with the plotting of the overall yearly averages on the y-axis and the years on the x-axis. Figure 9 shows all the fluctuations in pH levels over the five-year period and according to The Department of Water Affairs and Forestry (1996) pH has a target water quality range of 6.5-8.5 units and Radke (2006) argues that any measurements that lies outside of this range will result in the disruption in the optimal activity of various biological processes.

Furthermore, pH levels below desired ranges may cause fish to become susceptible to fungal infections, and physical damage to their gills, eyes, and skin. This threat to aquatic biodiversity will in turn affect the tourism sector of Plettenberg Bay, as tourists and scientists travel from all over the world to come and observe and study certain aquatic species. This water quality target range is the same for full contact recreational water use, if pH levels are outside of this range, The Department of Water Affairs and Forestry (1996) argues that it may result in discomfort and irritation to the eyes, ears, skin and mucous membranes of the nose and mouth. Tourists that visit Plettenberg Bay usually enjoy water activities and for that reason, it is imperative to constantly monitor the fluctuations in pH levels and to ensure that the final effluent discharged into the environment meets the specified regulations such that it will not alter nor damage the environment once discharged and it will not pose as a potential health risk for humans and aquatic life. From closely observing table 6 and figure 9 one can see that all the pH measurements over the five years fall within the target water quality range, meaning that the final effluent discharged into the environment was compliant with full contact recreational water use regulations.

Table 4-9: pH concentrations 2016-2020

Month	**2016**	**2017**	**2018**	**2019**	**2020**
Jan	7,36	7,79	7,98	7,29	7,24
Feb	6,98	7,35	7,45	7,05	7,43
Mar	7,02	7,08	6,83	7,18	7,26
Apr	6,96	7,27	6,76	7,24	6,95
May	7,02	7,22	6,89	7,21	7,01
Jun	6,95	7,30	7,03	7,19	7,04
Jul	7,25	7,25	6,90	7,04	7,21
Aug	7,14	7,10	7,07	7,09	7,86
Sep	7,10	7,06	6,99	7,08	6,85
Oct	7,11	7,15	7,18	7,13	6,90
Nov	7,33	7,49	7,27	7,26	7,53
Dec	7,90	7,72	7,21	7,25	7,48
Yearly Average	**7,18**	**7,31**	**7,13**	**7,17**	**7,23**

Table 4-10: Descriptive statistical data for pH.

pH	2016	2017	2018	2019	2020
Nbr. of observations	12	12,000	12,000	12,000	12,000
Minimum	6,950	7,060	6,760	7,040	6,850
Maximum	7,900	7,790	7,980	7,290	7,860
1st Quartile	7,010	7,138	6,898	7,088	6,995
Median	7,105	7,260	7,050	7,185	7,225
3rd Quartile	7,270	7,385	7,225	7,243	7,443
Mean	7,177	7,315	7,130	7,168	7,230
Variance (n)	0,065	0,053	0,102	0,007	0,084
Variance (n-1)	0,071	0,057	0,111	0,008	0,092
Standard deviation (n)	0,256	0,229	0,319	0,083	0,290
Standard deviation (n-1)	0,267	0,239	0,334	0,087	0,303
Skewness (Pearson)	1,752	0,925	1,388	-0,176	0,584
Kurtosis (Pearson)	2,534	-0,315	1,537	-1,393	-0,472
Standard error of the mean	0,077	0,069	0,096	0,025	0,087
Standard error of the variance	0,030	0,024	0,047	0,003	0,039

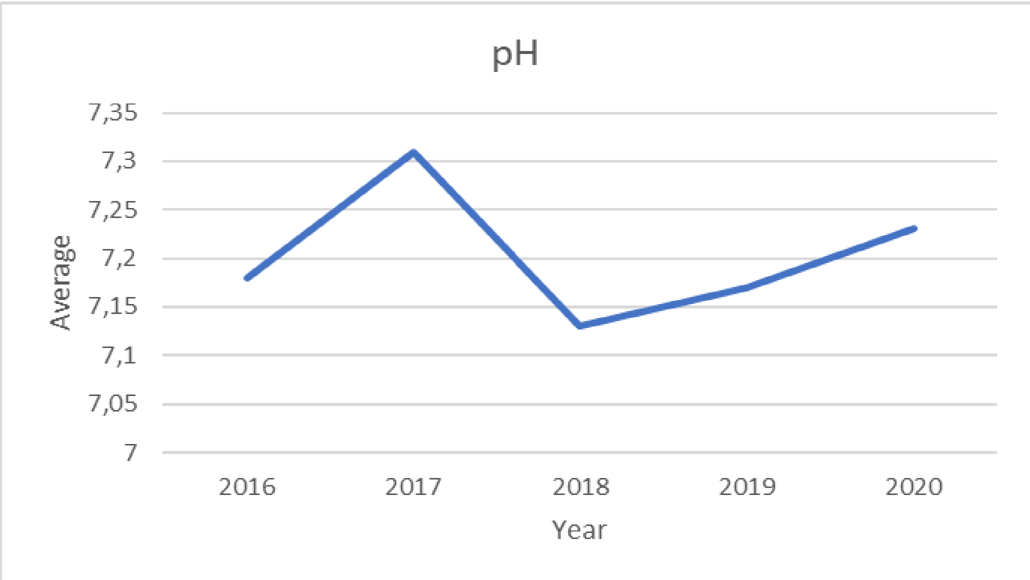


Figure 9: pH concentrations 2016-2020

4.6. E. coli

Table 7 shows the concentration of *E. coli* that was measured every month for five years (2016-2020). In table 7, each month has a total of five entries, representing the average concentration of *E. coli* for each year. An overall yearly average of these entries was calculated and used to produce the graph in figure 10. The graph gives a clearer visual depiction of the overall trend of the concentration of *E. coli* over the five years, with the plotting of the overall yearly averages on the y-axis and the years on the x-axis. *E. coli* according to Eden (2014) is used as an indicator organism to show the quality or hygienic status of water. Furthermore, The Department of Water Affairs and Forestry (1996) states that the target water quality range for *E. coli* is 0-130 counts per 100 mL for full contact recreational water use.

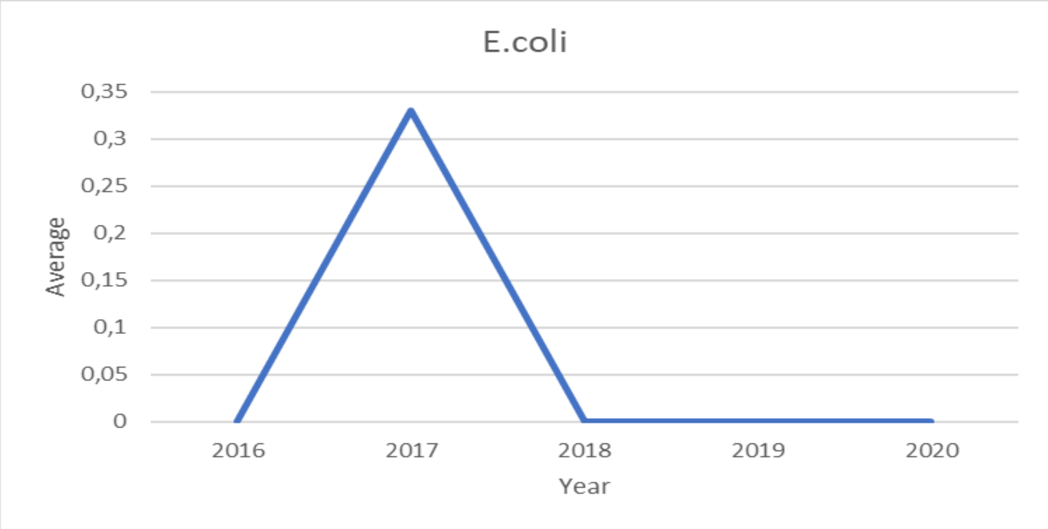
However, table 7 indicates that in September of 2017, there was a sudden detection of *E. coli* in the effluent, and it was measured at exactly 3.18 counts per 100 mL in the following month this concentration decreased to exactly 0.83 counts per 100 mL and this brought the overall year average for 2017 to 0.33 counts per 100 mL. This observed fluctuation in concentration was significant because this was the only anomaly during the five years as all the other monthly measurements had no detections of *E. coli*. However, the detected amount of *E. coli* still fell within the target water quality range and was not in significant amounts to cause gastrointestinal illnesses in humans as pointed out by The Department of Water Affairs and Forestry (1996). Centres for Disease Control and Prevention (2015) argues that faecal matter can enter waterbodies in different ways, including sewage overflows, sewage systems that are not working properly and polluted stormwater runoff.

Table 4-11: *E. coli* concentrations 2016-2020

Month	2016	2017	2018	2019	2020
Jan	0,00	0,00	0,00	0,00	0,00
Feb	0,00	0,00	0,00	0,00	0,00
Mar	0,00	0,00	0,00	0,00	0,00
Apr	0,00	0,00	0,00	0,00	0,00
May	0,00	0,00	0,00	0,00	0,00
Jun	0,00	0,00	0,00	0,00	0,00
Jul	0,00	0,00	0,00	0,00	0,00
Aug	0,00	0,00	0,00	0,00	0,00
Sep	0,00	0,00	0,00	0,00	0,00
Oct	0,00	0,00	0,00	0,00	0,00
Nov	0,00	0,00	0,00	0,00	0,00
Dec	0,00	0,00	0,00	0,00	0,00
Yearly Average	0,00	0,00	0,00	0,00	0,00

Table 4-12: Descriptive statistical data for E. coli*.*

E. coli	2016	2017	2018	2019	2020
Nbr. of observations	12	12,000	12,000	12,000	12,000
Minimum	0,000	0,000	0,000	0,000	0,000
Maximum	3,180	0,000	0,000	0,000	0,000
1st Quartile	0,000	0,000	0,000	0,000	0,000
Median	0,000	0,000	0,000	0,000	0,000
3rd Quartile	0,000	0,000	0,000	0,000	0,000
Mean	0,334	0,000	0,000	0,000	0,000
Variance (n)	0,788	0,000	0,000	0,000	0,000
Variance (n-1)	0,860	0,000	0,000	0,000	0,000
Standard deviation (n)	0,888	0,000	0,000	0,000	0,000
Standard deviation (n-1)	0,927	0,000	0,000	0,000	0,000
Skewness (Pearson)	2,714				
Kurtosis (Pearson)	5,817				
Standard error of the mean	0,268	0,000	0,000	0,000	0,000
Standard error of the variance	0,367	0,000	0,000	0,000	0,000



4.7. Data correlation

Tables below shows the correlations between ammonium, suspended solids (TSS),
Figure 10: Graph depicting trends in *E. coli* concentrations 2016-2020
conductivity (EC), nitrates, and pH. The value for *E. coli* were 0 almost in every year, the correlation was therefore not calculated for this parameter.

Table 4-13. Correlation analysis for the year 2016

	Ammonia	TSS	EC	Nitrates	pH
Ammonia	0.13191219	0.29593893	-0.4341489	0.26879452	0.29281519
TSS		0.66732377	-0.3470591	0.65387229	0.25765891
EC			-0.727449	0.56000065	0.08628513
Nitrates				-0.2648265	-0.3583146
pH					-0.0876119

Ammonia has a positive correlation with all the other variables. This means that as the level of ammonia increases, the levels of TSS, EC, nitrates, and pH also tend to increase linearly. TSS has a positive correlation with EC, nitrates, and pH. This indicates that as the level of TSS increases, the levels of EC, nitrates, and pH also tend to increase linearly. EC has a negative correlation with nitrates. This means that as the level of EC increases, the level of nitrates tends to decrease linearly. Nitrates have a negative correlation with both EC and TSS. This indicates that as the level of nitrates increases, the levels of EC and TSS tend to decrease linearly. pH has a negative correlation with all the other variables, including TSS, EC, nitrates, and ammonia. This indicates that as the pH level decreases, the levels of these variables tend to increase linearly.

Table 4-14. Correlation analysis for 2017

	Ammonia	TSS	EC	Nitrates	pH
Ammonia	0.0908075	0.25940355	0.04016517	-0.1016866	-0.1016866
TSS		0.93858894	-0.6127287	0.88447221	-0.1586804
EC			-0.2491697	0.70566193	-0.1716709
Nitrates				-0.3116017	-0.4861546
pH					-0.4849029

It can be seen that ammonia is positively correlated with TSS (total suspended solids) and EC (electrical conductivity), with correlation coefficients of 0.090 and 0.040, respectively. TSS is highly positively correlated with EC, with a correlation coefficient of 0.705. This suggests that as the concentration of TSS increases, so does the electrical conductivity. In contrast, ammonia is negatively correlated with nitrates and pH, with correlation coefficients of -0.102 and -0.102, respectively. Nitrates and pH are not strongly correlated with each other or with the other variables.

Table 4-15. Correlation analysis for 2018

	Ammonia	TSS	EC	Nitrates	pH
Ammonia	- 0.5708278	-0.2562718	0.46788751	-0.3504542	-0.3504542
TSS		0.63020796	-0.3723525	0.51682905	0.23006455
EC			-0.1035164	0.85433272	0.45097551
Nitrates				-0.2435433	0.32271033
pH					-0.0898979

Table 10 shows strong correlation coefficient mainly between two water quality parameters. For example, ammonia and column TSS shows the correlation coefficient between ammonia and TSS, which is -0.256. Some insight drawn from table 10 is that there is a negative correlation between ammonia and TSS, which suggests that high levels of ammonia may be associated with lower levels of suspended solids. A positive correlation between ammonia and electrical conductivity is also observed, which suggests that high levels of ammonia may be associated with higher electrical conductivity. However, the exact implications of this relationship seem unclear.

Table 4-16. Correlation analysis for 2019

	Ammonia	TSS	EC	Nitrates	pH
Ammonia	0.43938698	-0.1968686	-0.3894116	0.48419506	0.48419506
TSS		0.00580669	-0.86414	0.37229071	0.55284709
EC			0.12024532	0.22133158	0.63305909
Nitrates				-0.29049	0.66987496
pH					0.65273195

Table 11 shows that TSS and EC have a very weak positive correlation with a coefficient of 0.006, indicating that there is little or no relationship between them. TSS and nitrate concentration have a strong negative correlation with a coefficient of -0.864, indicating that as TSS increases, nitrate concentration tends to decrease. This relationship may be due to the fact that suspended solids can adsorb and remove nitrate from water. There is no correlation coefficient provided for TSS and pH, so it is not possible to determine the relationship between them. EC and nitrate concentration have a weak positive correlation with a coefficient of 0.221, indicating that as EC increases, nitrate concentration tends to increase slightly as well. This relationship may be due to the fact that both EC and nitrate concentration can be affected by the presence of dissolved ions in the water.

EC and pH have a moderate positive correlation with a coefficient of 0.633, indicating that as EC increases, pH tends to increase as well. This relationship may be due to the fact that conductivity can be affected by the concentration of dissolved ions, which can also affect the pH of water. Nitrate concentration and pH have a moderate positive correlation with a coefficient of 0.653, indicating that as nitrate concentration increases, pH tends to increase as well. This relationship may be due to the fact that nitrate is a weak base and can increase the pH of water.

Table 4-17. Correlation analysis for 2020

	Ammonia	TSS	EC	Nitrates	pH
Ammonia	0.31537668	0.25201815	-0.4382731	0.13865584	0.13865584
TSS		0.42109873	-0.6666387	0.25046787	0.13956141
EC			-0.5024325	-0.436573	0.13708247
Nitrate				0.17840304	0.15005924
pH					0.25455749

The correlation between ammonia and total suspended solids (TSS) is moderate and positive (0.32), meaning that as the concentration of ammonia increases, so does the concentration of TSS. This suggests that there may be common sources of pollution that contribute to both parameters in recreational water, such as agricultural or industrial runoff, or sewage discharge.

The correlation between ammonia and electrical conductivity (EC) is weak and negative (-0.44), indicating that as the concentration of ammonia increases, EC tends to decrease slightly. This may be due to the fact that ammonia is a weak electrolyte and can decrease the conductivity of water. The correlation between ammonia and nitrate is weak and positive (0.14), indicating that as the concentration of ammonia increases, so does the concentration of nitrate. Both ammonia and nitrate can be produced by nitrogen-based compounds, but the balance between them can vary depending on environmental conditions.

The correlation between ammonia and pH is weak and positive (0.14), suggesting that as the concentration of ammonia increases, pH tends to increase slightly as well. This may be due to the fact that ammonia is a weak base and can increase the pH of water. The correlation between TSS and EC is weak and positive (0.25), indicating that as the concentration of TSS increases, EC tends to increase slightly as well. This relationship may be due to the fact that TSS can contain dissolved ions, which can increase the electrical conductivity of water.

4.7.1. Summary of correlation analysis

The data correlation analysis aimed at identifying unique trends in the water quality data for the Plettenberg Bay region. In table 8, there is a positive correlation between ammonia and nitrate, while in table 12, there is a negative correlation. This suggests that there may have been changes in the sources of contamination or the environmental conditions that affect these parameters over time. Similarly, in table 9, there is a strong positive correlation between TSS and conductivity (EC), while in table 12, this correlation is not as strong. This could be due to changes in the types or amounts of contaminants in the water, or changes in the physical or chemical properties of the water over time.

Another interesting trend is the correlation between pH and the other parameters. In general, the correlation between pH and the other parameters is relatively weak across all five tables. However, in table 12, there is a stronger positive correlation between pH and ammonia than in the other tables. This could indicate a change in the source of ammonia in the water over time. Overall, these tables show that the correlation between different parameters in recreational water can vary over time. This suggests that regular monitoring of water quality is necessary to identify changes in contamination sources or environmental conditions, and to ensure the safety of recreational water users.

However, it is important to note that correlation does not necessarily imply causation, and further investigation would be needed to establish any causal relationships between the measured parameters. Nonetheless, the consistent correlations over the five years suggest that certain water quality parameters may serve as reliable indicators of the overall quality of recreational water bodies.

CHAPTER 5 : CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The study focused on six water quality parameters which were sampled from five sampling points in the greater Plettenberg Bay area. However, for this study, only the samples obtained from the final effluent were analysed and discussed in this study. This was due to the fact that the final effluent is discharged into The Gans River (figure 4) post-treatment. Plettenberg Bay is a vibrant tourist destination where tourists and residents use the Gans River for various water activities, it is imperative to ensure that the final effluent meets prescribed water quality standards so that it does not pose a health risk or environmental degradation once released into the environment.

Phungela (2022) discusses the impact of discharging poorly treated wastewater into the environment, the author further elaborates that this discharge has an overall negative impact on global water resource systems. The author further states that there is evidence of water resource quality deterioration in natural environments caused by effluent discharges. Therefore, it is important to examine the final effluent as it will have an impact on the overall surface water quality of the Gans River.

Physiochemical and microbiological parameters such as Ammonia, Suspended Solids, Conductivity, Nitrates, pH, and *E. coli* were examined to indicate the water quality of the Gans River. The overall water quality of the Gans River is deemed to be of good quality even though there were a few non-compliances with some of the prescribed standards. Various factors may influence the quality of water, with some factors being natural and/or anthropogenic. In table 2 the amount of ammonia present in the water is not considered to be excessive. Therefore, the ammonia levels can be described as compliant. However, there are a few noticeable surges in ammonia presence, and this can be attributed to the residual ammonia present in water after purification, as the Gans River is a final effluent discharge area. The Department of Water Affairs and Forestry (1996) states that chemical compounds in the case of full-contact recreational water should not be in such concentrations as to be toxic to humans if small quantities of water are ingested or absorbed through the skin. Furthermore, the Oregon Department of Human Services (2000) argues that any solution with a concentration greater than 1000 mg/L can cause severe burns and scarring to sensitive skin.

Table 3 and figure 6 are visual representations of suspended solids as a physiochemical indicator. Over the five-year period, the concentration of suspended solids has been deemed as compliant with standards prescribed by the South African Water Quality Guidelines, Volume 2: Recreational Use. Table 4 and figure 7 represent the conductivity measured over five years. The measurements obtained were found to be compliant with Volume 2 of the South African Water Quality Guidelines. Due to the existing relationship between suspended solids and conductivity.

According to the Department of Water Affairs and Forestry (1996) chemical compounds in the case of full-contact recreational water should not be in such concentrations as to be toxic to humans if small quantities of water are ingested or absorbed through the skin, taking this into account, when observing table 5 and figure 8 one can see that the concentration of Nitrates/Nitrites was completely compliant with the Department of Water Affairs and Forestry guidelines.

Table 6 and figure 9 are visual representations of pH as a physiochemical indicator of water quality, according to the Department of Water Affairs and Forestry (1996) pH has a target water quality range of 6.5-8.5 units. One can see in figure 9 that the fluctuations in pH levels never exceed 8.5 units and never go below 6.5 units. The lowest pH reading is 6.83 units, and the highest level was 7.98 units. Therefore, pH was completely compliant with the Department of Water Affairs and Forestry guidelines.

E. coli is considered to be a microbiological indicator of water quality, table 6 shows all the changes in *E. coli* levels in five years and one can observe and conclude that *E. coli* has been one of the most compliant indicators. However, this is except for levels recorded in the year 2017. This can be observed in the spike in 2017 in figure 9. As stated, before the quality of water can be influenced by natural and/or anthropogenic activities. Even with this apparent fluctuation in recorded levels, one can still deem *E. coli* to be compliant as the Department of Water Affairs and Forestry's prescribed target water quality range for *E. coli* is 0-130 counts per 100 mL for full contact recreational water use.

5.2. Recommendations

The study has provided a better understanding of the composition and water quality of the Gans River, which is where the final effluent is discharged. Based on the assessment of the presented data and information obtained the following recommendations are proposed.

- Seeing that the water is of good quality, the water quality monitoring program has been an effective tool for water quality assessment and should continue. However, more frequent sampling should take place.
- The Gans River area should be monitored closely and access to it should be more restricted. Unsupervised access to the river has created a leeway for people to pollute the river by discarding refuse nearby or into the river.
- The municipality should conduct environmental awareness programs in all the Plettenberg Bay communities and educate people about the importance of water conservation and protection.
- The municipality should conduct an integrated risk assessment and management plan for all the sampling sites to ensure that there may be no room for pollution.

The Bitou Municipality may do better by, obtaining more samples much more frequently, hiring more people to assist with the required workload and the analysis of the samples, and more environmental education and awareness needs to take place so that all residents and tourists are aware of the importance of environmental protection and conservation.

Moreover, the study recommends further research to investigate the occurrence of specific hazardous chemical compounds and biological contaminants such as endocrine disruptors and viruses resulting from anthropogenic activities in Plettenberg Bay in order to generate significantly more data and improve surveillance of viral contamination and physicochemical profile of recreational water.

Furthermore, the study suggests that there is a need to conduct a study to shed light on the possible statistical association between recreational demand and water quality status in different sites at Plettenberg Bay. Understanding how the quality of recreational water influences tourists' choices in Plettenberg Bay would provide evidence to support the improvement of sustainable tourism.

REFERENCES

Afework, B. 2018. *Energy education*. University of Calgary: https://energyeducation.ca/encyclopedia/Photochemical_smog [accessed on 10 December 2022].

Aldous, S. P. 2018. *Freshwater pollution: ecological impact assesment and remediation.* United Kingdom : Foundation for Water Research.

Berrisford, S. 2011. unravelling apartheid spatial planning legislation in South Africa. *Urban Forum* 22(3), 209-228.

Boehm, A.B. and Soller, J.A. 2020. Refined ambient water quality thresholds for human-associated fecal indicator HF183 for recreational waters with and without co-occurring gull fecal contamination. *Microbial Risk Analysis*, 16, p. 100139. Available at: https://doi.org/10.1016/j.mran.2020.100139.

Cotruvo, J. 2019. D*drinking water quality and contaminants guidebook*. Boca Raton: CRC Press.

DataStream. 2021. *Total Suspended Solids (TSS) and Total Dissolved Solids (TDS)*. A Monitor's Guide to Water Quality: https://datastream.org/en/guide/total-suspended-solids-and-total-dissolved-solids [Access on 15 July 2022].

David, E. and Niculescu, V.-C. 2021. Volatile Organic Compounds (vocs) as environmental pollutants: occurrence and mitigation using nanomaterials. *International Journal of Environmental Research and Public Health*, 18(24), p. 13147. Available at: https://doi.org/10.3390/ijerph182413147.

Department of EnvironmentalAffairs. 2019. *Briefing by Department of Environmental Affairs on the status of air quality in South Africa.* Pretoria: Climate Change and Air Quality.

Department of Human Services. 2000. *Health effects information: ammonia.* Portland, Oregon: Office of Environmental Public Health. United States of America.

Department of Water Affairs and Forestry 1996. *South African water quality guidelines (second edition), Volume 2: Recreational Use.* Pretoria: CSIR Environmental Services.

Eden, R. 2014. Enterobacteriaceae, coliforms and *E. coli* - Classical and Modern Methods for Detection and Enumeration. *Encyclopedia of Food Microbiology (Second Edition)*, 667-673.

Fadiran, A. O., Dlamini, S.C, and Mavuso, A. D. 2008. A Comparative study of the phosphate levels in some surface and ground water bodies of Swaziland. *Chemical Society of Ethiopia*, 22(2), 197-206 .

Fewtrell, L. 2004 "Drinking-water nitrate, methemoglobinemia, and global burden of disease: A discussion," *Environmental Health Perspectives*, 112(14), pp. 1371–1374. Available at: https://doi.org/10.1289/ehp.7216.

Fondriest Environmental Incorporated. 2013. *fundamentals of environmental measurements*. https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/

Garden Route District Municipality. 2020. *Effects of the national lockdown on air quality within the Garden Route District*. http://www.gardenroute.gov.za/2020/05/05/the-effects-of-the-national-lockdown-on-air-quality-within-the-garden-route-district/ [accessed on 15 September 2022]

Glavan, M. (ed.) 2018 *Water challenges of an urbanizing world*. IntechOpen. DOI: 10.5772/intechopen.68339.

Gordon. R. Craig and Associates. 2003. An Ecological Risk Assessment of ammonia in the aquatic environment. *Research Gate* , 527-548.

Gupta, R.C. (ed.) (2020) *Handbook of Toxicology of Chemical Warfare Agents*. Elsevier Academic Press.

Hempel, S. and Flemming, B. 2021. Benthic foraminifera of the Agulhas Bank Coastal Shelf in the vicinity of Plettenberg Bay, South Africa: A reconnaissance survey. *Geo-Marine Letters*, 41(2). https://doi.org/10.1007/s00367-021-00691-x.

Hudson-Edwards, K. A. 2003. Sources, mineralogy, chemistry and fate ofheavy metal-bearing particles in mining-affected river systems. *Mineralogical Magazine*, 205-217.

Jan Dirk van Elsas, A. V. 2011. Survival of *Escherichia coli* in the environment: fundamental and public health aspects. *International Society for Microbial Ecology*, 173-183.

Jang, J., Hur, H.G., Sadowsky, M. J., Byappanahalli, M.N., Yan, T. and Ishii, S. 2017. Environmental *Escherichia coli*: Ecology and public health implications-A Review. *Journal of Applied Microbiology*, 123(3), pp. 570–581. Available at: https://doi.org/10.1111/jam.13468.

Jones, S. 2020. *Conductivity in drinking water*. https://www.h2olabcheck.com/blog/view/conductivity#:~:text=Health%2FEnvironmental%20Concerns%3A,and%20therefore%20impact%20consumer%20satisfaction. [Accessed on 15 July 2022]

Kılıç, Z. 2020. The importance of water and conscious use of water. *International Journal of Hydrology*, 4(5), pp. 239–241. Available at: https://doi.org/10.15406/ijh.2020.04.00250.

King, E. 2021. *Plettenberg Bay nominated as Africa's leading beach destination, for 12th consecutive year*, *News24*. Available at: https://www.news24.com/news24/southafrica/news/plettenberg-bay-nominated-as-africas-leading-beach-destination-for-12th-consecutive-year-20210428 [Accessed: January 31, 2023].

Lenntech, 2019. *Water Treatment*. https://www.lenntech.com/processes/disinfection/chemical/disinfectants-sodium-hypochlorite.htm Accesed on 20 September 2022.

Lin, L., Yang, H. and Xu, X. 2022. Effects of water pollution on human health and disease heterogeneity: A Review. *Frontiers in Environmental Science*, 10. Available at: https://doi.org/10.3389/fenvs.2022.880246.

Massoud, M.A.,Fayed, R., Kamleh, R., El-Fadel. 2010. Environment Management System (ISO 14001) certification in developing countries: challenges and implementation strategies. *Environmental Science and Technology*, 1884-1887.

Meride ,Y. and Ayenew, B. 2016. Drinking water quality assessment and its effects on residents health in Wondo genet campus, Ethiopia. *Environmental Systems Research*, 5, (1).

National Geographic . 2019. *Smog*. https://www.nationalgeographic.org/encyclopedia/smog/ [accessed on 30 June 2022]

Opere, W.M., John, M. and Ombori, O. 2020. Occurrence of enteric viruses in surface water and the relationship with changes in season and Physical Water Quality Dynamics. *Advances in Virology*, 2020, pp. 1–11. Available at: https://doi.org/10.1155/2020/9062041.

Oram, B. 2014. *Ammonia in groundwater, runoff, surface water, lakes and streams*. https://water-research.net/index.php/ammonia-in-groundwater-runoff-and-streams [accessed on 10July 2022]

Oram, B. 2014. *Phosphate in surface water streams lakes*. https://water-research.net/index.php/phosphate-in-water [accessed on 10July 2022]

Oram, B. 2014. *Total Dissolved Solids (TDS).* https://water-research.net/index.php/phosphate-in-water. [accessed on 10July 2022]

Phungela, T. M. 2022. The impact of wastewater treatment effluent on Crocodile River quality in Ehlanzeni District, Mpumalanga Province, South Africa. *South African Journal of Science*, 1-8.

Radke, L. 2006. *pH of coastal waterways*. https://ozcoasts.org.au/indicators/biophysical-indicators/ph_coastal_waterways/ [accessed on 10July 2022]

Robert Tisserand, R. Y. (2014). Essential oil safety. *Science Direct*, 99-110.

Rusydi, A. F. 2018. Correlation between conductivity and total dissolved solid in various type of water: A review. *IOP Conf. Series: Earth and Environmental Science*, 2-7.

Schroeder, E. D. 2003. Water resources. *Encyclopedia of Physical Sciences and Technology*. Davis, California, United States of America: University of California.

Sciences, N. I. 2019. *Endocrine disruptors*:https://www.niehs.nih.gov/health/topics/agents/endocrine/index.cfm [accessed on 20 July 2022]

Sholl, J. 2011. *8 Hidden Toxins: What's Lurking in Your Cleaning Products?* https://experiencelife.com/article/8-hidden-toxins-whats-lurking-in-your-cleaning-products/ [accessed on 10July 2022]

Statistics South Africa. 2018. *How important is tourism to the South African economy*. https://www.statssa.gov.za/? [Accessed on 10 December 2022]

United States Environmental Protection Agency. 1997. Volunteer Stream Monitoring: A Methods Manual. Available from: https://www.epa.gov/sites/production/files/2015-06/documents/stream.pdf [Accessed on 16 september 2022]

Wasielesky, W.J., Poersch, L. H., Martins, T., G. and Miranda-Filho, K.C. 2016. Chronic effects of nitrogenous compounds on survival and growth of juvenile pink shrimp. *Brazilian Journal of Biology*, 77(3), pp. 558–565. Available at: https://doi.org/10.1590/1519-6984.18415.

Wolfgang Schultze, R. T. 2011. The concept of environmental performance and its measurement in empirical studies . *Journal of Management Control*, 375-412.

World Health Organization. 2006. *Guidelines for drinking-water quality.* Geneva: World Health Organization.

Yehia, Y. 2019. *The Importance of Tourism on Economies and Businesses.* Available at: https://globaledge.msu.edu/blog/post/55748/the-importance-of-tourism-on-economies-a [Accessed: February 6, 2023].

APPENDICES

Appendix A: Research permission from Bitou Municipality

munisipaliteit umasipala municipality

to be the best together

Private Bag X1002 Plettenberg Bay 6600
Tel+27 (0)44 501 3000 Fax +27(0)44 533 3485

Enquiries: Ettiene deWaal
Reference: 17/2/2/6
Date: 30 August 2021

Attention: Ms. Zovuyo Kolwapi

APPROVAL TO USE BITOU MUNICIPALITY'S WATER QUALITY DATA FOR ACADEMIC PURPOSES

Bitou Municipality hereby acknowledges receipt of your correspondence 17 July 2021, in which you requested permission to use the Water Quality Data of Bitou Municipality for academic purposes only.

Bitou Municipality grants you permission to utilise the data as requested under the following provisions:

1. That the data will be used for academic purposes only and nothing else
2. That Bitou Municipality will also gain access to the results of the study once completed at no cost to the Bitou Municipality

Bitou Municipality wishes you all the best with your studies and we look forward to seeing how your research can add value to the operations of the Purification Works.

Yours Sincerely

25/2/22

Acting Municipal Manager: Mr N van Stade

Appendix B: Ethics approval

Statement of Permission

A data permit is required for this study.

Reference no.	216277744/06/2022
Surname & name	Kolwapi, Z
Student Number	216277744
Degree	Master of Environmental Management
Title	A time-series analysis of freshwater quality in the Greater Plettenberg Bay municipality, Eastern Cape province.
Supervisor(s)	Prof Karabo Shale
FRC Signature	
Date	June 20, 2022

P.O. Box 1906 · Bellville 7535 South Africa ·Tel: +27 21 953 8677 (Bellville), +27 21 460 4213 (Cape Town)

Ethics Exemption Letter **Reference no: 216277744/06/2022**

Office of the Chairperson **Research Ethics Committee**	**Faculty of Applied Sciences**

On June 13, 2022, the Faculty Research Ethics Committee of the Faculty of Applied Sciences determined that the research activities related to a project to be undertaken by Kolwapi, Z. for a degree (Master of Food Science and Technology) at the Cape Peninsula University of Technology do not require ethics clearance. The ethics exemption for the project is approved.

Title of project:	A time-series analysis of freshwater quality in the Greater Plettenberg Bay municipality, Eastern Cape province.

Comments (Add any further comments deemed necessary, e.g. permission required)

1. Animal/human subjects are not involved in the proposed study.
2. This permission is granted for the duration of the study.
3. Research activities are restricted to those detailed in the research proposal.
4. The research team must comply with conditions outlined in AppSci/ASFREC/2015/1.1 v1, CODE OF ETHICS, ETHICAL VALUES AND GUIDELINES FOR RESEARCHERS.

Signed: Chairperson: Faculty Research Ethics Committee	23/06/2022
 Prof F Nchu	**Date**