Investigating the impact of effluent from wastewater treatment works on river water quality, Baths River, Caledon, Western Cape, South Africa

by

Zama Nosipho

Student Number: 2743776

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Declaration

I, Zama Nosipho, declare that this thesis is my own. It is being submitted for the degree of Master of Philosophy in integrated water resources management, at the University of Western Cape, Faculty of Science. This work has not been submitted before for any degree or examination in any other institution.

Zama Nosipho

Student number: 2743776

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Abbreviations and Acronyms

ºC	degrees Celsius
km	kilometre(s)
km^2	square kilometre(s)
m	metre(s)
m^3	Cubic metre(s)
mg/l	milligrams per litre
ml	millilitre(s)
mm	millimetre(s)
µg/l	micro grams per litre
mS/m	milli Siemens per meter
AEV	Acute effect value
ANOVA	Analysis Of Variance
BGCMA	Breede-Gouritz Catchment Management Agency
BOD	Biological Oxygen Demand
COD	Chemical oxygen Demand
DEA	Department of Environmental Affairs
DEADP	Department of Environmental Affairs and Development Planning
DO	Dissolved Oxygen
DWAF	Department of Water Affairs and Forestry
DWA	Department of Water Affairs
DWS	Department of Water and Sanitary
EC	Electrical Conductivity
E. coli	*Escherichia coli*
NWRS	National Water Resource Strategy
RHP	River Health Program
TDS	Total Dissolved Solids

TSS	Total Suspended Solids
USEPA	US Environmental Protection Agency
WCW	Water Care Works
WEF	Water Environment Federation
WISA	Water Institute of Southern Africa
WHO	World Health Organisation
WRC	Water Research Commission
WWTW	Waste Water Treatment Works

Glossary:

Anthropogenic: (Environmental pollution and pollutants) originating in human activity..

Biomonitoring: Process of detecting and assessing the state and continuing changes in ecosystems, components of biodiversity and landscape, including the types of natural habitats, populations and species

Bacterial Indicator: Types of bacteria used to detect and estimate the level of faecal contamination of water.

Riparian: Relating to or situated on the banks of a river.

Salmonella spp.: A group of bacteria that reside in the intestinal tract of humans and warm-blooded animals and are likely to cause disease.

Shigella spp.: Gram negative, non-sporulating, rod-shaped bacteria belonging to the family Enterobacteriaceae. Bacteria are optional intracellular pathogens that have high specificity for human hosts or primates.

Vibrio cholerae spp.: A genus of ubiquitous bacteria found in a wide variety of aquatic and marine habitats that cause infections in humans.

Waterbody: Significant accumulation of water.

Abstract

South Africa is facing a problem of many municipal waste water treatment works (WWTW) not working efficiently. The environmental impacts of poorly treated effluents on receiving water bodies have required special attention from researchers. In this study, the relationships between water quality variables in the Baths River in the Western Cape province of South Africa were evaluated upstream, at the source and downstream of the Caledon wastewater treatment works between March 2013 to March 2016. The assumption has been tested that water quality is deteriorating downstream of the Caledon Waste Water Treatment Works (WWTW) discharge point in the Baths River and are affected by this change in water quality. Water quality measurements (Physicochemical and Bacteriological microbial parameters) was conducted upstream, at the source and downstream of the Caledon Wastewater Treatment Works. A clear and significant deterioration in key water quality variables was observed upstream, at the source and downstream of the wastewater discharge point with pH, conductivity, total suspended solids and E. coli being elevated downstream and at the source, whilst dissolved oxygen was reduced downstream. ANOVA analyses revealed significant differences ($P<0.05$) in physic-chemical parameters between the upstream, the source and downstream sites of the Baths River. The Baths River was found to be moderately polluted and displayed an increasing pollution gradient from upstream to downstream of the wastewater discharge points. It has been noted that two spill raw sewage incidents have occurred since 2013 in the Caledon area upstream the Baths River. It appeared that this problem of untreated wastewater discharge was exacerbated during the period of heavy rains from 2013 up to 2016. It could explain the high levels of EC, Total Foecal Coliform and E.Coli upstream and downstream the Bath River. Mitigation measures that included constant monitoring, strengthening of compliance with the water legislations and the upgrade of the Caledon WWTW were suggested in order to minimize the impact instigated by treated waste water from the Caledon WWTW into the Baths River and other unknown point source and non-point source of pollution in the Baths River.

Keywords: ANOVA, Baths River; Caledon Waste Water Treatment Works; Non-point source; Point-source.

Chapter 1 Introduction

1.1 Background

Water crisis remained a risk of highest concern in South Africa (DWS, 2018). The country is classified as a mostly semi-arid country. Rural and urban communities needed access to fresh water yet, the considerable development of these populations requires the protection of water by Government by setting the balance between wastewater disposal and freshwater resources (Dos Santos et al., 2017). The protection of water resources has therefore become important to adequately treat the available water before use, as fresh water is being used to supply diverse ecological services like enabling fine reproduction of sea species and the bring in drinking water (Jackson et al., 2016). Water has a great impact on the environment and socio economic development as a result; water should be monitored, protected and treated to ensure its quality and quantity on any scale for the use of the populations (Wilcox et al., 2016). Inadequately treated wastewater effluents detained great amount of organic matter and nutrients which had negative impact on the receiving environment (Naidoo and Olairan, 2014). This problem could deteriorate the receiving environment through the excessive amount or poor quality of wastewater effluents. Several water sources are exposed to regular extreme fluctuations in microbial and chemical qualities as a result of the variety of the activities on the water body. That is why regulatory measures are required to implement efficiency in the treatment of wastewater effluents and its discharge, by doing so to protect the surrounding environment.

1.2 Statement of Research Problem

The BGCMA received complaints about raw sewage discharged into the Baths River from the neighbouring farmer who uses water from the Baths River for irrigation purposes. The complaints came since 2013, the BGCMA had a meeting with the Municipal officials to ascertain as where the source of the problem. During the meeting it became evident that there are recurrent spillages from the sewage pipeline which is situated upstream of the Waste Water Treatment Works (WWTW). During heavy rainy periods, the pipeline became blocked and there was raw sewage into the river. The pipeline was old, more than 25 years (BGCMA, 2017). After several complaints the BGCMA initiated a monitoring programme on behalf of the municipality. The programme started in 2013 October, monitoring upstream downstream and at source (discharge point) of the Caledon WWTW. The municipality was then advised to fix the pipeline to prevent further pollution. The WWTW works was also not complying as it could not accommodate the current inflow due to capacity not being able to cope with the incoming inflow as well as due to the population increase. The Municipality was advised to upgrade the WWTW and the pipeline. An application for the authorization to upgrade the pipeline as well as well to upgrade the WWTW as per BGCMA recommendation.

Baths River forms part the major rivers in the Breede-Gouritz Water Management Area that is prone to degradation due to the fact that it receives effluent from the Caledon municipal wastewater treatment works. The treatment process at Caledon municipal wastewater treatment works has been heavily influenced by the nature of the effluent, which is largely of industrial and domestic sewage origins. In particular, Electrical Conductivity (EC), Ammonia, Chemical oxygen Demand (COD), Total Suspended Solids (TSS), E.Coli. and Faecal Coliform have proved challenging. Limitations of the activated sludge process have been seen as the underlying origin of these problems. The municipal treatment works discharge large volumes of effluent into the river system which turn to change the quality of water in the river system. According to Singh and Kaushal, 2013, wastewater effluent constitutes the major source of the natural water pollution load.

1.3 Aim and objective of the study

1.3.1 Main Objective

To investigate the impact of final effluent from Caledon municipal wastewater treatment works on the Baths River water quality.

1.3.2 Specific objectives

This overall objective had the following objectives:

- To assess the performance of the Caledon WWTW over a period of four years by assessing the selected physical and chemical constituents of its influent and effluent over this period.

- To ascertain the physico-chemical and microbiological properties of the Baths River water upstream and downstream the Caledon WWTW in comparison to the DWA water quality standards for wastewater effluent discharge and

- To suggest mitigation measures to minimize the impact instigated by unprocessed waste water effluents from the Caledon WWTW into the Baths River.

1.4 Study significance

Various researches have been done on the quality of water resources of major rivers in the Gouritz Water Management Area (RHP, 2007; DEADP, 2011; DWA, 2012) but little is known about the degradation in the water quality resources of the Baths River in correlation with the treated effluent of Caledon wastewater treatment works. This research focused on the Caledon wastewater treatment works which discharges its effluents into the Baths River system. The quantity of fresh water in the province been critical and is currently threatened by microbial and chemical pollution as a result of untreated or partially treated wastewater effluents from municipal wastewater treatment works. The Baths River system has been selected for this study as wastewater effluents discharge from the Caledon WWTW are likely to pollute its surface and ground water . For the purpose of this research, water quality samples for physical parameters and microbial parameters have been chosen. This involves using the existing data collected from the period of 2013 to 2017 by the researcher.

1.5 Study conceptualisation: Scope and nature of the study

The current study was informed by the current joint research project among the CPUT, UWC and BGCAM and DWS. The project was arranged between the DWS and BGCMA project on water resource monitoring with includes water quality monitoring or assessment. Discharges from the wastewater treatment plants are considered one of the main sources of nutrients and organic pollutants (Englert et al., 2013) which influence the ecosystem health. Currently South Africa is experiencing Sewage discharge problems. The inappropriate treatment of sewage entering the aquatic ecosystems caused decline in the water quality of the receiving water body (Seanego and Moyo, 2013). In South Africa about 56% of the total 1 150 municipal waste water treatment works (WWTWs) and about 44% of the 962 water treatment works (WTWs) are in a poor or critical condition required pressing rehabilitation. About 11% of these WWTWs were totally dysfunctional (DWS, 2018). This indicates that these wastewater treatment plants are not adequately treating their effluents. The inefficiently treated effluents were discharged into the local water systems, which affects the downstream ecosystem and rural communities and also degrading the environment (Mothetha, 2016). The water quality in South Africa’s river systems was rapidly deteriorating as a result of increased discharge of wastewater effluents. The normal capability of rivers and reservoirs to trap toxic chemicals and nutrients in their sediments allowed these systems to collect pollutants, shifting the natural stability in environmental water quality, thus rising public and environmental health concerns (Olivier et al., 2015).

The Caledon WWTW deals with the treatment of waste water from the surrounding environment, nevertheless the current is focusing on risk assessment (impact of effluence on rivers), key sectors that need to coordinate implementation of preventive measures (monitoring) and the action plan that is required to enforce such monitoring. The current study will used the quantitative method approach whereby the existing water data will be analysed for compliance with the DWAF water quality discharge guideline The sampled physical water quality concentrations in accordance to water quality guidelines (TWQR for various uses) as stipulated by DWAF has been influenced due to poor sewage treatment. However, the nature, and subsequent impact of the imbalance, may be accentuated or reduced as a result of changes in river flow at the sampling points. River flow may differ as a result of a number of factors such as climatic changes with respect to rainfall, temperature and evaporation rates, gradient, riverbed roughness, width and river impoundment, among others (SRK, 2010). Subsequently the objective of sewage treatment is to produce a disposable effluent without causing harm to the surrounding environment, and also prevent pollution.

1.6 Research Questions

The research question drawn from the main objective of the study is as follows:

- Has the water quality of the Baths River declined with time in line with the discharge effluent from the Caledon WWTW?
- Does the water quality decline or recover with distance along the river system from the discharge point?

1.7 Hypothesis

It was hypothesised that there would be water quality deterioration, at the source and downstream of wastewater discharge points in the Baths River than upstream due to a discharge effluent from the malfunctioning Caledon WWTW and accumulation effect of the discharge downstream.

1.8 Description of the Research Area

The Baths River is located in the Overberg area which falls under the jurisdiction of the Breede Gouritz Catchment Management Agency in the Western Province. The river flows towards south until it joins the Oliphant River. The effluents from the Caledon WWTW are also discharged into this river which potentially contributes to an increase in contaminant loading in the river system. The effluents from the Caledon WWTW contribute to the continuous flow of the river making it perennial.

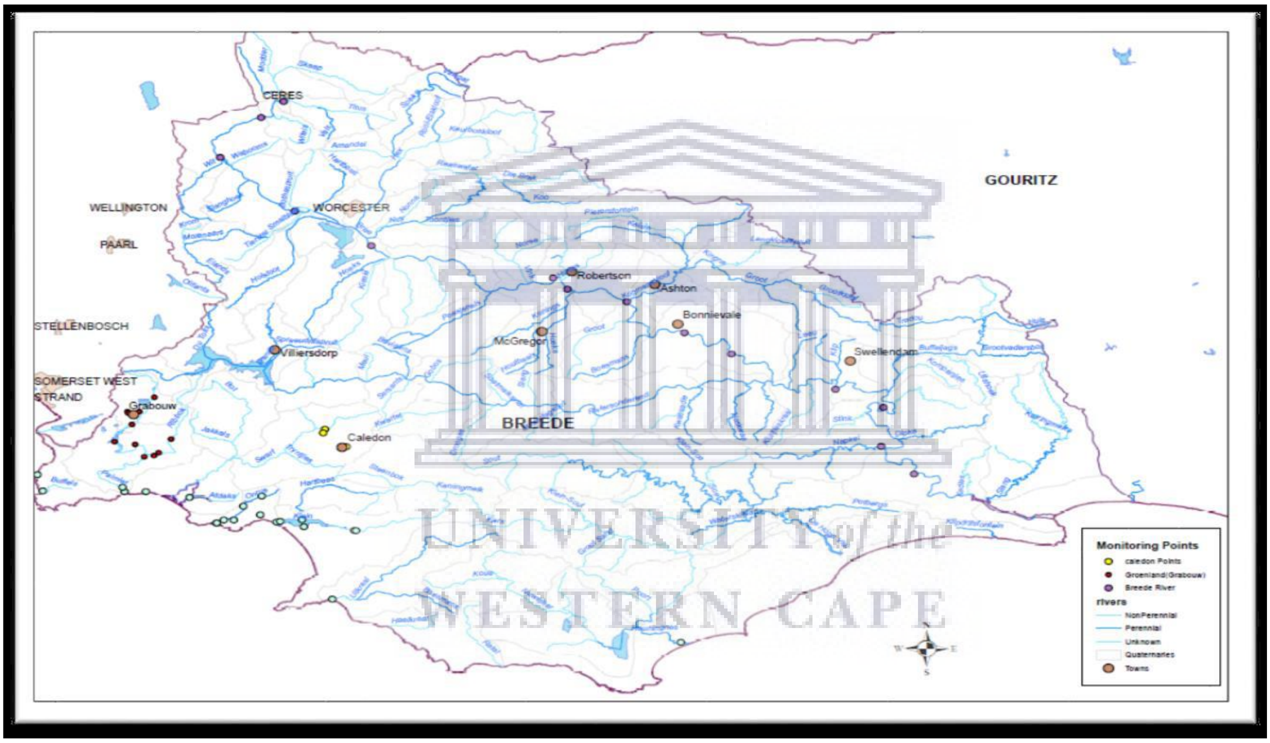

Figure 1: Breede-Gouritz Catchment Management Agency Period: March 2013 to March 2016 Surface Water Quality Monitoring Report.

1.8.1 Physiographic features of the study area

1.8.1.1 Hydrology

The Baths River system is a perennial river with an average flow rate of 111 × 106 m3 per annum (SRK, 2011). The flow rate increased to 200 × 106 m3 per annum due to the effluents discharged from the Caledon WWTW to the system (SRK, 2010). A growth in the flow of water is good as it ensures that the river converts into perennial resulting in the increase in the dilution capacity of the water quality constituents of river. Conversely, an increase of flow due to the wastewater effluents subject to the treatment efficacy could depreciate the water quality likewise. The River is surrounded by the Breede, Nuy, Kogmanskloof, Hoeks, Doring, Keisers rivers and tributaries (DWAF, 2005). Groundwater levels to west of the WWTW ranged between 29 to 39 mbgl, while shallower groundwater levels arose close to drainage courses (2,8 to 7,8 mbgl). The Baths River drains from SN and borders the eastern boundary of the WWTW. It was expected that groundwater levels will be shallow (~1 to 15 mbgl) at the WWTW.

1.8.1.2 Topography

The Catchment size was 4 512km2 .The study area was characterized by moderate, high hills and mountain landscape. The geology was characterized by quarzitic table Mountain sandstone, Bokkeveld and Malmesbury shales (RHP, 2011). The altitude of the study area could range up to 700 m above the seal level. The vegetation from South to South West Coast was mainly made of Mountain Fynbos, Central Mountain Renosterveld, Little Succulent Karoo (DWAF, 20004a).

1.8.3 Climatic conditions

The study area had a typical climate with Cold to warm conditions between October and March, and cold nights during winter. The average daily temperatures range from 10 °C to 20 °C (DWAF, 2004b).The rainfall pattern range from winter to all the year. The mean Annual Runoff (mm) was 247mm3 in the area. The mean Annual Precipitation 413mm .The Mean Annual Evaporation was about 1547 mm (RHP, 2011). The Bath River catchment was subjugated mostly by the dry season with high evaporation rate which may well lead to more concentration of salts in the river system. High flow of water also might transport more suspended substances and nutrients into the river making it more turbid.

1.8.4 Socio-economic features of the study area

The Baths River is a non-perennial river located in the in the Breede-Gouritz water management Area in Western Cape Province of South Africa. Small as it, the Baths River finds itself under pressure because of activities taking place around its small catchment including discharges from the Caledon wastewater treatment works (Figure 1). Increasing population rose pressure on the wastewater treatment works, forcing them to treat more than what they are designed for (Manungufala et al., 2011). Most of the inhabitants lived within the Overberg West and Upper to Central Breede areas (RHP, 2011). Population predictions indicated a resident's growth in the coastal areas, but a decline in inland areas. The total population was therefore expected to remain relatively constant. The economy of the region is largely agriculture-based, with tourism at resort towns along the coast. Broad vineyards and fruit orchards were developed under irrigation, fed by water from mountain streams and the Breede River as well as groundwater (RHP, 2011). Dryland wheat was cultivated between the Riversonderend and the coastal mountains, while livestock farming was practised throughout the region. Less than 1% of the national Gross Domestic Product comes from the Breede Area; however a big volume of the water accessible in the area is used within the Berg Water Management Area for economic expansion (RHP, 2011).

1.8.5 Description of the study sites

The research study covered three sites mainly at the Caledon named the source (discharge point) where treated water is discharge directly into the river. The upstream point situated upstream of the Caledon WWTW where agricultural activities and Livestock breeding are occurring. There some habitation that may results in domestic wastewater and sewage water as well. The downstream point is mainly an area of vegetation and pasturage .The River joins Swart River which flow directly into the Bot River.

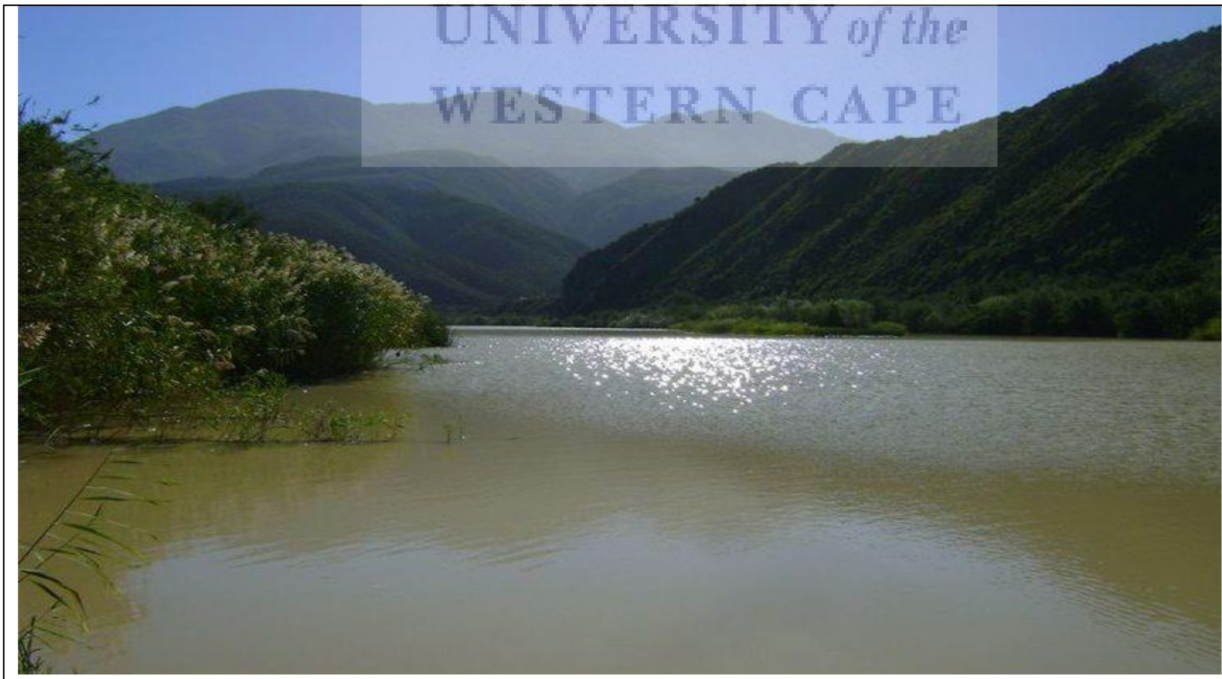

Figure 2: The Baths River.

The Caledon WWTW is located in the in the Breede-Gouritz water management Area in Western Cape Province of South Africa. The effluents from the Caledon WWTW are discharged into this river which potentially contributes to an increase in contaminant loading in the Baths River system.

Figure 3: Location of the Caledon WWTW.

1.9 Outline of the thesis report

Chapter 1: This chapter reviews the background information to the research, problem statement, study aim and study objectives, study significance, study conceptualisation, research questions and finally it outlines the study area. Chapter 2: It reviews the research involving the impacts municipal wastewater discharges on its neighbouring waterbody. Regulations concerning the wastewater discharge and wastewater treatment processes are also conferred in this chapter. Chapter 3: It Deals with research designs and methodology. It describes the quality control and assurance, research integrity, the method and materials used and their limitations are discussed in depth in this chapter. Chapter 4: This chapter emphases essentially on the study results and discussions and comparing them with previous within the same field of study. Chapter 5: This chapter condenses and concludes the research findings drawn from the study. Based on the conclusions from the study, recommendations for future research are made in this chapter.

Chapter 2 Literature Review

2.1 Introduction

This chapter presents the current states of water resources in South Africa. It also outlines the structure of Municipal Waste water, its treatment processes, the waste water regulation and opinions of other researchers through cases studies on related studies in South Africa.

2.2 The Current State of Water Resources in South Africa

South Africa is a strained water country in which the demand for water demand is higher or close to the available water supply (Motheta, 2016). South Africa is considered a semi-arid and water strained country. According to Botai et al. (2016) the average annual rainfall in the country is about 450 mm a year. This is below the world average annual rainfall of 860 mm. The rainfall in South Africa exhibits seasonal variation. It recorded rainfall patterns that mainly happening primarily during the summer months of November throughout to March (Botai et al., 2016). In the western region of the country, rainfall occurs in the winter months of May throughout August (Du Plessis and Schloms, 2017).Rainfall in South Africa varies throughout the country. The annual precipitation in the western regions is 200 mm. The eastern regions had rainfall ranging from 500 mm to 900 mm per year (Botai et al., 2016). The annual evaporation rate in South Africa was greater than 2000 mm (Schulze and Lynch, 2006). The country has few active rivers, and the total flow of all rivers in the country was approximately 49,000 cubic meters per year (NWRS, 2004).In the Western Cape, the mean annual maximum rainfall was 1,416.75 mm/year and the minimum was 175.026 mm/year. These predominant patterns of variable and unequally spread rainfall in the Province, combined with high evaporation rates led to extremely low transformation of rainfall to runoff (Pienaar et al., 2017).Rainfall in South Africa is periodic and river flow is frequently low or absent in winter season. In South Africa, DEA (2014) stated that water resources are stressed by increasing pollutant loads, including industrial effluents, domestic and commercial sewage, acid mine drainage, agricultural runoff and litter. Poorly operated and maintained municipal waste water treatment works are also a challenge in South Africa (DWS, 2018).

2.3. Municipal Effluents composition

As a semi-arid country, a vital alarm in South Africa is future water demand (DEA, 2014). Several studies have pointed out those industrial and domestic sewage effluents as major source of waste water (Rizzardini and Goi, 2014). Other activities include agriculture and timber industry. Wastewater comprises liquid waste discharged from domestic residences, commercial and industrial or agricultural areas, and can enclose variety of probable contaminants depending on the discharged amounts of substances (Naidoo and Olaniran, 2014).

Municipal effluent brought about external pollutants into the waterways commonly through discharge of fluid effluents comprising a mixture of treated “black water” from sewage and “grey water” from all extra domestic and industrial wastewater (Motheta, 2016). Black water refers to wastewater from the toilets, which contains human waste and can be a public health risk if not treated well (Henze, 2008). Grey water refers to the wastewater from the kitchens and bathroom sinks, baths, showers, industries and laundry which are of a lesser health risk because it does not contain human waste (Henze, 2008). According to Friedler et al. (2013), 40% – 60% of main pollutant discharged in the form of biological oxygen demand (BOD) and chemical oxygen demand (COD) originate from, kitchen sink, dishwasher wastewater with food residues, oils, fats, detergents, ditch cleaners and bleaching agents.

Municipal effluents consist of a combination of domestic wastewater, wastewater from commercial and industrial plants and urban run-off (DEA, 2014). The composition of a typical municipal wastewater contains grit, debris, suspended solids, nutrients (Nitrates and Phosphates) and organic chemicals as well as metals and varies significantly from one place to another (Henze, 2008). Urine is the main contributor to nutrients in household wastes (Table 1) (Henze, 2008). This can be ascribing to disparities in the discharged amounts of substances. High levels of contaminants in river water systems causes an increase in biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), toxic metals and faecal coliform make such water unsuitable for drinking, irrigation and aquatic life (Trivedi et al. 2008).

Table 1: Sources for household wastewater components and their values for 'non-ecological' lifestyle (Henze, 2008).

Parameter	Unit	Toilet		Kitchen	Bath/ laundry	Total
		Total[1]	Urine			
Wastewater	m^3/yr	19	11	18	18	55
COD	kg/yr	27.5	5.5	16	3.7	47.2
BOD	kg/yr	9.1	1.8	11	1.8	21.9
N	kg/yr	4.4	4.0	0.3	0.4	5.1
P	kg/yr	0.7	0.5	0.07	0.1	0.87
K	kg/yr	1.3	0.9	0.15	0.15	1.6

2.4 The Municipal Wastewater Treatment Processes

Wastewater treatment plants are the boundary between human waste and both the aquatic and soil environments (Stalder et al., 2012). In South Africa, 56% of waste water treatment works and 44% of water treatments work were in a poor or critical condition and 11% were dysfunctional (DWS, 2018).The core objective used internationally with regard to the level of treatment of municipal effluent prior to discharge is to reduce waste loads, mainly those of suspended solids and biochemical oxygen demand (DEA, 2014). Treatment levels of municipal effluent (sewage) can generally be categorised into: Preliminary treatment, Primary treatment, Secondary treatment and Tertiary treatment that include disinfection.

2.4.1. Preliminary treatment

Preliminary treatment deals with the removal of wastewater constituents that may cause maintenance or operational problems with the treatment operations, processes, and adjuvant systems (Tchobanoglous et al., 2004).The head of works is the point of entry of the wastewater into the treatment works site where treatment begins with the waste going through a screening process to remove items that cannot get through the treatment process (Rogers and Leal, 2010). Preliminary treatment of wastewater removes about

35% of BOD, 30% of COD, 60% of suspended solids (TSS) and only 10% - 20% of the total nitrogen and total phosphorus (Radojevic and Baškin, 1999). The preliminary treatment stage completes after the heavier solids such as grit and sand is allowed to settle out in channels for removal to a landfill site (WISA, 2002).

2.4.2 Primary Treatment

Primary treatment is principally a physical abstraction process. Primary treatment consists of a combination of biological process that stimulates biodegradation by microorganisms. This includes aerobic stabilization ponds, trickling filters and activated sludge processes, as well as anaerobic reactors and lagoons. At this stage grit, suspended solids and scum are removed in two stages which are pre – aeration and sedimentation. The core role of primary sedimentation is to allow separation of the solid and liquid phase fractions in the wastewater thereby reducing the suspended solids content of the influent wastewater (Boyd and Mbelu, 2009). The water is left to settle so that the solids can sink to the bottom and, oil and grease can rise to the top (DEA, 2014). The suspended solids are tattered off the bottom and the scum of oil and grease is washed off with water jets. The scum and the solids are then collected and combined to form sludge and sent off for secondary treatment (Grady et al., 2011).

2.4.3 Secondary treatment

Secondary treatment provides for the oxygenation of the liquid fraction flowing from the primary settling tanks (WISA, 2002). In the secondary treatment the conventional and most popular process is activated sludge (WATER 21, 2013). The liquid and solid wastes treat from the primary treatment stage are separated through settling and sludge is disposed of or treated (DEA, 2014). Secondary treatment decreases the concentrations of dissolved and colloidal organic substances and suspended matter in the wastewater (WEF, 2008). In the secondary treatment, 90% organic nitrogen, organic phosphorus and heavy metals associated with solids are removed from the wastewater as they settle at the tank forming the sludge (Naidoo and Olaniran, 2014). Secondary treatment includes the processes of aeration in an activated sludge system or treatment in biological filtration and secondary settling.

2.4.4 Tertiary treatment

Tertiary treatment generally consists of some form of chemical treatment. Tertiary treatment is the further removal of suspended solids or nutrients and/or disinfection before discharge to the receiving watercourse (Tempelton and Butler, 2011). Usually tertiary treatment at a sewage works involves a series of ponds, wetlands or reed beds that are installed to offer a degree of polishing of the treated effluent discharged from the mechanical treatment process (DWA, 2013). The principal aspect of tertiary treatment is disinfection. Preferably, water designed for human consumption should be free from microorganisms, though, in practice this is an unreachable goal (Gray, 2005). Biological effluents from domestic wastewater treatment are required to be disinfected before reclaim since they still hold microorganisms of intestinal origin, such as helminthic ova and faecal coliform bacteria such as *Escherichia coli* (Liberti et al. 2000). Dysfunctional Waste Water Treatment Plant result in sewage effluent, been discharge in nearby water bodies.

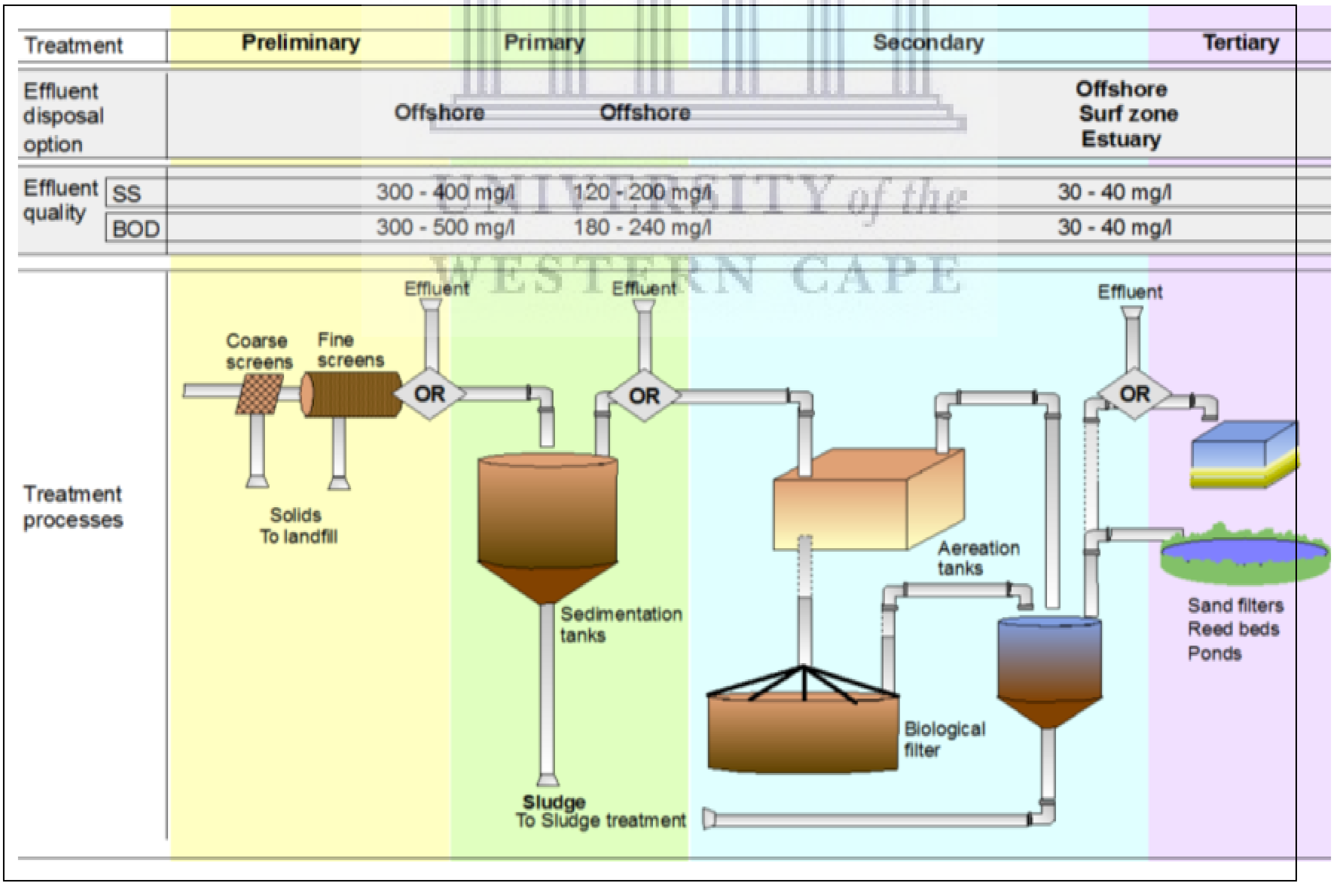

Figure 4: Typical Municipal Waste Water Treatment Plant Processes (DEA, 2014).

2.5 Regulation of wastewater treatment plants In South Africa

The national Water Act (No. 36 of 1998) (NWA) allows the discharge of effluents in the water resource in an environmental way. Many communities still rely on raw water from surface water resources for their daily supply (DWA, 2013). Therefore, it is very important that water users comply with the required discharge standards of the Department and avoid polluting water resources. The South African Constitution in Section 24 (b) (ii) of the Act guarantees everyone the right to the protection of the environment, for the benefit of present and future generations, through reasonable legislative and other measures to ensure ecologically sustainable development and use of natural resources. While promoting justifiable economic and social development. (DWA, 2013).

Multi-level cooperative governance is required by the water quality management of WWTW. National Water Act: The NWA provides the framework for the utilization, development and protection of the country's water resources. It legislate wastewater discharge into the water resource. Water Services Act 108 of 1997, provided the framework that should guide the provision of water services. The local Government: Municipal Systems Act 32 of 2000 ensured universal access to essential services that are affordable to all (Mamabolo, 2012). Additional mechanisms include performance management systems to assess municipalities' performance.

Wastewater treatment plants in South Africa are controlled by the Constitution of the Republic of South Africa of 1996.The regulation specifically involves, the National Environmental Management Act 107 of 1998, the National Water Act 36 of 1998, the Water Services Act 108 of 1997, Provincial legislation, Municipal guidelines and other Government policies relevant to Local Government (Gopo, 2013).

The Constitution through it inter alia at Chapter 7 states that Local Government has the responsibility to deliver a safe and healthy environment to its community in an ecological manner. The Constitution also inflicts at Schedule 4B the role of providing water, sanitation and wastewater treatment facilities on Municipalities to communities in need (Gopo, 2013).

The responsibility rests with the district municipalities but can be assumed by a local municipality if the district municipality does not have the capacity to do so. Although the local government has the right to govern the affairs of its communities on its own initiative. It needs support and oversight from other national and provincial governments to ensure the sustainable delivery of wastewater services (Gopo, 2013).

2.6 Effects of Physico-chemical and biological pollutants from Municipal wastewater effluents

Detailed monitoring and assessment of water resources are required for sustainable water resource management (Hodgson and Manus, 2006). Water pollution resulting from physical and chemical compounds from wastewater has become an alarming concern in the developing countries (Lokhande et al., 2011).

2.6.1. Physico-chemical Parameters

Physico-chemical Parameters are crucial for water quality assessment and monitoring. The components consist of and not in totality; electrical conductivity, chemical oxygen demand; suspended solids, dissolved oxygen; pH and Nutrients (phosphates, ammonia; nitrites and nitrates). Sewage effluent that has not been processed correctly affects the water quality of the receiving water bodies leading to high conductivity, suspended solid, salts, nitrogen, phosphorus and low dissolved oxygen levels in rivers .

2.6.1.1. Electrical conductivity (EC)

Conductivity is a general indicator of water quality change and it is a measure of the total amount of dissolved material in a water sample (Dallas and Day, 2004).

Electrical conductivity measure of the capacity of the water to conduct an electric current (WRC, 2006). Conductivity rises in direct proportion to dissolved ion concentrations (Boyd, 2015). Therefore conductivity increase with increase in the inorganic dissolved solids concentration of water and vice versa. The general requirements for purification of wastewater, regulation 991, postulate Conductivity not exceeding 75mS/m (DWAF, 1984).

2.6.1.2 Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) is the amount of reducing substances that must be oxidized in water by a chemical method (Zhanga et al. 2017). COD is one of the significant indicators for measuring any wastewater discharge situation. COD is determined by a test that measures the amount of oxygen consumed during the chemical oxidation of the organic contaminant in water, resulting in inorganic end products (Naidoo, 2013). The test is based on the chemical decomposition of dissolved or suspended solids in water and indicates the amount of dissolved oxygen used. As a result, the amount of COD is proportional to the amount of contaminants in the water sample. The higher the COD, the higher the presence of contaminants in the sample and vice versa. According to the general requirements for sewage treatment in Regulation 991, the COD must not exceed 75 mg / l (DWAF, 1984).

2.6.1.3 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) refers to all suspended particles in water that will not pass through a mesh. Suspended solids are present in wastewater and various types of industrial wastewater. TSS in high impacts the aquatic environment by rendering the surface water turbid and increasing the temperature of the water waterbody it subsequently begins to lose its ability to support the diversity of aquatic life (Wilson, 2010).

2.6.1.4 pH

It measures the amount of the acid balance of a solution and it is controlled by the dissolved chemical compounds and biochemical processes in the solution. pH is a vital variable in water quality assessment because it effects many biological and chemical processes within a water body and all processes associated with water supply and treatment (Mohale, 2011). Most fresh waters in South Africa are relatively well buffered and more or less neutral, with pH ranges between 6 and 8 (Day and King, 1995). The TWQGR for pH as respects Aquatic Ecosystems is 0.5 of a pH unit variation. The fluctuation of pH of water affects the solubility of chemicals which could also distress the availability of toxic and nutritive chemicals to the aquatic organisms.

2.6.1.5 Nutrients (ammonium)

A nutrient is a chemical compound that is essential to plant cells for growth (Wamsley, 2000). Any water body with higher concentrations nutrients will undergo a risk of experiencing eutrophication problems (Owuor et al., 2007). Nitrogen occurs in the surface waters in several forms like ammonium, nitrite, nitrate, and urea and nitrogen gas. When taken in the oxidised form, nitrogen must be reduced before it can be incorporated into organic molecules (Bachelor et al. 1992). Odjadjare and Okoh (2010) echoed that the final wastewater effluents are the suppliers of nitrate in the receiving surroundings. Ammonia results from sewage discharges; industries using ammonia or ammonium salts; industrial discharges and commercial fertilizers (Naidoo, 2013). In surface or ground water ammonium generally results from the decomposition of nitrogenous organic matter, and is one of the elements of the nitrogen cycle (Dallas and Day, 2004).

2.6.2 Biological Contamination

Faecal pollution is one of the water quality challenges South Africa is facing (DWS, 2014). The current microbial monitoring programme undertaken by the Department of Water and Sanitation in 2014 focuses only on hotspots and therefore does not reflect the current status in the whole country. The source of the problem is mainly from the discharge of untreated or poor quality effluent from waste water treatment works into the river system and runoffs from overflowing manholes (DWS, 2014). The wastewater from the municipal system has substantial amount of pollutants in the form of pathogenic organisms, which leads to decline of water quality of the waterbodies they settled into (Englert et al., 2013).Biological Parameters in microbial forms of are crucial in identifying the presence of microorganisms associated with the transmission of water-borne diseases and the presence of faecal pollution (Ashbolt, 2015). Water for human consumption must be free of microorganisms, although in practice it is an unattainable goal (Gray, 2005). It is not practical to regularly monitor all types of microorganisms in wastewater; therefore, the indicator organisms are measured as substitutes (Tempelton and Butler, 2011). In addition, the tests required to detect specific pathogens are still considered long and expensive (Ritter, 2010). The most common indicator organisms are faecal coliforms (Tempelton and Butler, 2011). Faecal indicator bacteria are used as

suitable indicators of faecal pollution of the aquatic environment, commonly linked to an increased threat of gastrointestinal and respiratory illness (Haile et al. 1999).
Escherichia coli (E.coli) is used as a bacterial indicator of faecal pollution. E.coli may comprise up to 97% of coliform bacteria in human faeces. The presence of E.coli is an indicator of the potential occurrence of other microbial pathogens including viruses and parasites, as well as bacterial pathogens such as salmonella spp., shigella spp., Vibrio cholerae spp., campylobacter jejuni, Campylobacter coli and Yersinia enterocolitica (DWAF, 1996). These bacteria cause gastrointestinal diseases like gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever (DWAF, 1996).

2.5 Relevant Selected Case Studies through South Africa

In 2009, Igbinosa and Okoh assessed the treated final effluent quality of a wastewater treatment plant located in a rural community in Eastern Cape Province, South Africa for a period of 12 months. Their study revealed that the discharge of sewage effluents with a TDS level above 470 mg / l would have had a negative impact on aquatic life, rendering the receiving water unfit for consumption.
Dungeni et al. (2010) study evaluating the effectiveness of four wastewater treatment plants in Gauteng Province, namely Zeekoegat, Baviaanspoort, Rayton and Refilwe Water Care Works (WCW), in removing bacteria Pathogens and viral indicators have shown that wastewater treatment facilities that inefficiently dispose of contaminants have environmental impacts.

The investigation of the Caledon WWTW hydrology in Western Cape by the SRK Consulting (2010) revealed that large volumes of effluent are discharge by the WWTW into the Baths river system which turn to change the quality of water in the river system. The works are not functioning efficiently due to lack of maintenance and sufficient capacity to treat increasing inflow of waste water into their systems.

A study conducted by Seanego and Moyo (2013), in Limpopo, South Africa, while examining the influence of sewage works on physio-chemical and biological characteristics of the Sand River, revealed that the water quality of the Sand River was deteriorating downstream the waste water treatment works.

A study by Wanda et al. (2016) on the Eerstehoek Waste Water Treatment Plant in Mpumalanga revealed the occurrence of high levels of BOD, low levels of dissolved oxygen (DO), *E. coli*, nitrates and phosphates especially in raw water samples. It is suggested that a point-of-use system should be introduced to treat water planned for domestic purposes in the clean-water-deprived areas.

A study by Pillay and Olaniran (2016), while investigating the treatment efficiency of two independent wastewater treatment plants (WWTPs) in Durban, Kwazulu Natal in South Africa in order to determine the impact of treated effluent discharge on the physicochemical and microbial quality of the receiving water bodies over a 6-month period exposed the poor operational status of these WWTPs and sketch out the need for better water quality monitoring and enforcement of severe guidelines.

A study by Jordaan and Bezuidenhout (2016), on the investigation of the Bacterial community composition of an urban river in the North West Province, South Africa, in relation to physico-chemical water quality on the Mooi River revealed that urbanisation and inadequate Waste Water Treatment Work caused the overall water quality of this river to deteriorate.

Chapter 3 Research Designs and Methodology

3.1 Introduction

The methods and materials used in this research are explained in detail in this chapter. These methods highlight the present water condition around the Caledon WWTW and also predict what could happen in the future if current discharges trends are not improved. The data collection techniques followed the standard ethical principles and guidelines implemented by the Department of Water Affairs and Forestry (DWAF, 1996). A complete layout of this study has been provided by the Breede-Gouritz Catchment Management Agency (BGCMA). The BGCMA has received an email from the researcher detailing the way its data will be used in this research. The objectives of this research were achieved by conducting an assessment of the Caledon WWTW and the impact it has on the Baths River system water quality. Various water analysis methods were applied. The methods below clearly indicate the processes and actions taken to achieve the objectives of the study.

3.2 Research design

3.2.1 Research design methods

The study followed the quantitative design approach involving taking water quality samples upstream, downstream and at source of the Caledon Waste Water Treatment Works.

3.2.1.1 Statistical Analyses

In this study, the water quality parameters were observed along the Baths River monitoring stations (upstream and downstream points) and at the Caledon wastewater treatment plant points (source or effluent). The selected stations were determined based on the data reported from 2013 to 2016 by the BGCMA. The data were initially arranged according to the stations and year of monitoring and interpolation was used to obtain all the missing data. In this study, the spatial variations of the Baths River and Caledon WWTW water quality parameters were analysed per annum.

In statistical analyses, the values below the detection limits are often censored or substituted with a constant value such as zero. The same rule was applied in this study to set all observation value below detection limits to zero. In this study, data were standardized to increase the homogeneity of the dataset and to enhance data normality and to ensure that all parameters are close in terms of their variances (Yidana et al., 2010). All statistical calculations were done with the statistical package SPSS (SPSSInc. Chicago, IL, USA) and graphs where generated with Microsoft Excel.

3.2.1.2 A multiple post-hoc comparison test

A one-way analysis of variance (ANOVA) and multivariate analysis were used to identify differences in water quality parameters among the twelve months of study, four years and three sites, since samples were collected per parameters temporally and spatially. The level of significance (α) was 0.05 and the *p* values obtained were referred to as model *p* in the results section. A model *p* less than 0.05 indicate that at least two of the months, year or sites differ in parameters from each other. A multiple post-hoc comparison test was completed to determine where differences lie between specific months, year or sites (Scheffé test for parametric data or Dunnett's-T3 test for non-parametric data) at confidence level of $p \leq 0.05$.

3.2.1.3 Discriminant Analysis

The aim of discriminant analysis is to determine if the water quality variables for the Baths river system had changed from 2013 to 2016, and also to explore the perception that the water quality in three sectional areas (source, upstream and downstream points) of the Caledon WWTW were differing from each other. This analysis helped in determining if there is an improvement in terms of water quality across the Baths river system. The linking of multivariate data sets containing water quality parameters was computed using a 1-tailed Pearson product-moment correlation (Oberholster, and Botha, 2010) and canonical discriminant functions analysis (Kaselowski and Adams, 2013) to search for relationships and significance there-after between environmental parameters and sampling stations areas spatially and temporally at confidence levels of $p \leq 0.05$ and $p \leq 0.01$.

3.2.2 Sampling design

The primary data was collected from the source at the Caledon WWTW (discharge point), upstream and downstream of the Baths River. The water samples were collected in duplicates for each point and stored in different light proof insulated cooler boxes prior to analysis. Samples for microbiological and chemical analysis were stored in separate cooler boxes. The samples for chemical analysis microbiological and were collected using a 200 ml plastic containers and 200ml glass bottles respectively. The chemical and microbial samples were transported to the laboratory within 12 hours of sampling.

3.2.3 Study population

The physico-chemical and biological parameters were selected for the purpose of this study. The parameters of concern include pH, Electrical Conductivity, Ammonia, Chemical Oxygen demand, Total Suspended Solid, E.coli and Fecal Coliform. The parameters were chosen as they are pertinent to the pollution emanating from the Waste Water Treatment Works.

3.2.4 Data type and data source

3.2.4.1 Desktop study

Desktop study involved assembling literature from different sources locally and globally. This also advises on which parameters are important to analyse for this study when it comes wastewater effluents. It also provided the best methods that can be used to achieve the objectives of the study.

3.2.4.2 Data Collection

Primary data was collected for this study. The samples were collected from the 3 monitoring points identified by the Breede Gouritz Catchment Management Agency. The data collected were organised into three stations:

- Upstream point (Reference point before wastewater effluent enters the Baths River);
- Effluent point or source(Treated wastewater from the Caledon WWTW at the discharge point which in this case is the Baths river);
- Downstream point (Points downstream the effluent point along the Baths River system).

The study covers the period of March 2013 to March 2016.

3.2.4.3 Primary data

The primary data were collected from the source at the Caledon WWTW (Influent point), at effluent points and upstream and downstream of the Baths River. The water samples were collected in duplicates for each point and stored in different light proof insulated cooler boxes prior to analysis. Samples for microbiological and chemical analysis were stored in separate cooler boxes.

The samples for microbiological and chemical analysis were collected using a 200 ml bottle and plastic containers, respectively. They were transported to the laboratory within 12 hours of sampling.

3.3 Research methodology

In this research, quantitative methods were used to gather the relevant data. Bryman (2001) refers to research as a technique for collecting data. Similarly, Mouton (2001) highlights the importance of research methodology as a procedure that researchers apply to reduce, organize, and analyse data in the process of undertaking scientific research in social science. Accordingly, Literature review, secondary data analysis, sampling was done to gather the data needed for this research.

3.3.1 Objective 1

The primary data were sampled and analysed by Swift (Pty) Ltd. Lab for microbial, and AL Abbott for chemical parameters. They were used to validate if the Caledon WWTW was within the same range in terms of treatment efficiency during the same periods.

3.3.2 Objective 2

These primary data were used to assess contamination trends and loads within the river system over a period of time, which can be used to project future contaminant trends and loads.

3.3.3 Objective 3

The parameters analysed were selected based on the availability of secondary data from Caledon WWTW to allow for comparison.

3.4 Quality control/Quality Assurance

During the laboratory analysis of the water samples, the standard and accredited methods for water quality analysis were followed.

3.4.1 Reliability of findings

The key elements of the research objectives are developing consistent and valid methods to obtain reliable results. No sample preservation was done as all the samples were analysed immediately after sampling by Swift (Pty) Ltd and AL Abbott Laboratories. These findings were established and made credible and confirmed by more than a few institutions like the Swift (Pty) Ltd. Lab for microbial findings, and AL Abbott for chemical parameters as well by the Breede Gouritz Catchment Management Agency for the overall.

3.4.2 Validity of findings

Intercomparisons assessment with the Caledon WWTW data for the same periods of study were performed to evaluate the performance of the analytical methods used and the way they were applied by Swift (Pty) Ltd and AL Abbott Laboratories as well as for the verification of results.

3.5 Research Integrity

This study actively adhered to the ethical principles and professional standards essential for the responsible practice of water and environmental research in South Africa established by the Department of environmental Affairs (DEA), The Department of Water and Sanitation (DWS) and the Water Research Council (WRC).

3.5.1 Technical integrity

The principles and practices were adopted as a personal credo, not simply accepting them as impositions by rule makers. Honesty, trustworthiness, and high regard for the scientific record were applied. Physical measurements were done in situ because the values of these variables changes quickly after sample collection. The instrument was calibrated against a standard calibration solution. The probes were calibrated in the field prior to sampling to provide reliable measurements. In addition all supporting information such as time and weather were recorded before leaving each sampling point. These observations were recorded so as to assist in interpretation of analytical results. Samples exceeding the highest standards were diluted and reanalysed.

3.5.2 Regulatory Laws

The environmental impacts owing to municipal wastewater effluent dumping are regulated by various legislations. The legislations for dealing with the antagonistic impacts of municipal wastewater effluent disposal on the environment include the National Environmental Management Act 107 of 1998 (NEMA) and National Water Act (NWA Act no 36 of 1998).These regulations and laws have been considered throughout the research period and research practice and methodologies.

3.5.2 Ethical integrity

After finalizing the research dissertation, the investigator had to acquire ethical clearance from the University of Western Cape research ethics committee before data collection could proceed. The investigator with the assistance of the study supervisors wrote a letter to Caledon WWTW authorities requesting an authorization to access the Caledon

WWTW for sample collection and request the secondary data. Another request letter was prepared to the Breede-Gouritz Catchment Management Agency requesting authorization to utilize their data through Swift (Pty) Ltd and AL Abbott Laboratories. Permission letters from both the Caledon WWTW and the Breede-Gouritz Catchment Management Agency granting authorization (See Annexure A and B) were used as the supporting documents for the ethics clearance application. The researcher waited for the ethics clearance approval from the University before commencing with data collection and analysis (See Annexure C).

3.6 Limitations of the study

Owing to financial restrictions for the collection and laboratory analyses of the water samples; the primary data were collected for only four years from March 2013 to March 2016. The study mainly focused on the primary data available from the BGCMA. The primary data sampled and analyzed were used to validate the secondary data to see if the Caledon WWTW was within the same range in terms of treatment efficiency during the period. These historic and primary data were used to assess contamination trends and loads within the river system between March 2013 to March 2016, which can be used to project future contaminant trends and loads. Phosphate, Nitrogen, Chlorine and Heavy metals were not analyzed due to financial constrictions and time. Only seven parameters were used for assessment of the treatment efficiency of the wastewater treatment works (pH, Electrical Conductivity, Ammonia, Chemical Oxygen demand, Total Suspended Solid, E.coli and Faecal Coliform) for four years and was done as a result that the Caledon WWTW was able to monitor those seven parameters at the influent points. These seven parameters were used based on the continuity of data at the influent and effluent points for the entire study period.

3.7 Experimental Analysis for Primary Data

3.7.1. Physico-chemical analysis

Measurements were taken at each site for pH, electrical conductivity (EC), total suspended solids (TSS) and dissolved oxygen (DO) using an Aquaread multi-parameter probe.

3.7.2 Nutrient analysis

The water samples were analysed for nutrients using standard spectroquant test-kit techniques on a Merck spertroquant pharo100. The nutrients that was tested for is ammonium. Water quality results were compared to the Target Water Quality Requirement (TWQR) for aquatic ecosystems as set out by DWAF (1996).

For ammonium, 5 ml of the pre-filtered sample was pipetted into a test tube and 0.60 ml of reagent NH4-1 from the Cat.No. 114752 Spectroquant® Ammonium Test was added and mixed with the solution. One level blue microspoon of reagent NH4-2 from the Cat.No. 114752 Spectroquant® Ammonium Test was added to the previous solution and shaken vigorously until the reagent was completely dissolved and left for a reaction time of 5 minutes. Four drops of ammonium reagent NH4-3 from the Cat.No. 114752 Spectroquant® Ammonium Test was added and mixed and the reaction was left for a further 5 minutes, then the solution was transferred to a quartz cuvette of 5.0 mm and placed in the spectrophotometer for reading.

3.7.3 COD determination

COD from the water samples were analysed using the Colorimetric method as followed by LaPara *et al*. (2000) and O'Dell (1993). All the culture tubes and screw caps were washed using H2SO4 (20%) to prevent contamination (O'Dell, 1993). Trace contamination were removed from the tubes by igniting them in a muffle furnace (oven) for an hour at a temperature of 500 ºC. 2.5 ml of sample was pipetted into different tubes. About 1.5 ml of the digested solution is added to the tubes and the mixture is allowed. About 3.5 ml of catalyst solution (silver sulphate) were introduced into solutions. The mixture was then shaken and placed in a processor block (oven) for two hours at 150 ° C. The tubes were then removed from the oven, cooled and mixed, and precipitation was allowed to settle. The process was repeated until a stable baseline was achieved. The calibration curve was plotted using the response from the instrument against the standard concentration. Samples exceeding the highest standards were diluted and reanalysed.

3.7.4. E. Coli Quantification

E. coli in the water samples were enumerated using a Membrane filtration methods and these analysis were done within eight (8) hours of sampling (Dufour et al. 1981 , US-EPA, 2004). A volume of 1 litre of water samples were filtered through the bacteria retains membrane. After filtration, the bacteria retain membrane were placed on a selective and differential medium, modified membrane – Thermotolerant Escherichia coli (mTEC) agar, incubated at 35 ± 0.5°C for 2 ± 0.5 hours to resuscitate injured or stressed bacteria and then incubate at 44.5 ± 0.2°C for 22 ± 2 hours (USEPA, 2004). The target colonies on modified mTEC agar are red or magenta in colour after the incubation. The numbers of colonies were counted after incubating the membrane at room temperature. The numbers of colonies were used to calculate the E. coli present in the water samples. E. coli present were calculated as follows:

$E.coli$ mg/l= $(number\ of\ filtered\ colonies\ /sample\ volume) \times 100$

Chapter 4 Results and Discussions

4.1 Introduction

The chapter presents and discusses the results from methods that have been described in the previous chapter. The samples collected from the source, upstream and downstream points of the Caledon WWTW were aimed on evaluating the effectiveness and of the wastewater treatment works in treating final effluent before discharge and also to assess the impact of the wastewater effluents on the Baths River.

All raw values of the water quality component measured during the study period were included in the appendix A, B & C. Relevant sections of the data have been presented in the results. Specific water quality variables have been discussed in this chapter comparing mean values at different sites for the months covering the study period along with ranges. Results were compared to target TWQR values for wastewater discharge limits set out in the water quality guidelines for wastewater discharge in South Africa (DWAF, 1996) for appropriate variables for upstream and downstream point and as well to DWAF, 1996 recommended guideline values for the discharge of wastewater effluents into a water resource system for source point.

The study, the performance of the Caledon WWTW and the water quality in the Baths River were assessed between 2013 up to 2016, to test if the wastewater treatment works was improving or deteriorating with regards to wastewater treatment. Monthly assessment of the wastewater works (source) and of the Baths River (upstream and downstream) were done to assess the treatment effectiveness of the Caledon WWTW of and the water quality as well as the source of pollution in the Baths River. The water quality was assessed using the pH, chemical oxygen demand, electrical conductivity, total suspended solids, ammonia, total coli form and Escherichia coli. The results were statistically analyzed using Microsoft Excel for creating graphs and SPSS software for statistical analyses to assess the treatment effect via one-way ANOVA (Figures 5, 6, 7 and 8).

4.2 Assessment of performance of Caledon WWTW

4.2.1 Water quality parameters at the Caledon WWTW source

Water quality parameters were recorded at the source in order to assess the performance of the Caledon WWTW over a period of four years from 2013 to 2016 and are presented in Tables 2 and described in graphs 5, 6,7and 8 and appendix A.

Table 2: Relationships between some water quality parameters, mean + SD and TWQR at the source of the Caledon WWTW between February 2013 to March 2016.

Parameters	Minimum values	Maximum values	Source Mean + SD	TWQR (1996)
pH	7.29	8.70	7.83± 0.36	5.5-9.5
COD (mg/L)	50.10	250.00	153.21± 50.78*	≤ 75 mg/L
Conductivity(mS/cm)	89.50	290.00	189.02± 42.04*	≤75 mS/m
TSS (mg/L)	4.00	86.00	22.27± 19.13	<25 mg/L
Ammonium (mg/L)	0.10	57.80	26.99± 14.6*	≤10 mg/L
Faecal Coliform	13.00	30000.00	4067.87±	1000 cfu/100
E.coli (count/100ml)	13.00	30000.00	2648.43±	≤ 100 cfu/100

SD: Standard Deviation, – indicate that TWQR value for wastewater discharge limits was not available.* indicate values above the TWQR for Aquatic ecosystem.

pH

pH modification over the addition of acidic / basic chemicals is an important part of any wastewater treatment system as it allows for the separation of dissolved waste from water during the treatment process.

Table 2 shows that the pH value ranged from 7.29 – 8.70 (7.83 ± 0.36) at the source point at the Caledon WWTP source.

The highest pH of 8.70 was recorded in February 2014 and May 2016 and the lowest pH of 47.29 was recorded in April 2016 (appendix A). In comparison to DWA wastewater discharge limits (5.5 to 9.5); all the pH values measured at the source during the study period was within acceptable limits throughout the study period. Figure 5 showed that all water quality samples were essentially alkaline throughout the duration of the study, suggesting the presence of chemicals and nutrients in the water which is a minor worry as far as the pH of that water is concerned.

The Kolmogorov-Smirnov normality test showed the pH data are normally distributed among sites, months and years as determined by one-way ANOVA (df (46), $p = .388$). There was no statistically significant difference between months for pH at the source as determined by one-way ANOVA ($F (11, 48) = 48.607$, $p = .057$). No statistically significant differences between years ($p = 0.546$) was recorded.

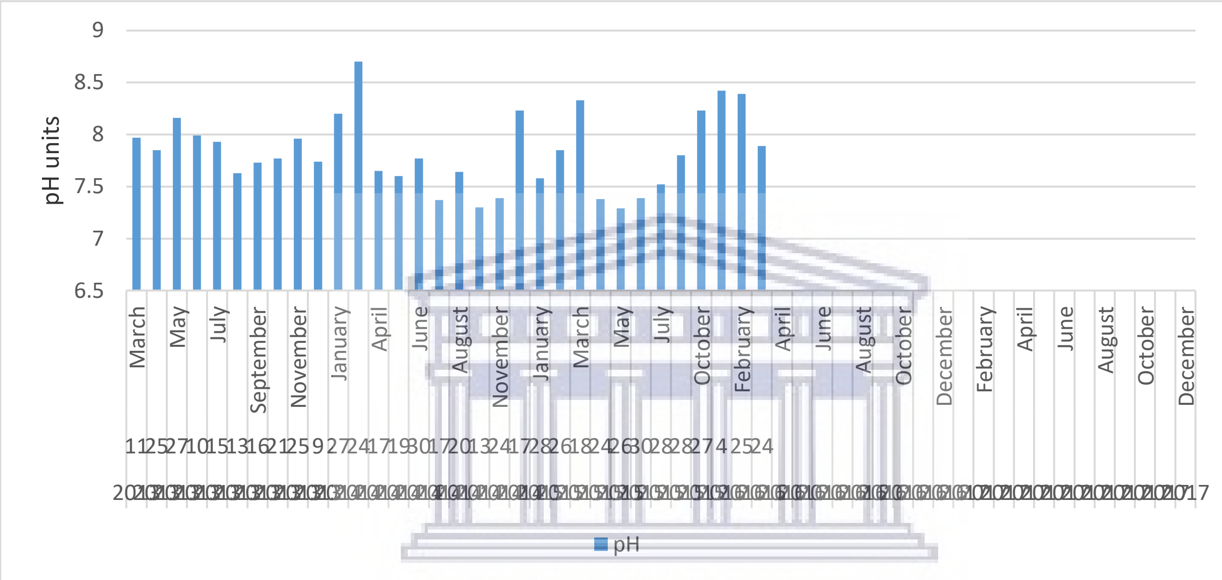

Figure 5: pH variations at Caledon WWTP source.

EC

The EC level ranged from 89.50– 290.00 mS/m with a total mean value of 189.02 ± 42.04mS/m at the Caledon WWTP source (Table 2).

The highest EC of 290 mS/m was recorded on in in February 2016 and the lowest EC 0F 89.5 mS/m was recorded in April 2016 (appendix A). In comparison to DWA wastewater discharge limits ≤75 mS/m; all EC values measured at the source during the study period were above the acceptable DWA wastewater discharge limits. The mean total electrical conductivity at the Caledon WWTW source point (189.02 mg/l, table 2) was above the DWA wastewater effluent limit of 75mS/m.

This might be attributed to inadequate ion removal from the Caledon WWTW. This suggests that the Caledon WWTW was not able to remove some amount of ion in the wastewater before discharged in the Baths River. Any pollution increase in terms of EC could pose a possible health risks to the downstream users of water. Waterborne diseases such as may occurred.

The Kolmogorov-Smirnov normality test showed the EC data are normally distributed months and years as determined by one-way ANOVA (df (46), p = .252).There was a statistically significant difference between months for electrical conductivity as a whole as determined by one-way ANOVA (F (11, 215) = 33.383, p = 0.00). However, no statistically significant differences between years (p = 0.722) recorded meaning that there were no significant variation in the value of EC over the study period.

Total Suspended Solids (TSS)

The concentrations TSS ranged from 4 – 86 mg/l with a mean of 22.27 ± 19.13mg/l at the Caledon WWTP source (Table 2).

The highest TSS of 86 mg/l was recorded on in February 2016 and the lowest TSS of 4 mS/m was recorded in June 2015 (appendix A). In comparison to DWA wastewater discharge limits <25 mg/L; most of the TSS values measured at the source during the study period was over the acceptable DWA wastewater discharge limits except for the month of June in 2015 where a value of 4 mS/m was recorded . This illustrates that there was ineffectual sludge settlement during the sedimentation stage at Caledon WWTW.

The Kolmogorov-Smirnov normality test showed the TSS data are normally distributed among sites, months and years as determined by one-way ANOVA (df (46), p = .225).There was a statistically significant difference between months as a whole for total suspended solids concentrations as determined by one-way ANOVA (F (11, 72) = 2.22, p = 0.025). No significant differences between years (p = 0.517) were observed

Chemical Oxygen Demand (COD)

The COD measurements ranged from 50.10 – 250 mg/l with a mean value of 153.21 ± 50.78mg/l at the Caledon WWTP source (Table 2).

The highest COD of 250 mg/l was recorded on in February 2016 and the lowest COD of 50.10 mg/l was recorded in November 2014 (appendix A). In comparison to DWA wastewater discharge limits ≤ 75 mg/L; most of the COD values measured at the source during the study period was over the acceptable DWA wastewater discharge limits except for the month of November in 2014 were an acceptable value of 50.10 mg/l was recorded .These results demonstrate ineffectiveness in treating COD in the influent before discharging into the Baths River system. Effluents at source point, of the Caledon WWTW did not comply with the set limits 75 mg/L for COD in most of the sampling months (Figure 6). The presence of high COD in the effluent wastewater could be as well attributed to the presence of sulphides, sulphites, thiosulphate and chlorides that cause interference to COD (Agyemang et al., 2013).

High concentrations were recorded at the source point (Figure 6) and this could be due to the municipal wastewater containing residual food waste from households, antifreeze and emulsified oils. The results also showed that the Caledon WWTW source did impact on the receiving Bath river system. The presence of high COD in the effluent wastewater could be as well attributed to the presence of sulphides, sulphites, thiosulphate and chlorides that cause interference to COD (Agyemang et al., 2013).

High concentrations were recorded at the source point (Figure 6) and this could be due to the municipal wastewater containing residual food waste from households, antifreeze and emulsified oils. The results also showed that the Caledon WWTW source did impact on the receiving Bath river system.

The Kolmogorov-Smirnov normality tests showed the COD data are normally distributed among sites, months and years as determined by one-way ANOVA (df (46), $p = .204$).There was a statistically significant difference between months as a whole for COD concentrations as determined by one-way ANOVA ($F (11, 72) = 2.22$, $p = 0.025$). No significant differences between years ($p = 0.517$) were observed.

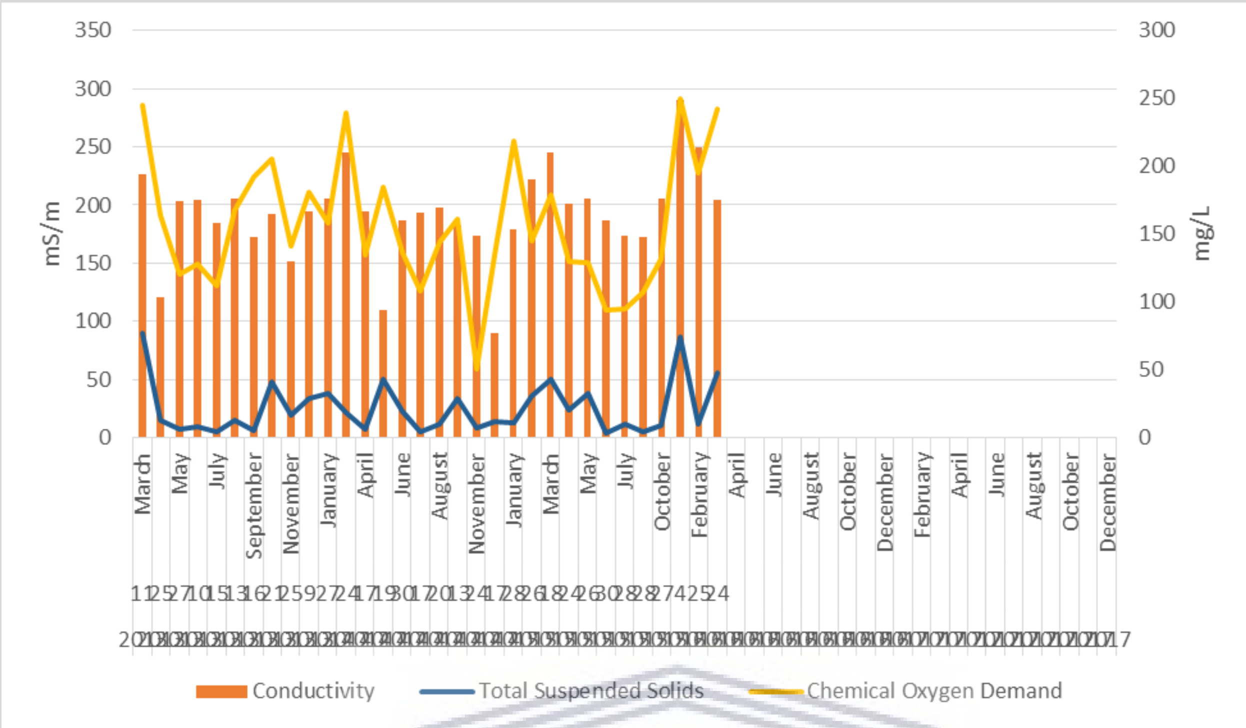

Figure 6: Relationships between Electrical conductivity, Chemical Oxygen Demand and Total Dissolved Solids variations during the study period at the Caledon source.

Ammonia – nitrogen (NH3-N)

The ammonia concentration ranged from 0.10 – 57.80 mg/l with a mean value of 26.99 ± 14.6 mg/l at the Caledon WWTP source (Table 2).

The highest ammonia of 57.80 mg/l was recorded on in July 2013 and the lowest ammonia of 0.10 mg/l was recorded in February 2015 (appendix A). In comparison to DWA wastewater discharge limits ≤10 mg/L; most of the ammonia values measured at the source during the study period was over the acceptable DWA wastewater discharge limits except for the month of February 2015 (0.10 mg/l), February 2014(0.15 mg/l), March and July 2015(7.8 mg/l, 7.1 mg/l) and February 2016 (6.6 mg/l).

The ammonia concentrations at the source of the Caledon could entail that consuming such water would affect the respiratory systems of many animals including human beings (DWAF, 1996). The study reveals that the treatment works was inept to discharge effluent (Figureb7) with less ammonia concentration than DWA wastewater discharge limits of 10 mg/l.High ammonium concentration at the source point could be attributed to a variety of wastewater inadequately treated influents from household wastes, agricultural wastes and industrial wastes within the Caledon WWTW vicinity.

The Kolmogorov-Smirnov normality test showed that the for dissolved ammonium data are normally distributed among months and years as determined by one-way ANOVA (df (46), $p = .203$).There was a statistically significant differences between months as a whole for dissolved ammonium ($F (11,430) = 19.177$, $p = 0.00$) as determined by one-way ANOVA. Statistically significant differences were also observed between years ($F (5, 430) = 3.078$, $p = 0.010$).

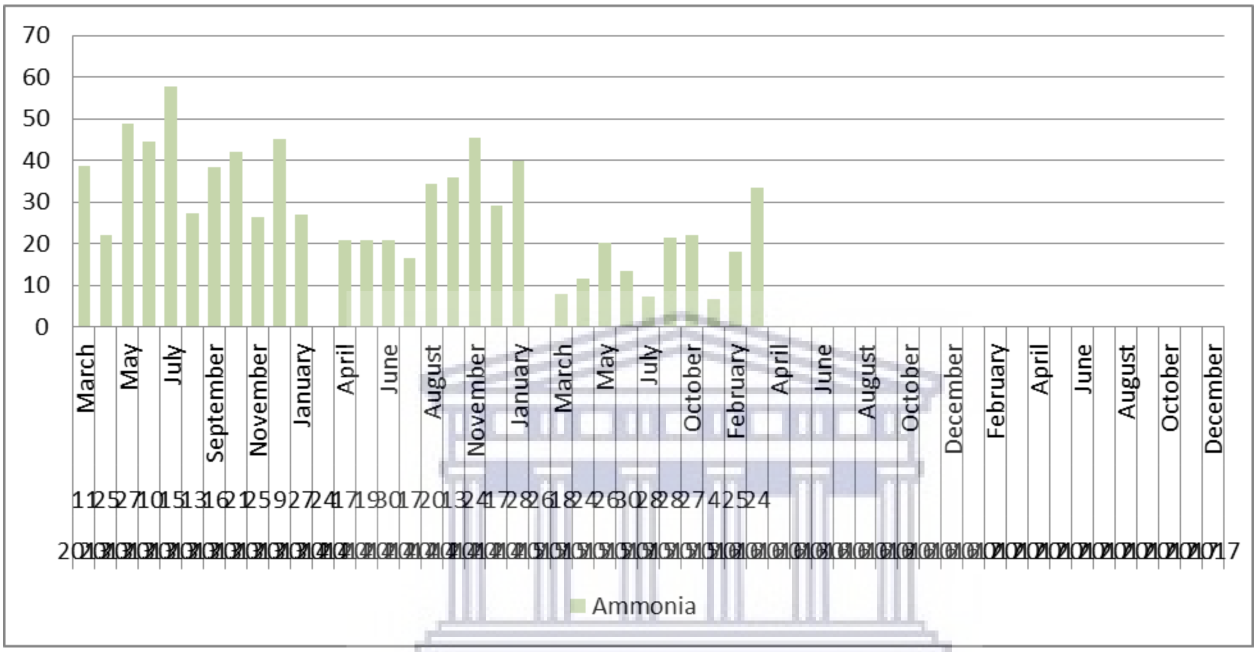

Figure 7: Dissolved ammonium concentrations at the source of the Caledon WWTP.

Total Faecal Coliform

Total coliforms has been defined as all those aerobic or facultative anaerobic, gram-negative, on-spore-forming, oxidase-negative, rod-shaped bacteria which have the capacity to ferment lactose with gas and acid formation within 48 h at 35 °C while faecal coliforms have been defined as those coliforms which can proliferate at an elevated temperature of 44.5 °C (WHO, 2008). The study showed that the total faecal coliform count ranged from 13 – 30000 counts/100 ml with a mean 4067.87 ± 10485.33 counts/100 ml at the source point (Table 2).

The highest total coliforms of 30000 counts/100 ml were recorded on in February 2016 and lowest total coliforms of 13 counts/100 ml was recorded in September 2015 (appendix A). In comparison to DWA wastewater discharge limits ≤1000 cfu/100 ml; most of the total coliforms values measured at the source during the study period were within the acceptable DWA wastewater discharge limits except for the month of the month of June in 2015 (1200 cfu/100 ml) and February 2016 (30000 counts/100 ml) where the values recorded were above the limits.

This might suggest that in that specific in February 2016 the Caledon WWTW might not have worked efficiently. The Caledon WWTW showed reduction efficiencies of total faecal coliform during some sampling periods but the level found in the effluent exceeded the recommended guideline value of 1000 counts/100 ml for faecal indicator organisms in wastewater effluents.

The Kolmogorov-Smirnov normality test showed that the data for total faecal coliform are normally distributed among months and years as determined by one-way ANOVA (df (46), p = .470).There were no statistically significant differences between months (p= 0.169) and between years (p = 0.739) as a whole for the total faecal coliform concentrations as determined by one-way ANOVA meaning that there were no significant variation in the value of total faecal coliform over the study period.

Escherichia coli (E. coli)

Escherichia coli (E. coli) present in the water are a measure of the amount of faecal bacteria present in the water .The study revealed that the *E. coli* count ranged from 13 – 30000 counts/100 ml with a mean 2648.43 ± 5763.56 counts/100 ml at the source point (Table 2).

The highest *E. coli* counts of 30000 counts/100 ml were recorded on in February 2016 and the lowest *E. coli* count of 13 counts/100 ml was recorded in September 2015 (appendix A). In comparison to DWA wastewater discharge limits ≤100 cfu/100 ml; most of the *E. coli* values measured at the source during the study period were above the acceptable DWA wastewater discharge limits throughout the study period except for the month of the month of September in 2015 (13 cfu/100 ml) and February 2016 (30000 counts/100 ml) where the values recorded was below the limits. This could suggest that by February 2016, Caledon's WWTW may not have worked effectively. The reduction in *E. coli* counts at the source point (Figure 8) could be the result of disinfection of wastewater using chlorine, ozone or ultraviolet (USEPA, 2004).

The Kolmogorov-Smirnov normality test showed the data for E. coli are normally distributed among sites, months and years as determined by one-way ANOVA (df (46), p = .359).There were no statistically significant differences between months (p= 0.169), between years (p = 0.739) and between sites (p = 0.739) as a whole for *E.coli* concentrations as determined by one-way ANOVA at the source point.

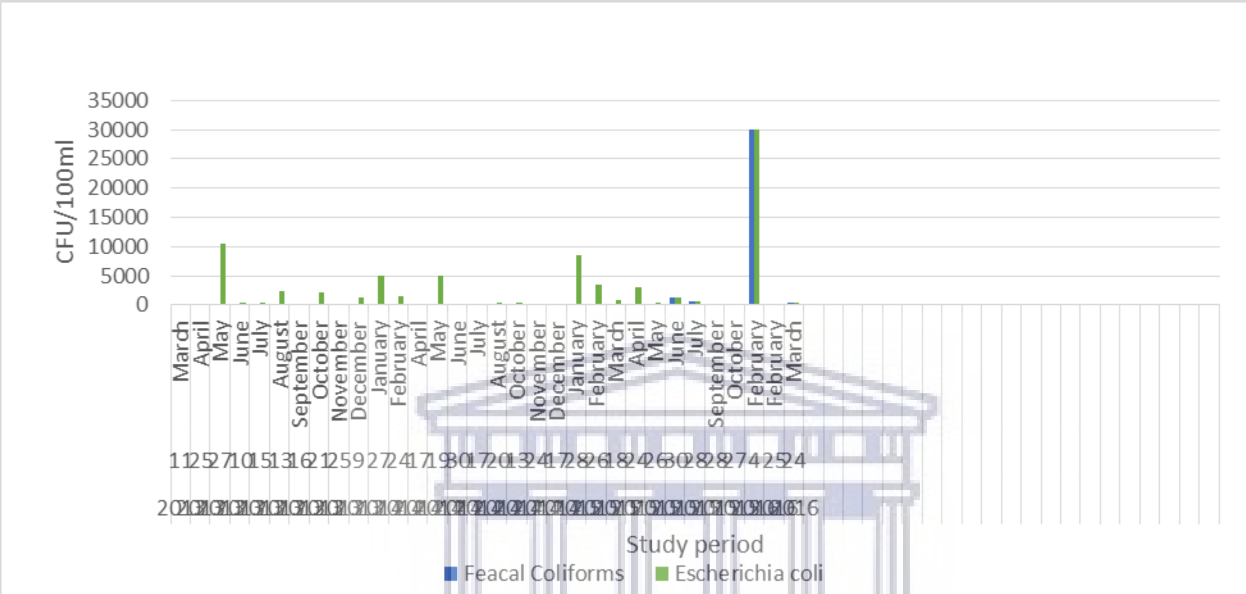

Figure 8: Relationships between Faecal coliform and Escherichia coli variations during the study period at the source of the Caledon WWTW.

4.2.2 Evaluation of the **Caledon WWTW performance**

The study were performed over the period of four years from 2013 to 2016, whereby some sampling covered almost the entire years from January to December such as 2013, 2014, 2015 while others such as in 2016 covered only February to May. The parameters studied in order to evaluated the performance of the Caledon WWTW were pH, Conductivity, Suspended solids, ammonia as Nitrogen, Chemical oxygen demand Total Fecal E.coli and *E.coli.*These parameters were chosen to test the water in term of organisms (Total Fecal E.coli and *E.coli*), solids content (EC and TSS), organic matter (COD and ammonia as Nitrogen) that night have bypass the stages of waste water treatment plant at specific temperature. High COD is incidental sign of the organic content. Ammonia is inorganic and produces an oxygen demand.

Some essential parameters such as chlorine, sulphate, calcium and sodium and phosphate were not studied as per our hypothesis the problem at the Caledon WWTW was not the nonperformance rather linked to the defected raw sewage pipelines upstream the Caledon WWTW.

All the sampling and test were performed in association with the Breede Overberg Catchment Management Agency (BGMA) and tested in adequate laboratory like A.L. Abbot and Associates PTY Ltd to attest the reliability of the results.

From the above tables and figures, the Caledon WWTW performances were worst in the year 2016, moderate in years 2014 and 2015 and better in year 2013 (appendix A). It is evident that the final effluent of the Caledon WWTW throughout the study period is not complying with the general wastewater limit standards and has deteriorated from 2013 to 2016. The Theewaterskloof Municipality to whom the Caledon WWTW belongs must be inform as to what will be done to ensure compliance and prevent further pollution of the receiving environment. The increase in population in the area combined with the obsolete and low capacity WWTW could be causes to the situation observe. Downstream users would be negatively impacted by the pollution emanating from the wastewater treatment works. A plan of action must be taken to rectify this.

4.3 Assessment of the physico-chemical and microbiological water properties of the Baths River

Water quality parameters recorded at the upstream and downstream of the Caledon WWTP along the Baths River are presented in Tables 3, 4 as well as figures 9,10,11,12,13,14,15 and 16.

Table 3: Relationships between some water quality parameters, mean + SD and TWQR in the Baths River upstream of the Caledon WWTW between February 2013 to March 2016.

Parameters	Minimum values	Maximum values	Upstream Mean + SD	TWQR (1996)
pH	6.14	7.89	6.70 ± 1.35	5.5-9.5
COD (mg/L)	10.80	355.00	48.74± 59.05	< 75 mg/l
Conductivity(mS/cm)	38.5	199.00	75.14± 36.14*	<75 mS/cm
TSS (mg/L)	0.10	160.00	23.30± 28.45	< 25 mg/l
Ammonium (mg/L)	0.10	17.60	2.08 ± 4.08	≤10 mg/l
Faecal Coliform	43.00	9000.00	1335.89±	1000 cfu/100
E.coli (count/100ml)	0.00	30000.00	5790.27±	≤100 cfu/100

SD: Standard Deviation, – indicate that TWQR value for wastewater discharge limit was not available.* indicate values above the TWQR for Aquatic ecosystem.

Table 4: Relationships between some water quality parameters, mean + SD and TWQR in the Baths River downstream of the Caledon WWTW between February 2013 to March 2016.

Parameters	Minimum values	Maximum values	downstream Mean	TWQR (1996)
pH	6.80	8.29	7.02± 1.82	5.5 – 9.5
COD (mg/L)	21.2	248.00	68.50± 45.95	< 75 mg/l
Conductivity(mS/cm)	65.50	260.00	110.60± 49.31*	<75 mS/cm
TSS (mg/L)	4.00	34.00	16.59± 16.70	< 25 mg/l
Ammonium (mg/L)	0.10	15.90	4.81± 4.34	≤10 mg/L
Faecal Coliform	24.00	4000.00	1115.42±	1000 cfu/100
E.coli (count/100ml)	0.00	30000.00	3823.00±	≤ 100cfu/100

SD: Standard Deviation, – indicate that TWQR value for wastewater discharge limit was not available.* indicate values above the TWQR for Aquatic ecosystem.

4.3.1 pH value

Tables 3 & 4 displayed pH values ranging from 6.14 – 7.89 (6.70 ± 1.35) at the upstream point, and from 6.80 – 8.29 (7.02 ± 1.82) at downstream point. The highest pH of 8.70 was recorded on in in February 2014 and May 2016.At the upstream site the highest pH of 7.89 recorded in February 2016 and lowest pH of 6.14 was recorded in July 2013 (Appendix B). As for the downstream site the highest pH of 8.29 recorded in February 2016 and lowest pH of 6.60 was recorded in October 2014 (Appendix C). In comparison to DWA wastewater discharge limits (5.5 to 9.5); all the pH values measured at upstream and downstream of the Caledon WWTW along the Baths River, during the study period was within acceptable limits.

Figures 9 and 10 further highlighted that all the water quality samples were mostly alkaline throughout the entire period of study which suggests the presence of chemical and nutrients in the water. There was an increase in terms of mean pH between the upstream point (6.70) and downstream point (7.02) and this suggests that some form of wastewater treatment was not achieved and that the pollution source might have been generated either at the upstream of the Caledon WWTW or at the source.

Commonly there should be a decrease in pH value from the source wastewater down to the downstream point could be attributed to the dosing of sulphuric acid to the source wastewater at the pre-treatment section process, in order for the biological processes to be effected (Agyemang et al., 2013). Based on the DWA effluent discharge limits, the pH of the Baths river water would not adversely impact its use for domestic and recreational uses. A comparison with the study by Pillay and Olaniran (2016) on similar river system showed some similarities with a pH range of 6.30 – 7.87.

The Kolmogorov-Smirnov normality tests showed the pH data are normally distributed among months and years; upstream (df (48), p = .346) and downstream (df (48), p = .344) as determined by one-way ANOVA. There was no statistically significant difference between months for pH at the source as determined by one-way ANOVA (F (11, 48) = 48.607, p = .057). No statistically significant differences between years (p = 0.546) and between sites (p = 0.858) were recorded.

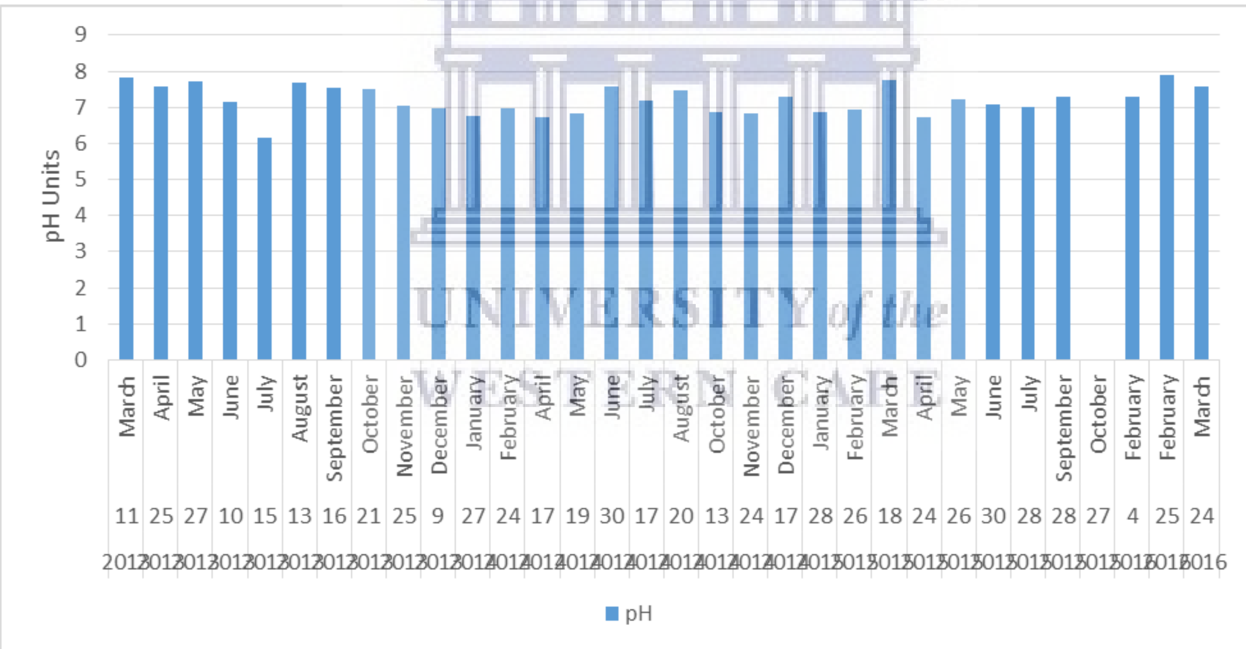

Figure 9: pH variations upstream of the Caledon WWTP.

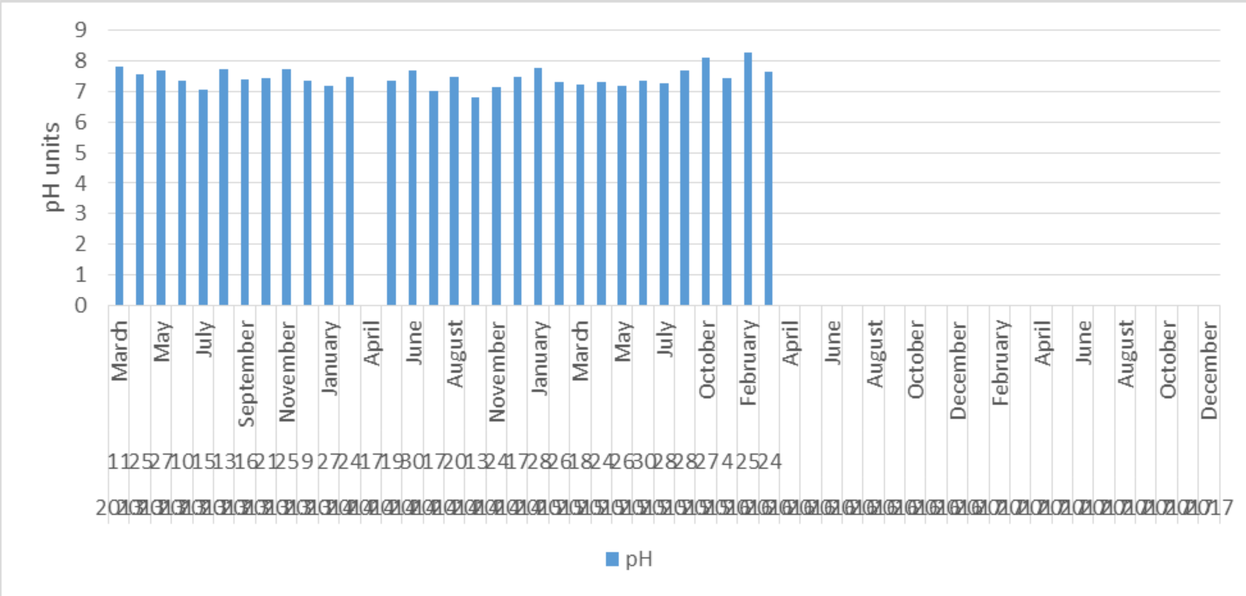

Figure 10: pH variations downstream of the Caledon WWTP.

4.3.2 Electrical conductivity (EC)

Tables 3 and 4 show that the EC level ranged from 38.50 – 199.00 mS/m with a total mean value of 75.14 ± 36.14mS/m at upstream point and from 65.50 – 260.00 mS/m with a total mean value of 110.60 ± 49.31 mS/m at downstream point.

The highest EC of 199.00 mS/m recorded in March 2013 and lowest EC of 38.50 mS/m was recorded in May 2014 upstream the Bath River (Figure 11 & Appendix B). As for the downstream site the highest EC of 199.00 mS/m was recorded in February 2016 and lowest EC of 65.50 mS/m was recorded in October 2013 (Figure 12 & Appendix C). In comparison to DWA wastewater discharge limits (<75 mS/cm); there was fluctuation in EC values measured upstream and downstream of the Bath River, during the study period with some above the acceptable limits and others within.

The study revealed that the Baths River was not capable to drop marginally the total mean concentration level of electrical conductivity from the upstream (65.50 mS/m) to the downstream point (110.60 mS/m).This suggests that there could be other unnamed contaminants gaining access to the watershed.

EC is largely attributed to the dissolved ions from the disintegrated plant matter. The EC of the surface water is a valuable indicator of salinity with total salt content (Agoro et al., 2018).An increase in EC values points to the high amount of dissolved inorganic substances in ionized form .It might be attributed to high dissolved ions originating from the spillages from the Caledon WWTW sewage pipeline which is situated upstream of the WWTW and the households contents from the wastewater influent (BGCMA, 2017) as well as agricultural practice upstream. Not to forget that the effluent from the Caledon WWTW might have contributed to that increase. Another reason could be the accumulation effect and other natural processes along the river system or any other activities downstream the Bath River that could increase in EC concentration.

The Kolmogorov-Smirnov normality tests showed the pH data are normally distributed among months and years; upstream (df (48), p = .181) and downstream (df (48), p = .241) as determined by one-way ANOVA.There was a statistically significant difference between months for electrical conductivity as a whole as determined by one-way ANOVA (F (11, 215) = 33.383, p = 0.00). However, no statistically significant differences between years (p = 0.722) and between sites (p = 0.926) were recorded

4.3.3 Total Suspended Solids (TSS)

Tables 3 and 4 show the concentrations of suspended solids ranged from 0.10 – 160 mg/l with a mean of 23.30 ± 28.45 mg/l at the upstream point and from 4 – 34 mg/l with a mean of 16.59 ± 16.70 mg/l at the downstream point.

The highest TSS of 160 mg/l recorded in January 2015 and lowest TSS of 0.10 mg/l was recorded in October 2016 upstream the Bath River (Figure 11 & Appendix B). As for the downstream site the highest TSS of 34 mg/l was recorded in October 2013 and lowest TSS of 4 mg/l was recorded in October 2015 (Figure 12 & Appendix C). Throughout the study period, the means concentrations of suspended solids upstream and downstream the Baths River did not exceed the DWA waste discharge standards of 25 mg/l (Figure 11 and 12).

There was a decrease in means TSS from upstream (23.30 mg/l) to downstream point (16.59 mg/l).This could be due to the dilution capacity of the Bath River system. The leakages from the raw sewage pipelines which is located upstream of the WWTW and the household's contents from the wastewater could be the reason of the high content of TSS upstream.

Increase concentration of suspended solids could results in an increase the temperature of the water as the suspended solids could contributes to high turbidity of the river system. However, the wastewater discharged into the Baths river system from defected pipelines upstream could contributes to accumulation of suspended solids load into the Baths River which could in future impact negatively on the water quality for the downstream users.

The Kolmogorov-Smirnov normality tests showed the pH data are normally distributed among months and years; upstream (df (48), $p = .287$) and downstream (df (48), $p = .241$) as determined by one-way ANOVA. No significant differences between years ($p = 0.517$) and sites were observed ($p = 0.517$).

4.3.4 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) measurements upstream and downstream the Baths River are presented in Tables 3 and 4 and illustrated in Figures 11& 12 which ranged from 10.80 – 355.0 mg/l with a mean of 48.74 ± 59.05mg/l at the upstream point and from 21.2 – 244.0 mg/l with a mean of 68.50 ± 45.95 mg/l at the downstream point.

The highest COD value of 355.0 mg/l recorded in July 2013 and lowest COD value of 10.80 mg/l was recorded in March 2016 upstream the Bath River (Figure 11 & Appendix B). As for the downstream site the highest COD of 244.0 mg/l was recorded in July 2013 and lowest COD value of 21.2 mg/l was recorded in October 2015 (Figure 12 & Appendix C). Throughout the study period, the means concentrations of Chemical Oxygen Demand (COD) fluctuated upstream and downstream the Baths River with values exceeding the DWA waste discharge standards of < 75 mg/l and other within the limit (Figure 11 and 12).This may be attributed to inefficiency of the WWTW to manage wastewater within its vicinity. High levels of COD in water may point to poor water standards caused by the Caledon WWTW or farmed effluent discharges upstream as well as the issue of Caledon sewage pipeline spillage upstream, which may in turn have resulted in higher oxygen depletion that affects aquatic organisms.

The means concentrations of COD did fairly change from the upstream stream to downstream (Figure 11 and 12). The slight change in term of COD concentration at the downstream point is due to dilution taking place between the upstream and downstream points. This however suggests that the Caledon WWTW did not add to the positive ecological integrity of the river system.

The Kolmogorov-Smirnov normality tests showed the pH data are normally distributed among months and years; upstream (df (48), p = .267) and downstream (df (48), p = .195) as determined by one-way ANOVA.There was a statistically significant difference between months as a whole for COD concentrations as determined by one-way ANOVA (F (11, 72) = 2.22, p = 0.025). No significant differences between years (p = 0.517) were observed.

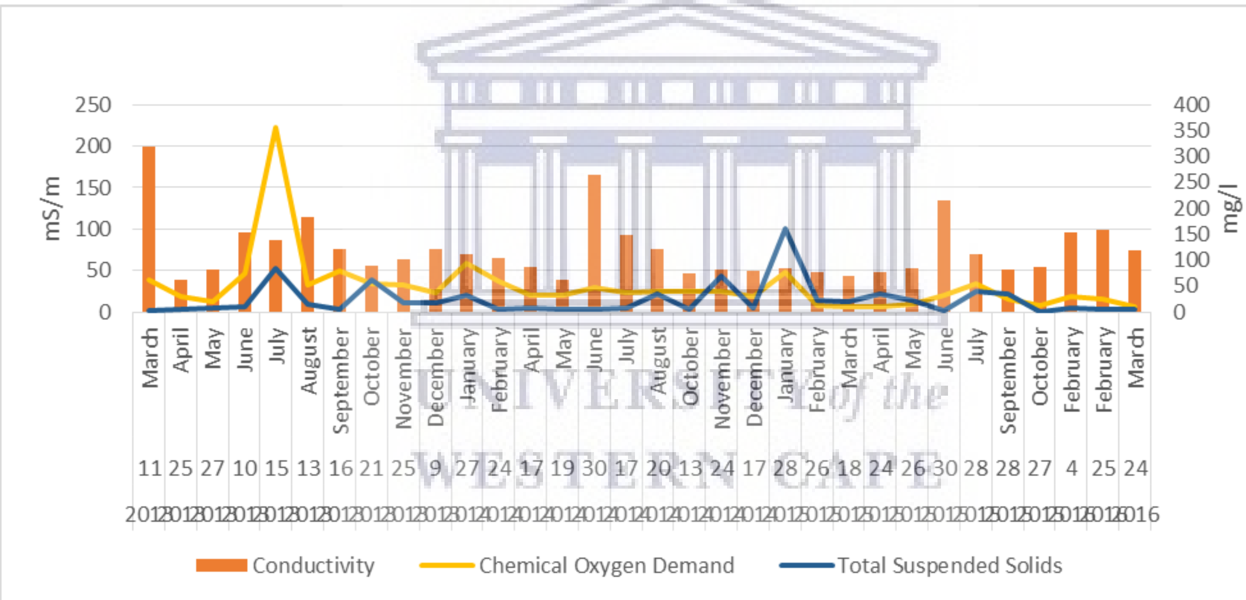

Figure 11: Relationships between Electrical conductivity, Chemical Oxygen Demand and Total Dissolved Solids variations during the study period upstream the Caledon WWTW.

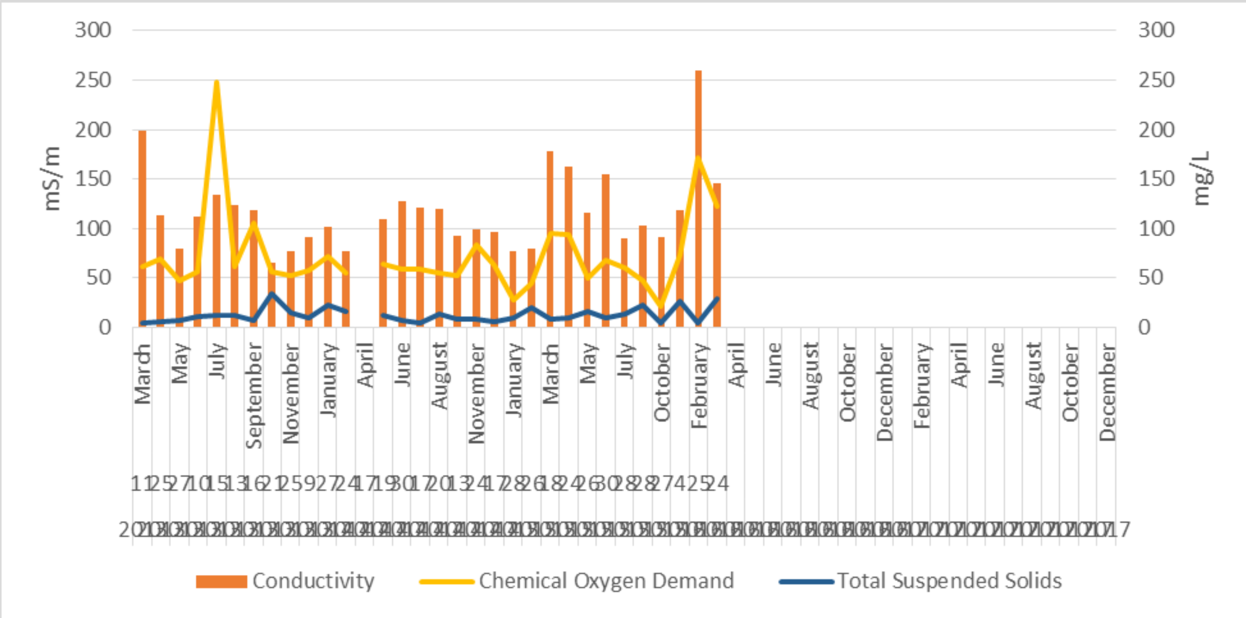

Figure 12: Relationships between Electrical conductivity, Chemical Oxygen Demand and Total Dissolved Solids variations during the study period downstream of the Caledon WWTW.

4.3.5 Ammonia – nitrogen (NH3-N)

Tables 13 & 14 demonstrated that ammonia concentration ranged from 0.10 – 17.60 mg/l with a mean value of 2.08 ± 4.08 mg/l at upstream point, and from 0.10 – 15.90 mg/l with a mean value of 4.81 ± 4.34 mg/l at downstream point.

The highest ammonia value of 17.60 mg/l recorded in January 2014 and lowest ammonia values of 0.10 mg/l were recorded in August and December of 2015 and from January to September 2015 upstream the Baths River (Figure 13 & Appendix B). As for the downstream site the highest ammonia of 15.90 mg/l was recorded in February 2016 and lowest ammonia values of 0.10 mg/l were recorded in from January to March 2015 (Figure 14 & Appendix C).

Throughout the study period, the concentrations of ammonia fluctuated upstream and downstream the Baths River with values exceeding the DWA waste discharge standards of < 10 mg/l and other within the limit (Appendixes B & C). Regardless of been within the DWA waste discharge standards, the mean concentration ammonia doubled from upstream (2.08 mg/l) to the downstream point (4.81 mg/l) (Figure 14) .It could be attributed to anthropogenic activities such as agricultural activities upstream the Caledon WWTW.

Ammonia can be broken down by nitrifying bacteria to form nitrite and nitrates in the present of dissolve oxygen (WHO, 2013a). A study by Lemley et al (2014) found that the nitrates load into the water bodies pose a threat to water quality around the Gouritz Water Management Area where the Caledon WWTW and the Baths River are located.

The Kolmogorov-Smirnov normality tests showed the pH data are normally distributed among months and years; upstream (df (48), $p = .377$) and downstream (df (48), $p = .223$) as determined by one-way ANOVA. Statistically significant differences were also observed between years ($F (5, 430) = 3.078$, $p = 0.010$). No significant differences between sites ($p = 0.517$) were observed.

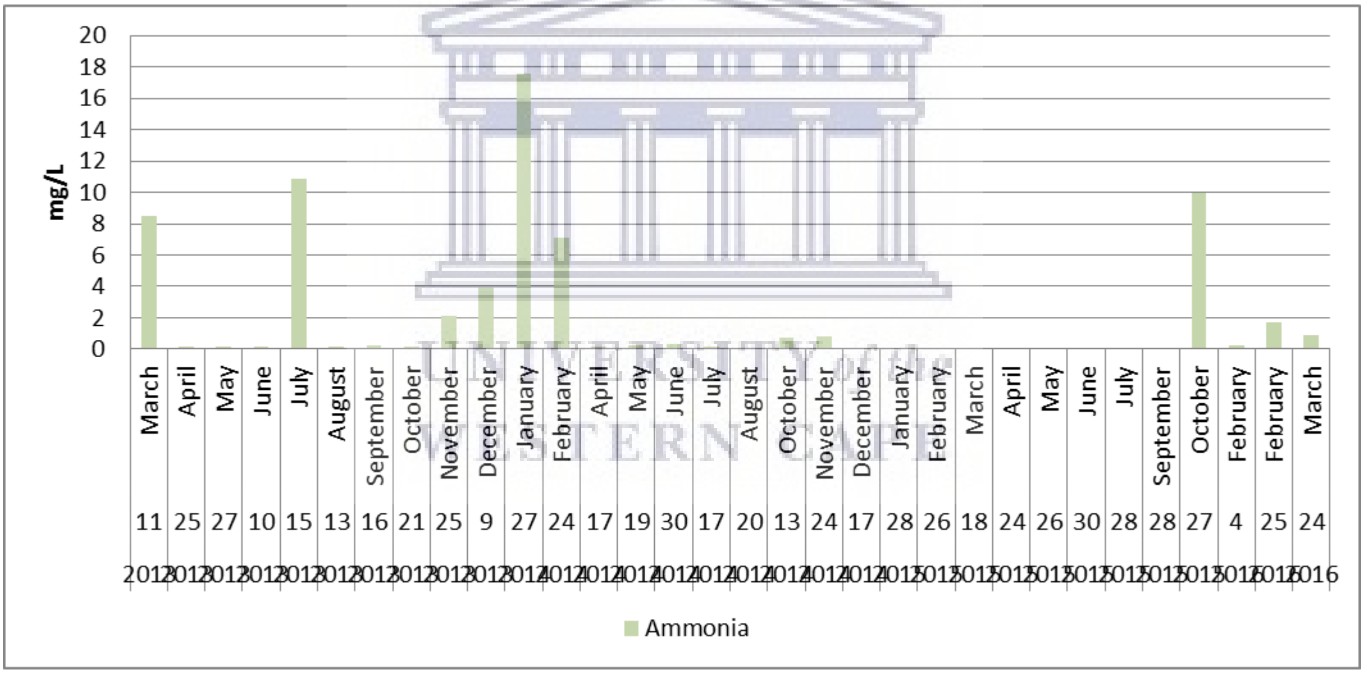

Figure 13: Dissolved ammonium concentrations upstream of the Caledon WWTP.

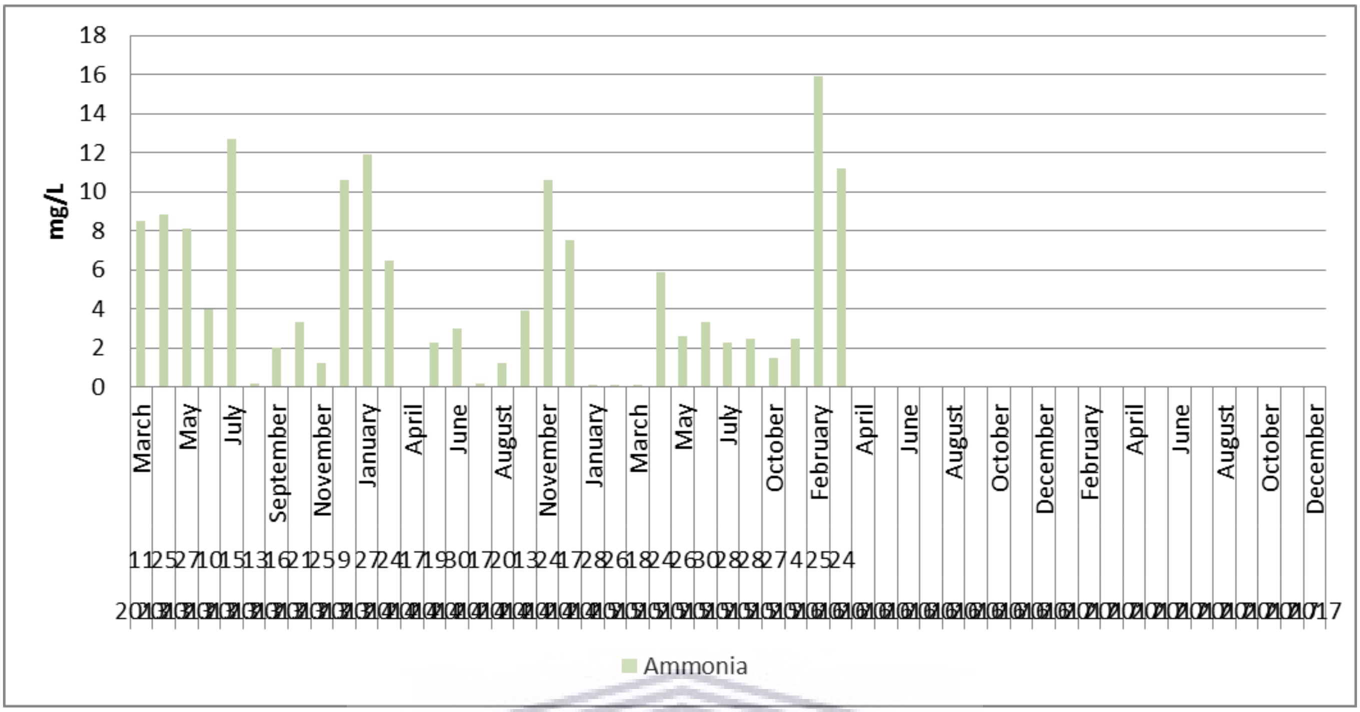

Figure 14: Dissolved ammonium concentrations downstream of the Caledon WWTP.

4.3.6 Faecal coliform

Faecal coliform values for upstream and downstream of the Caledon WWTW for this study are represented in table 3 & 4 and illustrated in Figures 15 & 16. The study revealed that the total faecal coliform count ranged from 43 – 9000 counts/100 ml with a mean of 1335.89 ± 2895.92 counts/100 ml at the upstream point, and from 24 – 4000 counts/100 ml with a mean of 1115.42 ± 1358.39 counts/100 ml at the downstream point.

The highest total faecal value 9000 counts/100 ml recorded in July 2015 and lowest total faecal values of 43 counts/100 ml were recorded in September of 2015 upstream the Bath River (Figure 15 & Appendix B). As for the downstream site, the highest total faecal of 4000 counts/100 ml was recorded in February 2016 and lowest total faecal value of 24 counts/100 ml was recorded in September 2015 (Figure 16 & Appendix C). Throughout the study period, the means concentrations of total faecal fluctuated upstream and downstream the Baths River with values exceeding the DWA waste discharge standards of 1000 counts/100 and other within the limit (Appendixes B & C).

Faecal coliform could be detected in substantial amount during the study period at both sites. This suggested that the high levels of water contamination have continued for many years until when this study was completed. Figure 15, however, indicated a possible direct relationship between the spillages from the sewage pipelines situated upstream of the WWTW (BGCMA, 2013) and the concentration of Faecal coliform. Spillages from busted Caledon pipelines seemed to be among the significant cause of the increased faecal coliform upstream of the Baths River.

The Kolmogorov-Smirnov normality tests showed the pH data are normally distributed among months and years; upstream (df (48), p = .424) and downstream (df (48), p = .478) as determined by one-way ANOVA.There were no statistically significant differences between months (p= 0.169) and between years (p = 0.739) and between sites (p = 0.739) as a whole for the total faecal coliform a concentrations as determined by one-way ANOVA.

4.3.7 *Escherichia coli*

The study revealed that the E. coli count ranged from 0 – 30000 counts/100 ml with a mean of 5790.27± 10109.50 counts/100 ml at the upstream point and from 0 – 30000 counts/100 ml with a mean of 3823.00 ± 7813.07 counts/100 ml at the downstream as shown in Tables 3 and 4. The highest E. coli value (9000 counts / 100 ml) recorded in July 2015 and the lowest E. coli value of 43 counts / 100 ml were recorded in September 2015 upstream of the Bath River (Figure 15 and Appendix B). For the downstream site, the highest E. coli count of 4000 counts / 100 ml was recorded in February 2016 and the lowest E. coli count of 0 counts / 100 ml was recorded in January 2015 (Figure 16 and Appendix C). Throughout the study period, the concentrations in E. coli the upstream and downstream of the Baths River were exceeding DWA wastewater standards of ≤ 100cfu/100 ml (Appendixes B and C) (DWAF, 1996), except for the January 1015 and September 2015 at downstream site. E. coli could be identified considerably during the study period at both sites. This implied that high levels of water contamination have continued for many years until the end of this study.

Figure 15, though, point out a potential direct relationship between WWTW sewer pipe spills (BGCMA, 2013) and E. coli high concentrations upstream the Caledon WWTW. Spilled Caledon sewer pipes appeared to be one of the main causes of the increase in E.

coli upstream of the Baths River. This also indicates that using the river water without treating could pose sequential health hazard to the public. The high concentrations of E. coli present at the upstream and downstream points (Figures 15 & 16) could be attributed to the wastewater containing sanitary wastes from the Caledon pipeline spillage and runoff into the river Baths River, respectively (BGCMA, 2017). When these waters are used as sources of drinking water and the water is not treated or inadequately treated, E. coli may end up in the drinking water transmitting infectious diseases such as cholera, typhoid, hepatitis and cryptosporidiosis (WHO, 1993).

The Kolmogorov-Smirnov normality tests showed the pH data are normally distributed among months and years; upstream (df (48), p = .346) and downstream (df (48), p = .355) as determined by one-way ANOVA. There were no statistically significant differences between months (p= 0.46), between years (p = 0.739) and between sites (p = 0.739) as a whole for E.coli concentrations as determined by one-way ANOVA.

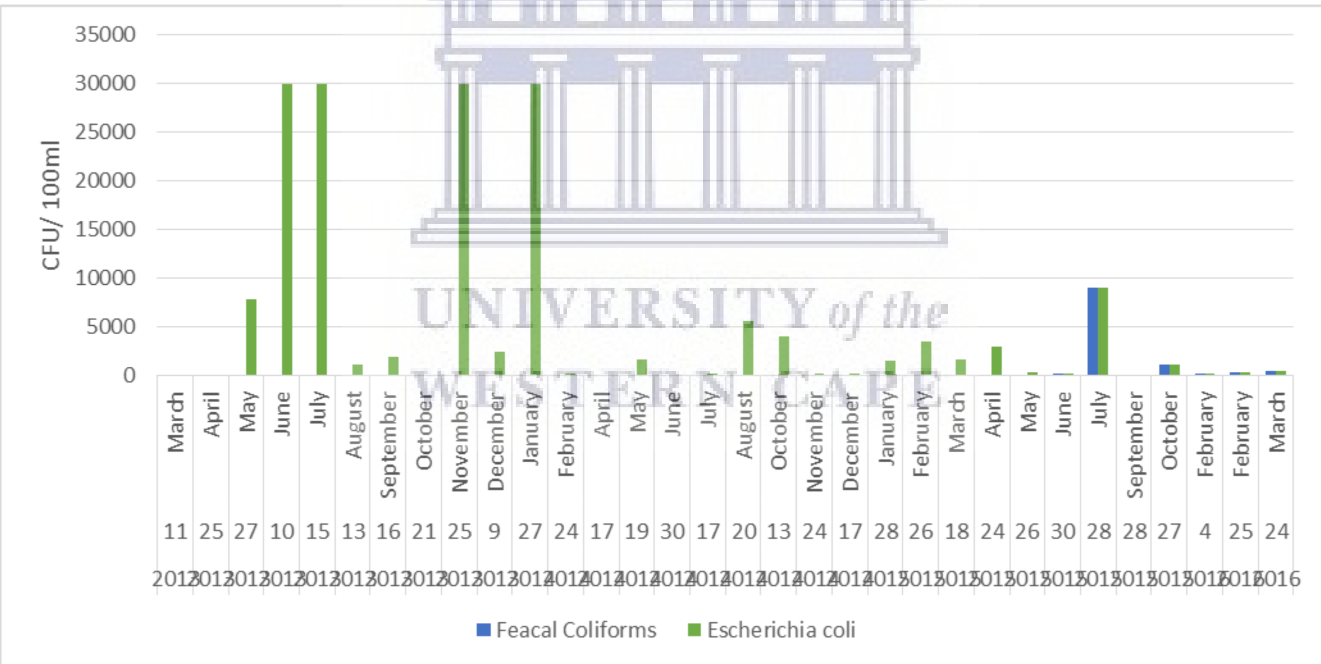

Figure 15: Relationships between Faecal coliform and Escherichia coli variations during the study period upstream of the Caledon WWTW.

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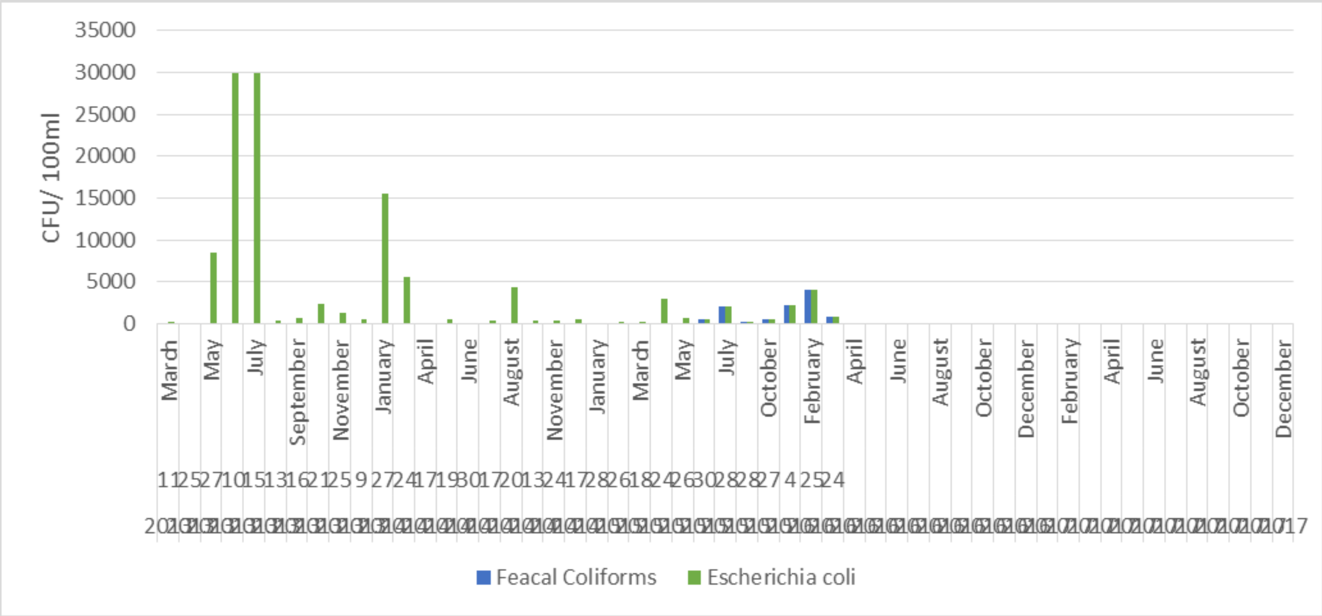

Figure 16: Relationships between Faecal coliform and Escherichia coli variations during the study period downstream of the Caledon WWTW.

4.3.8 Discriminant Analysis

A Pearson product-moment (Table 5) correlation coefficient analysis was performed to assess the relationship between physico-chemical water parameters and biological parameter concentrations spatially and temporally between 2013 and 2016.

Table 5: Pearson 1-tailed correlation matrix for some physico-chemical and biological parameters recorded at the Caledon WWTP and the Bath River during the study period.

Years	Sites	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
2013	Caledon Source	1	.737[a]	.544	-.597	.19962
	Caledon Downstream	1	.861[c]	.741	.309	.19311
	Caledon Upstream	1	.921[a]	.848	.469	.36871
2014	Caledon Source	1	.820[d]	.673	.264	.38342
	Caledon Downstream	1	.944[e]	.890	.	.
	Caledon Upstream	1	1.000[d*]	1.000	1.000	.00000
2015	Caledon Source	1	.335[f]	.112	.	.

	Caledon Downstream	1	.758[g]	.575	.	.
	Caledon Upstream	1	.964[h]	.929	.	.
2016	Caledon Source	1	1.000[i*]	1.000	.	.
	Caledon Downstream	1	1.000[i*]	1.000	.	.
	Caledon Upstream	1	1.000[e*]	1.000	.	.

a. Predictors: (Constant), TSS, Conductivity, E-Coli, Ammonia , COD; b. Dependent Variable: pH; c. Predictors: (Constant), TSS, E-Coli, Ammonia , Conductivity, COD; d. Predictors: (Constant), TSS, Conductivity, Ammonia , E-Coli, COD; e. Predictors: (Constant), TDS; f. Predictors: (Constant), TSS, E-Coli, Ammonia; g. Predictors: (Constant), TSS, Ammonia , Total Coliforms; h. Predictors: (Constant), TSS, E-Coli, Ammonia , Conductivity; i. Predictors: (Constant), TSS, Ammonia). *. Correlation is significant at the 0.05 level (1-tailed).

There were no correlation between water quality parameters upstream, at the source downstream the Caledon WWTW, Pearson's r = .921 and r = .737, r = .861, one-tailed test) in 2013 respectively. This means that the water quality upstream the Caledon has not affected on the water quality downstream the Caledon WWTW in 2013.

The obtained value of Pearson's r =1.000 (Upstream); r = .820 (Caledon source), r = .944, (Caledon downstream), one-tailed test in 2014, suggested that there was no correlation between the water quality of these sites. This means that the water quality upstream the Caledon has not affected on the water quality downstream the Caledon WWTW in 2014.

There were no correlation between water quality parameters upstream, at the source downstream the Caledon WWTW Pearson's r = .964 and r = .335, r = .758, one-tailed test) in 2015 respectively. This means that the water quality upstream the Caledon has not affected on the water quality downstream the Caledon WWTW in 2015.

There were a strong positive correlation between water quality parameters upstream, at the source and downstream the Caledon WWTW Pearson's r = 1.00 one-tailed test in 2016 (Table 5).The water quality upstream might have affected the water at the source and downstream the Caledon WWTW.

A Correlation was as well observed between the water quality upstream of the Caledon WWTW in 2014 and the water quality at the upstream, at the source and downstream the Caledon WWTW in 2016 r = 1.00 one-tailed test. It suggested similar episode of watershed contamination at those sites. It had been reported by the BGMA and the nearby residents of Caledon sewage pipeline spillage which might have trigger the pollution.

4.3.9 Water quality upstream and downstream the Bath River summary

The study was conducted over a four-year period between 2013 to 2016. Some samples covered almost all years from January to December, such as 2013, 2014 and 2015, while others, as in 2016, only covered February to May. The parameters studied to evaluate the water quality of the Bath River in comparison of the effect of the Caledon WWTW were pH, conductivity, suspended solids, ammonia in the form of nitrogen, and chemical oxygen demand, faecal coliform and E. coli.

Some essential parameters such as Total phosphorus, calcium and sodium have not been studied. Our hypothesis was that the problem at Caledon's WWTW was not only the non-performance, but as well link with to the raw sewer pipes that failed upstream of Caledon WWTW that is why more focus were done of biological parameters. All samples and tests were conducted in association with the Breeding Overberg Catchment Management Agency (BGMA) and tested in appropriate laboratories such as A. L. Abbot and Associates PTY Ltd to attest to the reliability of the results. Based on the tables and figures above, the water quality upstream and downstream the Baths River has worsen from 2013 to 2016 (Appendixes B & C).

It is evident that the final effluent from Caledon WWTW together with the spilled raw sewage pipelines upstream the River has been the major cause of that deterioration throughout the study period. The Municipality of Theewaterskloof must be informed of to ensure compliance and prevent further pollution of the receiving environment. The increase in the population in the region, combined with the obsolete Caledon WWTW and low capacity, could be one of the causes of the situation observed. Pollution from wastewater treatment facilities would have a negative impact on downstream users. An action plan must be put in place to remedy this.

4.4 Development of an intervention plan to remedy to the problem of the Caledon WWTW low performance and the Baths River water quality deterioration

It should be noted that two spill incidents have occurred since 2013. It looked like this problem of sewage discharge exacerbated during the period of heavy rain. According to Section 19 of the National Water Act (Act 36 of 1998):

1. “An owner of a land who occupies on which an activity was performed or undertaken which has caused pollution of water pollution must take reasonable measures to prevent such pollution from occurring, continuing or recurring”.

2. The measures referred to in sub-section 1 may include measures to –

a- Cease, modify or control any act or process causing the pollution;

b- Comply with any prescribed waste standards or management practice;

c- Contain or prevent the movement of pollutants;

d- Eliminate any source of the pollution;

e- Remedy the effect of the pollution; and

f- Remedy the effects of any disturbance to the bed and banks of a watercourse”.

Two interventions should be performed in order to resolve the problem of water quality in the Bath River. They consist of renovating the sewer pipelines upstream the Baths River as well upgrading and increasing the capacity of the entire Caledon WWTW.

4.4.1 Rehabilitation of the sewer pipelines upstream the Caledon WWTW

The following table summarise the process of rehabilitating the sewer pipeline upstream the Caledon WWTW.

Table 6: Summary of the renovation process for the Caledon sewer pipeline.

Water use Activities & Purpose	Properties & Dimensions (m)	Co-ordinates	
		Start	End
Replacing the existing sewer pipeline within 500m of Baths River To upgrade the existing sewer pipeline	Portion 16 of the Farm 410 Klip Heuvel, Caledon Dimension-200 mm to 600 mm	34°22’72.73"S 19°40'91.76"E	34°23'36.36"S 19°43'50.62"E
Replacing the existing sewer pipeline within 500m of Baths River To upgrade the existing sewer pipeline	Remainder of Farm 410, Portion 20, Klip Hevel, Caledon Dimention-200 mm to 600 mm	34°20'58.93"S 19°39'12.12"E	34°23'36.36"S 19°43'50.62"E

Water use Activities & Purpose	Properties & Dimensions (m)	Co-ordinates	
		Start	End
Replacing the existing sewer pipeline within 500m of Baths River To upgrade the existing sewer pipeline	Portion Farm of Farm 410 Klip Heuvel, Caledon Dimention-200 mm to 600 mm	34°21'92.79"S 19°39'78.29"E	34°23'36.36"S 19°43'50.62"E
Replacing the existing sewer pipeline within 500m of Baths River and associated wetland features To upgrade the existing sewer pipeline	Remainder of Farm 410, Portion 3, Klip Heuvel, Caledon Dimension-300 mm to 600 mm	34°22'04.43"S 19°40'17.99"E	34°23'36.36"S 19°43'50.62"E
Replacing the existing sewer pipeline within 500m of Baths River and associated wetland features To upgrade the existing sewer pipeline	Remainder of Farm 1, Klip Heuvel, Caledon Dimension-300 mm to 600 mm	34°22'47.24"S 19°40'58.44"E	34°24'47.58"S 19°10'48.37"E
Replacing the existing sewer pipeline within 500m of Baths River and associated wetland features To upgrade the existing sewer pipeline	Remainder of Farm 1, Klip Heuvel, Caledon Dimension 200 mm to 600 mm	34°23'04.08"S 19°41'57.14"E	34°24'47.58"S 19°10'48.37"E
Replacing the existing sewer pipeline within 500m of Baths River and associated wetland features To upgrade the existing sewer pipeline	Remainder of Farm 1, Klip Heuvel, Caledon Dimension 200 to 600mm	34°24'23.91"S 19°42'87.61"E	34°24'47.58"S 19°10'48.37"E
Replacing the existing sewer pipeline within 500m of Baths River and associated wetland features To upgrade the existing sewer pipeline	Farm 68, Klip Heuvel, Caledon Dimension 200mm to 600mm	34°23'66.64"S 19°42'74.09"E	34°24'47.58"S 19°10'48.37"E
Replacing the existing sewer pipeline within 500m of Baths River and associated wetland features To upgrade the existing sewer pipeline	Farm 46, Klip Heuvel, Caledon Dimension 200 mm to 600 mm	34°23'36.36"S 19°43'50.62"E	34°24'47.58"S 19°10'48.37"E

4.4.2 Upgrading of the Caledon WWTW

The upgrading of Caledon WWTW will allow it to comply with legislative frameworks (Section 19 of the National Water Act, Act 36 of 1998).

The Caledon WWWT is located on portion 15 of farm Uitvlugt No.365 and Portion 20 of Farm, Kliephuevel No.410, approximately 3.2 km north-west of the town.
The current works consists of the inlet works, a lime dosing room, a raw sewage lift pump station, a balancing tank, a biological reactor, two clarifiers, four maturations ponds, one Total Sewage Effluent (TSE) irrigation dam, one sludge holding dam, a sludge dewatering building and eight sludge drying bed.

The increase in its capacity to 4.8 ML/day will allow it treats resourcefully domestic and industrial effluent as the treated effluent is discharged into Baths River after it has been disinfected. The irrigation of irrigate 2Ml/day at Blue Crane Golf Estate is essential. The construction of an additional clarifier, additional aeration capacity, chemical disinfection unit, an automatic mains failure generator in close proximity to the raw sewage, lift pump as well as the installation of a parshall flume are mandatory. The water quality in Baths River is poor. This poses a threat to the downstream farmers who use the water for irrigation purposes. Although no boreholes were dug at the site to assess the groundwater quality at the WWTW. Effluent is being disposed by means of gravity drainage from the effluent ponds to an open grass veld area with the drainage path leading to a concrete culvert outlet and into the Bath's River. The upgrade of Caledon Wastewater Treatment Works will lead to an improvement in the water quality in the receiving reaches of the Bath River. The application of drill monitoring boreholes on the" upstream" and "downstream" sides of the WWTW should be done prior to upgrading construction.

4.5 Summary chapter

The chapter discuss the results obtain from 2013 to 2016 while assessing the performance of the Caledon WWTW and the physicochemical and biological properties of the Bath river.
It was found that the Caledon WWTW was not functioning properly and that total coliform and E.coli were the predominant pollutant of its effluent into the Baths River. High means COD, Conductivity and Ammonium at the source also confirmed its poor performance.
The assessment of the physicochemical and biological properties of the Bath River revealed a correlation between the water quality upstream of the Caledon WWTW, the water quality at the source and the water quality downstream. It was found that

downstream water quality was affected by the events upstream Caledon WWTW coupled with the low performance of the Caledon WWTW.

Looking at in the spilled sewer pipelines upstream the Caledon, it could be partially confirmed that our hypothesis was correct. While assessing the performance of the Caledon WWTW, it was found that it was low. Therefore it could be said that the busted sewer pipelines together Caledon WWTW undesirable performance are responsible for the deterioration of the Bath river water quality.

An intervention plan that includes rehabilitation of the sewer pipelines and the upgrades of the Caledon WWTW was proposed to treat efficiently the domestic and industrial waste water in its vicinity.

It should be wise to monitor the water quality in the vicinity of the Caledon WWTW until the intervention plan is initiated .A broad investigation with broad spectrum of the study of water quality parameters is advised on both the Caledon WWTW and along the Baths River to collect data that might help during future interventions.

Chapter 5 Conclusions and recommendations

5.1 Introduction

Multivariate statistical techniques such as discriminant analysis, test for normality and collinearity analysis were used to assess the performance of the Caledon WWTW between 2013 and 2016 by evaluating the selected physical and chemical constituents of its influent and effluent over that period. It was concluded that the Caledon WWTW performances had deteriorated from 2013 to 2016 as it failed over the period of study to reduce the loading of ammonia, COD, electrical conductivity, *E.Coli* into the Baths River.

The physico-chemical and microbiological properties of the Baths River water upstream and downstream the Caledon WWTW were ascertained in comparison to the DWA water quality standards for wastewater effluent discharge. Several of those parameters such as (EC, Ammonia, TSS, and *E.Coli*) did not comply with the DWA water quality standards for wastewater effluent discharge, upstream as well downstream the Baths River.

Mitigation measures that included constant monitoring, strengthening of compliance with the water legislations and rehabilitation of the Caledon WWTW were suggested in order to minimize the impact instigated by unprocessed waste water effluents from the Caledon WWTW into the Baths River and other unknown point and non-point sources of pollution in the Baths River.

5.2 Summary of Results

The parameters studied to assess the performance of Caledon WWTW were pH, conductivity, suspended solids, and ammonia in the form of nitrogen, chemical oxygen demand, total faecal coliform and *E. coli*. The study highlighted that ammonia, E. coli, electrical conductivity and COD were loading high at the source point during the sampling periods. Certain essential parameters such as chlorine, sulphate, calcium, sodium and phosphate were not studied conferring to our hypothesis and because of financial constraints. The problem at Caledon WWTW was not only the non-performance of the WWTW but unforeseen events but as well related to broken raw sewer pipelines upstream of Caledon WWTW that consented with our hypothesis.

The parameters studied to evaluate the water quality of the Bath River in comparison of the DWA water quality standards for wastewater discharge were pH, conductivity, suspended solids, ammonia in the form of nitrogen, chemical oxygen demand, faecal coliform and E. coli. There was strong positive spatial correlation for all the seven water quality parameters (ammonia, COD, electrical conductivity, Foecal Coliform, E. coli, pH and suspended solids) analysed through the discriminant analysis. All the seven Parameters were the most significant parameters to discriminate upstream and downstream points in 2016. The study also revealed that the seven water quality parameters (ammonia, COD, electrical conductivity, Foecal Coliform, *E.Coli*, pH and suspended solids) were the most significant parameters to discriminate between upstream and downstream points in 2014.

The mitigation measures suggested reducing the impact initiated by untreated waste water effluents from the Caledon WWTW and the water quality of upstream and downstream the Baths River included continual water quality monitoring along the Baths River, reinforcement of the water legislation in the Caledon municipality and upgrading of Caledon WWTW. The increase the Caledon WWTW capacity to 4.8 ML/day will allow it treats resourcefully domestic and industrial effluent as the treated effluent is discharged into Baths River after it has been disinfected. The restoration of the sewer pipelines upstream the Caledon WWTW will stop raw sewage from entering the bath river therefore reducing the total population into the River.

5.3 Conclusions and recommendations on the performance of the Caledon WWTW

It is apparent that the final Caledon effluent from Caledon WWTW during the study period did not meet the general DWA standards for wastewater treatment discharge and has deteriorated from 2013 to 2016. The quality of the water at the source and downstream of the wastewater discharge points has decreased in quality, which supports our hypothesis.

The Municipality of Theewaterskloof to which the Caledon WWTW belongs must be informed of what will be done as to guarantee compliance with waste water discharge legislations and avoid additional pollution of the receiving environment.

The increase in the population in the region, combined with the obsolete Caledon WWTW and low capacity, could be one of the causes of the situation observed. Pollution from wastewater treatment facilities would have a negative impact on downstream users. An action plan must be put in place to remedy this situation.

The study was also limited in data of some set of physicochemical parameters. This study recommends further studies to focus on evaluating the impact of phosphorus, fluoride, sodium, and heavy metals discharged from the plant on the water of the Baths River.

5.4 Conclusions and Recommendations on the Physico-Chemical Water Quality upstream and downstream the Baths River

Among the seven physico-chemical water quality parameters studied , electrical conductivity (EC) and E. Coli were loading high upstream and downstream of the Bath River as compared with the water quality compliant values for discharge waste water effluent by the DWA. Based on those results it could be concluded that, electrical conductivity and E. coli were the most significant water quality parameters at those points. There was deterioration in water quality, at the source and downstream of the wastewater discharge points in the Baths River than upstream due to a discharge effluent from the wastewater treatment plant in Caledon down and the accumulation effect of the downstream release which supported our hypothesis.

Agricultural activities upstream the Caledon WWTW could have explained the increase EC. As for the high E. coli content unforeseen events may be the cause of it.

Continual water quality monitoring along the Baths River should be implemented. The monitoring plan should be focused on electrical conductivity (EC) and *E. Coli* and as well be extended to other parameters such as phosphorus; Nitrogen, Calcium, Sodium and fluoride and that could not be studied due to financial constraints. Besides heavy metals, other organic pollutants especially the emerging pollutants need to be evaluated as there are agricultural activities upstream the Caledon WWTW. This will give a comprehensive assessment of the performance of the wastewater treatment process as well a complete water quality status of the Baths River upstream and downstream the Caledon WWTW.

5.5 Conclusions and Recommendations on Mitigation Measures to be Implemented in the Study Area

A water monitoring plan that include the evaluation all the point source and non-point source of pollution in the Bath River should be implemented upstream and downstream the river. This continual water quality monitoring should be done throughout the year and extended to other water quality parameters as to produce a comprehensive assessment of the water quality status of the Baths River.

Water quality legislations in the study area should be reinforced to prevent further pollution of the water system in the area. According to Section 19 of the National Water Act (Act 36 of 1998): "An owner of a land who occupies on which an activity was performed or undertaken which has caused pollution of water pollution must take reasonable measures to prevent such pollution from occurring, continuing or recurring". The Caledon Municipality should comply with law, and take necessary action prevent this contamination from occurring, continuing or recurring.

Two interventions should be made to address the water quality problem of the Bath River. This should involve the improvement of the sewer pipelines upstream of the Baths River, as well as upgrading and increasing the capacity of the entire Caledon WWTW. The renovation of Caledon WWTW will enable it to comply with the legislative frameworks (Section 19 of the National Water Act, Act 36 of 1998).

5.6 Surprising Results

It has been noted that two spill raw sewage incidents have occurred since 2013 in the Caledon area upstream the Baths River. It appeared that this problem of wastewater discharge was exacerbated during the period of heavy rains from 2013 up to 2016. It could explain the high levels of EC, Total Foecal Coliform and *E.coli* upstream and downstream the Bath River. This confirm our problem statement that there were recurrent spillages from the sewage pipeline which were situated upstream of the Caledon WWTW. At every raining episode, the pipelines became blocked and there were raw sewage into the Bath River. This therefore concluded that water quality monitoring strategy for the summer and winter season should be the same and a similar pattern should also be used for the autumn and spring seasons.

Broken sewage pipelines should be replaced or repaired. An entire screening of all the sewage pipelines around the Caledon WWTW should be performed to evaluate which one need restoration.

References

Agoro, M.A, Okoh, O.O., Adefisoye, M.A. and Okoh, A.I. 2018. Physicochemical Properties of Wastewater in Three Typical South African Sewage Works.Polish *Journal of Environmental Studies,* ***27****(2):491-499.*

Agyemang, E.O., Awuah, E., Darkwah, L., Arthur, R. and Osei, G. 2013. Water quality assessment of a wastewater treatment plant in a Ghanaian Beverage Industry. *International Journal of Water Resources and Environmental Engineering*, ***5****(5):272-279.*

Ashbolt, N.J. 2015. Microbial Contamination of Drinking Water and Human Health from Community Water Systems. *Current Environmental Health Report,* ***2****(1): 95-106*. doi: 10.1007/s40572-014-0037-5.

BGCMA (Breede-Gouritz Catchment Management Agency). 2017. PERIOD: March 2013 to March 2016 Surface Water Quality Monitoring ReportCaledon WWTW. Internal communication.

Boyd, C.E. 2015. Water Quality: An Introduction. Second edition. Springer Publishers, London.

Botai, C.M., Botai, J.O., Dlamini, L.C., Zwane, N.S. and Phaduli.E. 2016. Characteristics of Droughts in South Africa: A Case Study of Free State and North West Provinces. *Water,* ***8****: 439*. doi:10.3390/w8100439

Dallas, H.F. and Day, J.A. 2004. The Effect of Water Quality Variables on Aquatic Ecosystems: A Review. Water Research Commission. Report No. TT224/04.

Day, J.A. and King, J.M. 1995. Geographical patterns and their origins, in the dominance of major ions in South African rivers. *South African Journal of Sciences,* ***91****: 299-306.*

DEA (Department of Environmental Affairs). 2014. National Guideline for the discharge of effluent from Land-based source into the coastal Environment. Pretoria, South Africa. RP101/2014.

DEADP (Department of Environmental Affairs and Development Planning). 2011. Western Cape IWRM Action Plan: Status Quo Report Final Draft. Chapter 10: The Gouritz WMA. 263-286. Western Cape Provincial Government, Cape Town.

Plessis, J.A. and Schloms, B. (2017). An investigation into the evidence of seasonal rainfall pattern shifts in the Western Cape, South Africa .*Journal of South. African Institute of Civil Engineering,* ***59****(4)*.

Dos Santos, S., Adams, A.E.A., Neville, G., Wada, Y., de Sherbinin, A., Mullin Bernhardt, E. and Adamo, B. 2017. Urban growth and water access in sub-Saharan Africa: Progress, challenges, and emerging research directions.*Science of The Total Environment, (****607- 608****): 497-508.*

Dufour, A.P., Strickland, E.R. and Cabelli, V.J.1981. Membrane filter method for enumerating Escherichia coli. *Applied and environmental microbiology,* ***41****(5), pp.1152-1158.*

Dungeni, M., van der Merwe, R.R. and Momba, M. 2010. Abundance of pathogenic bacteria and viral indicators inchlorinated effluents produced by four wastewater treatment plants in the Gauteng Province, South Africa. *Water SA,* ***36****(5).*

DWA (Department Of Water Affairs, South Africa). 2012. Green Drop Progress Report. Chapter 13: Western Cape Province. 398-45.

DWA (Department Of Water Affairs). 2013. Green Drop Final Report of 2013. Volume 2 .Department of Public Works. Wastewater Systems. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry).1984. General and Special Standards. Regulation No. 991 18 May 1984. Government Gazette No.9225.

DWAF (Department of Water Affairs).1996. Water quality guidelines for South Africa: Recreational Water Use. 2nd Edition. Pretoria.

DWAF (Department Of Water Affairs and Forestry). 2004a. Breede River Basin Study. Reports and GIS Data. Directorate of National Water Resource Planning, Pretoria.

DWAF (Department of Water Affairs and Forestry).2004b. Breede Water Management Area: Internal Strategic Perspective. Directorate Water Resource Planning. Pretoria.

DWAF (Department of Water Affairs and Forestry). 2005. Breede River Ecological Water Requirements Study. Riverine RDM Report. Pretoria.

DWS (Department of Water and Sanitation). 2014. The National State of Water Resources Quarterly Report July to September 2014. Submitted by Kwazikwakhe Majola. Approved by Moloko Matlala. Republic South Africa.

DWS (Department of Water and Sanitation). 2018. National Water and Sanitation Master Plan. Volume 1: Call to Action. Version 8.3. Ready for the Future and Ahead of the Curve18 January 2018 .Republic South Africa.

Englert, D.; Zubrod, J.P., Schulz, R. and Bundschuh, M. 2013. Effects of municipal wastewater on aquatic ecosystem structure and function in the receiving stream. *Science of the Total Environment,* ***454-455***(0)*:401-410.*

Friedler, E., Butler, D. and Alfiya, Y. 2013. Wastewater composition. Source Separation and Decentralization for Wastewater Management.TA Larsen, KM Udertand J.Lienert (eds.), IWA Publishing, London, UK, pp. 241-257.

Jackson, M.C., Weyl, O.L.F., Altermatt, F., Durance,I., Friberg,N., Dumbrell, A.J., Piggott, J.J. , Tiegs, S.D., Tockner, K., Krug, C.B., Leadley, P.W. and Woodward, G . 2016. Chapter, Twelve - Recommendations for the Next Generation of Global Freshwater Biological Monitoring Tools. *Advance Ecology Research,* ***55****: 615-636****.***

Jordaan, K. and Bezuidenhout, C.C. 2016. Bacterial community composition of an urban river in the North West Province, South Africa, in relation to physico-chemical water quality.*Environmental Science and Pollution Research ,****23****: 5868.*

Kaselowski, T.and Adams, J.B. 2013. Not so pristine - characterising the physico-chemical conditions of an undescribed temporarily open/closed estuary. *Water SA,* ***39****(5): 627-636.*

Gopo, Q.N. 2013. Regulation of wastewater treatment plants in the Ba-Phalaborwa Municipality. Unpublished MSc, North-West University.

Grady, J.R., Daigger, G.T., Love, N.G., Filipe, C.D. and Grady, C.L. 2011. Biological wastewater treatment. IWA Publishing.

Gray, N.F. 2005. Water Technology: an Introduction for Environmental Scientists and Engineers. Oxford: Boston Elsevier/Butterworth-Heinemann.

Haile, R.W., White, J.S., Gold, M., Cressey, R. and Mc Gee, C. 1999. The health effects of in ocean water contaminated by storm drain runoff. *Epidemiology, 10: 355-363.*

Henze, M. 2008. Biological Wastewater Treatment: Principles Modelling and Design. Edited by M. Henze, M.C.M. van Loosdrecht, G.A. Ekama and D. Brdjanovic. Published by IWA Publishing, London, UK. ISBN: 9781843391883.

Hodgson, K. and Manus, L. 2006. A drinking water quality framework for South Africa. *Water SA,* ***32****(5):673-678*.

Igbinosa, E. and Okoh, A. 2009. Impact of discharge wastewater effluents on the physico-chemical qualities of a receiving watershed in a typical rural community. *International Journal of Environmental Science and Technology,* ***6****(2):175-182.*

Lapara, T.M., Alleman, J.E. and Pope, P.G. 2000. Miniaturized closed reflux, colorimetric method for the determination of chemical oxygen demand. *Waste Management,* ***20****(4):295-298.*

Liberti, L., Lopez. A, Notarnicola, M., Barnea, N., Pedahzur, R. and Fattal, B. 2000.Comparison of advanced disinfecting methods for municipal wastewater reuse in agriculture. *Water Science and Technology,* ***42****:215-220.*

Lokhande, R.S., Singare, P.U. and Pimple, D.S. 2011. Toxicity study of heavy metals pollutants in waste water effluent samples collected from Taloja industrial estate of Mumbai, India. *Resources and Environment,* ***1****(1):13-19.*

Mamabolo, M.F. 2012. Effects of cooperative governance in the sewage treatment works in the upper Vaal River. Unpublished MSc,North West University.

Mothetha, L.M. 2016. Evaluation of the Impacts of Municipal Wastewater Treatment On The Receiving Environment: A Case Study of the Olifantsvlei Wastewater Treatment Plant in the Gauteng Province, South Africa. Unpublished MSc, University of South Africa, March 2016.

Naidoo, S. and Olaniran, A.O. 2014. Treated wastewater effluent as a source of microbial pollution of surface water resource. *International Journal of Environmental Research and Public Health,* ***11****: 249 -270.*

NWRS (National Water Resource Strategy). 2004. Chapter 2 - South Africa’s Water Situation and Strategies to Balance Supply And Demand. First Edition, September 2004.

Oberholster, P.J. and Botha, A.M. 2010. Use of remote sensing and molecular markers to detect toxic cyanobacterial hyperscum crust: A case study on Lake Hartbeespoort, South Africa. *African Journal of Biotechnology*, ***9****: 8791-8799.*

O’dell, J.W. 1993. The determination of Carbon Oxygen Demand by Semi- Automated Colorimetric. Environmental Monitoring System laboratory office of Research and Development U.S. Environmental Protection Agency Cincinnati,
Ohio 45268, Method 410.4-1.

Odjadjare, E.E., Obi, L.C. and Okoh, A.I. 2010. Municipal wastewater effluents as a source of listerial pathogens in the aquatic milieu of the Eastern Cape Province of

South Africa: A concern of public health importance. International journal of environmental research and public health, 7(5):2376-2394.

Owuor, K., Okonkwo; J., Van Ginkel, C.E., and Scot.W. 2007. Environmental factors affecting the persistence of toxic phytoplankton in the Hartbeespoort Dam.WRC ReportNo.1401/3/07.Pretoria.

Oliver,T.H.,Heard,M.S.,Isaac,J.B.,Roy,D.B., Procter,D., Eigenbrod,F., Freckleton,R., Hector,A., Orme,D.L., Petchey,O.L., Proença,V., Raffaelli,D., Suttle,K.B., Mace,G.M., Martín-López,B., Woodcock,A.B.and Bullock,J.M.2015. Biodiversity and Resilience of Ecosystem Functions. *Trends in Ecology & Evolution, **30**(11): 673-684.*

Pienaar, A., Brent, A.C., Musango, J.K. and de Kock, I.H. 2017. Water Resource Infrastructure Implications of a Green Economy Transition in the Western Cape Province of South Africa: A System Dynamics Approach. *South African Journal of Industrial Engineering, **28**(2):78-94.*

Pillay, L. and Olaniran, A. 2016. Assessment of physicochemical parameters and prevalence of virulent and multiple-antibiotic-resistant Escherichia coli in treated effluent of two wastewater treatment plants and receiving aquatic milieu in Durban, South Africa. *Environmental Monitoring and Assessment, **188**(5).*DOI:10.1007/s10661-016-5232-4

Radojevic, M. and Baškin, V.N. 1999. Practical environmental analysis. Royal Society of Chemistry.

RHP (River Health Programme). 2007. State of Rivers Report: Rivers of the Gouritz Water Management Area. Department of Water Affairs and Forestry, Pretoria.

RHP (River Health Program). 2011. The River of the Breede Management Area. State of the Rivers Report. Pretoria.

Ritter, J.A. 2010. Water Quality. 4th edition. Printed in the United States of America.

Rizzardini, C.B. and Goi, D. 2014. Sustainability of Domestic Sewage Sludge Disposal. *Sustainability, **6**: 2424-2434.*

Rogers, P. and Leal, S. 2010. Running Out Of Water. Palgrave. Macmillan USA.

Schulze, R.E. and Lynch, S.D. 2006. Annual Precipitation, In R.E. Schulze. ed. 2006. South African Atlas of Climatology and Agrohydrology, Water Research Commission, Pretoria, South Africa, WRC Report 1489/1/06, Section 6.2.

Seanego, K.G.and Moyo, N.A.G. 2013. The effect of sewage effluent on the physico-chemical and biological characteristics of the Sand River, Limpopo, South *Africa. Physics and Chemistry of the Earth,* ***66****:75-82.*

Singh, U. and Kausual, R.K. 2013. Treatment of wastewater with low cost adsorbent – a review. VSRD International Journal of Technical & Non-Technical Research, 4, pp. 2319-2216. e-ISSN: 0976-7967

Sibanda, T., Selvarajan, R. and Tekere, M. 2015. Urban effluent discharges as causes of public and environmental health concerns in South Africa's aquatic milieu. *Environmental Science and Pollution Research,* ***22****(23):18301-18317.*

SRK Consulting. 2010. Caledon Waste Water Treatment Works. Hydrogeological Investigation. Report Prepared for The Blue Crane Signature Golf Estate and Theewaterskloof Municipality. Compiled by L.J., Groenewald. Report No 406594/1.Febrauary 2010.

Stalder, T., Barraud, O., Casellas, M., Dagot, C. and Ploy, M.C. 2012. Integron involvement in environmental spread of antibiotic resistance. Frontier in Microbiology. 3:119. doi: 10.3389/fmicb.2012.00119.

Tempelton, M.R. and Butler, D. 2011. An Introduction to Wastewater Treatment. Ventus Publishing UK.

Tchobanoglous, G. Burton, F.L. and Stensel, H. D. 2004. Wastewater EngineeringTreatment and Reuse. Mc-Graw Hill. New York.

Trivedi, R. C., Bhardwaj, R.M. and Agrawal, S. 2008. Biological Monitoring of Water Quality in India-Needs and Constraints. Proceeding of Taal 2007/2008, pp.1-6.

USEPA (United States Environmental Protection Agency). 2004. Primer for municipal wastewater treatment systems. United States Environmental Protection Agency. EPA 832-R-04-001.

Wanda, E.M.M., Mamba, B.B. and Msagati, T.A.M. 2016. Determination of the water quality index ratings of water in the Mpumalanga and North West provinces, South Africa. Physics and Chemistry of the Earth, Parts A/B/C, 92:70-78.

Wamsley, RD. 2000. Perspective on eutrophication of surface waters; Policy/research needs in South Africa. WRC Report No. KV129/00.

Water 21. 2011. Of droughts and flooding rains: riparian adaptation to climate. Change. October 2011. International Water Association. London. UK.

WEF (Water Environment Federation). 2008. Operation of Municipal Wastewater Treatment Plants. Volume 3: Solids Processes. McGraw-Hill. New York.

Wilcox, J., Nasiri, F., Sarah Bell, S., and Saifur Rahaman, M. 2016. Urban water reuse: A triple bottom line assessment framework and review. *Sustainable Cities and Society* ***27:****448–456.*

Wilson, P.C. 2010. Water Quality notes: Water Clarity (Turbidity, Suspended solids and Color). University of Florida. http://edis.ifas.ufl.edu/pdffiles/SS/SS52600.pdf [Accessed date: 03/04/2018].

WISA (Water Institute of Southern Africa). 2002. Handbook for the Operation of Wastewater Treatment Works.

WHO (World Health Organization). 2003. Ammonia in drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality. Geneva, World Health Organization (WHO/SDE/WSH/03.04/01).

WHO (World Health Organization). 2008. Guidelines for Drinking-water Quality (Electronic Resource): Incorporating 1st and 2nd Addenda, Volume 1, Recommendations, 3rd ed.; World Health Organization: Geneva, Switzerland, 2008.

WRC (Water Research Commission). 2006. Handbook for the Operation of Water Treatment Works. TT 265/06.

Zhanga, F., Xuea, H., Maa, X. and Wanga, H. 2017. Grey Prediction Model for the Chemical Oxygen Demand Emissions in Industrial Waste Water: An Empirical Analysis of China. 13th Global Congress on Manufacturing and Management, GCMM 2016. *Procedia Engineering,* ***174****: 827- 834.*

Appendixes

Appendix A: Raw Data Caledon WWTW source

Area	Sampling Point	Year	Day	Month	pH	Conductivity	Ammonia	Chemical Oxygen Demand	Feacal Coliforms	Escherichia coli	Total Suspended Solids
Caledon 1	Caledon at Source	2013	11	March	7.97	226	38.5	245		28	90
Caledon 1	Caledon at Source	2013	25	April	7.85	121	22.1	164			15
Caledon 1	Caledon at Source	2013	27	May	8.16	203	48.9	120		10500	7
Caledon 1	Caledon at Source	2013	10	June	7.99	204	44.6	128		410	9
Caledon 1	Caledon at Source	2013	15	July	7.93	185	57.8	112		410	5
Caledon 1	Caledon at Source	2013	13	August	7.63	206	27.4	168		2400	15
Caledon 1	Caledon at Source	2013	16	September	7.73	172	38.2	192		170	6
Caledon 1	Caledon at Source	2013	21	October	7.77	192	42	205		2100	48
Caledon 1	Caledon at Source	2013	25	November	7.96	151	26.4	141		60	19
Caledon 1	Caledon at Source	2013	9	December	7.74	194		181		1200	34
Caledon 1	Caledon at Source	2014	27	January	8.2	205	26.9	158		5100	38
Caledon 1	Caledon at Source	2014	24	February	8.7	245	0.15	239		1600	21
Caledon 1	Caledon at Source	2014	17	April	7.65	194	20.9	135			7
Caledon 1	Caledon at Source	2014	19	May	7.6	110	20.9	185		5000	50
Caledon 1	Caledon at Source	2014	30	June	7.77	187	20.7	136			22

Caledon 1	Caledon at Source	2014	17	July	7.37	193	16.5	108		230	5
Caledon 1	Caledon at Source	2014	20	August	7.64	198	34.3	144		500	12
Caledon 1	Caledon at Source	2014	13	October	7.3	182	35.8	161		350	33
Caledon 1	Caledon at Source	2014	24	November	7.39	173	45.5	50.1		140	8
Caledon 1	Caledon at Source	2014	17	December	8.23	89.5	29	135		160	14
Caledon 1	Caledon at Source	2015	28	January	7.58	179	39.9	219		8600	13
Caledon 1	Caledon at Source	2015	26	February	7.85	222	0.1	145		3400	36
Caledon 1	Caledon at Source	2015	18	March	8.33	245	7.8	179		900	50
Caledon 1	Caledon at Source	2015	24	April	7.38	201	11.6	130		3000	24
Caledon 1	Caledon at Source	2015	26	May	7.29	205	20.3	129		380	38
Caledon 1	Caledon at Source	2015	30	June	7.39	187	13.4	94	1200	1200	4
Caledon 1	Caledon at Source	2015	28	July	7.52	173	7.1	95.1	560	560	12
Caledon 1	Caledon at Source	2015	28	September	7.8	172	21.3	107	13	13	5
Caledon 1	Caledon at Source	2015	27	October	8.23	206	21.9	132	130	130	10
Caledon 1	Caledon at Source	2016	4	February	8.42	290	6.6	250	30000	30000	86
Caledon 1	Caledon at Source	2016	25	February	8.39	250	18	195	300	300	11
Caledon 1	Caledon at Source	2016	24	March	7.89	204	33.4	242	340	340	56

*Shaded data represent maximum and minimum positive values for each water quality parameter. Empty cases mean no values were obtained for that specific water quality.

Appendix B: Raw Data Caledon WWTW upstream

Area	Sampling Point	Year	Day	Month	pH	Conductivity	Ammonia	Chemical Oxygen Demand	Feacal Coliforms	Escherichia coli	Total Suspended Solids
Caledon	Caledon Upstream of WWTW	2013	11	March	7.83	199	8.5	61.6		18	4
Caledon	Caledon Upstream of WWTW	2013	25	April	7.57	39.2	0.15	29.2			5
Caledon	Caledon Upstream of WWTW	2013	27	May	7.71	51.4	0.15	20.1		7900	7
Caledon	Caledon Upstream of WWTW	2013	10	June	7.15	96.2	0.15	73.7		30000	10
Caledon	Caledon Upstream of WWTW	2013	15	July	6.14	87	10.9	355		30000	84
Caledon	Caledon Upstream of WWTW	2013	13	August	7.7	114	0.15	51.2		1200	16
Caledon	Caledon Upstream of WWTW	2013	16	September	7.54	75.5	0.25	79.9		1917	5
Caledon	Caledon Upstream of WWTW	2013	21	October	7.52	56.1	0.15	54.6		0	62
Caledon	Caledon Upstream of WWTW	2013	25	November	7.06	63	2.1	52.6		30000	18
Caledon	Caledon Upstream of WWTW	2013	9	December	6.99	75.9	3.9	36.9		2500	18
Caledon	Caledon Upstream of WWTW	2014	27	January	6.76	69	17.6	93.6		30000	32
Caledon	Caledon Upstream of WWTW	2014	24	February	6.96	64.5	7.1	60.9		230	6
Caledon	Caledon Upstream of WWTW	2014	17	April	6.72	54.4	0.15	32.8			8
Caledon	Caledon Upstream of WWTW	2014	19	May	6.82	38.5	0.2	31.4		1700	5
Caledon	Caledon Upstream of WWTW	2014	30	June	7.58	166	0.3	47.8			5
Caledon	Caledon Upstream of WWTW	2014	17	July	7.19	93	0.15	37		300	8
Caledon	Caledon	2014	20	August	7.48	76.5	0.1	40		5600	35

	Upstream of WWTW										
Caledon	Caledon Upstream of WWTW	2014	13	October	6.86	45.9	0.75	38.9		4000	5
Caledon	Caledon Upstream of WWTW	2014	24	November	6.83	51	0.85	40.8		270	69
Caledon	Caledon Upstream of WWTW	2014	17	December	7.3	49	0.1	29.8		220	7
Caledon	Caledon Upstream of WWTW	2015	28	January	6.88	52	0.1	76		1500	160
Caledon	Caledon Upstream of WWTW	2015	26	February	6.95	48.1	0.1	12.9		3500	22
Caledon	Caledon Upstream of WWTW	2015	18	March	7.77	43	0.1	11.5		1700	20
Caledon	Caledon Upstream of WWTW	2015	24	April	6.74	48	0.1	11.4		3000	34
Caledon	Caledon Upstream of WWTW	2015	26	May	7.21	53.5	0.1	16.3		340	22
Caledon 3	Caledon Upstream of WWTW	2015	30	June	7.07	135	0.1	33.5	200	200	4
Caledon 3	Caledon Upstream of WWTW	2015	28	July	7.02	69	0.1	55.8	9000	9000	40
Caledon 3	Caledon Upstream of WWTW	2015	28	September	7.3	51.1	0.1	24.3	43	43	34
Caledon 3	Caledon Upstream of WWTW	2015	27	October		55	10	12	1200	1200	0.1
Caledon 3	Caledon Upstream of WWTW	2016	4	February	7.31	96.5	0.28	29.5	240	240	9
Caledon 3	Caledon Upstream of WWTW	2016	25	February	7.89	98.5	1.7	25.5	350	350	5
Caledon 3	Caledon Upstream of WWTW	2016	24	March	7.56	74	0.91	10.8	490	490	6

*Shaded data represent maximum and minimum positive values for each water quality parameter. Empty cases mean no values were obtained for that specific water quality.

Appendix C: Raw Data Caledon WWTW downstream

Sampling Point	Year	Day	Month	pH	Conductivity	Ammonia	Chemical Oxygen Demand	Feacal Coliforms	Escherichia coli	Total Suspended Solids
Caledon Downstream of WWTW	2013	11	March	7.83	199	8.5	61.6		18	4
Caledon Downstream of WWTW	2013	25	April	7.58	113	8.8	69.2			6
Caledon Downstream of WWTW	2013	27	May	7.7	80	8.1	47.1		8500	7
Caledon Downstream of WWTW	2013	10	June	7.35	112	4	56.3		30000	11
Caledon Downstream of WWTW	2013	15	July	7.07	134	12.7	248		30000	12
Caledon Downstream of WWTW	2013	13	August	7.73	124	0.15	61.6		420	12
Caledon Downstream of WWTW	2013	16	September	7.41	118	2	106		690	7
Caledon Downstream of WWTW	2013	21	October	7.46	65.5	3.3	55.8		2400	34
Caledon Downstream of WWTW	2013	25	November	7.72	77.5	1.2	52.6		1300	15
Caledon Downstream of WWTW	2013	9	December	7.37	91.5	10.6	57		460	10
Caledon Downstream of WWTW	2014	27	January	7.2	102	11.9	71.9		15600	23
Caledon Downstream of WWTW	2014	24	February	7.5	76.8	6.5	55.6		5500	16
Caledon Downstream of WWTW	2014	17	April							
Caledon Downstream of WWTW	2014	19	May	7.35	109	2.3	64.7		520	12
Caledon Downstream of WWTW	2014	30	June	7.7	128	3	58.3			7
Caledon Downstream of WWTW	2014	17	July	7.03	121	0.15	59.2		380	5
Caledon Downstream of	2014	20	August	7.5	120	1.2	55.1		4300	14

WWTW										
Caledon Downstream of WWTW	2014	13	October	6.8	92.5	3.9	52.7		350	8
Caledon Downstream of WWTW	2014	24	November	7.15	99.5	10.6	83.9		360	8
Caledon Downstream of WWTW	2014	17	December	7.48	96	7.5	62.4		540	6
Caledon Downstream of WWTW	2015	28	January	7.79	77	0.1	27.6		0	10
Caledon Downstream of WWTW	2015	26	February	7.31	79	0.1	44.3		4	20
Caledon Downstream of WWTW	2015	18	March	7.25	178	0.1	94.7		230	9
Caledon Downstream of WWTW	2015	24	April	7.3	162	5.9	94.3		3000	10
Caledon Downstream of WWTW	2015	26	May	7.2	116	2.6	50.4		630	16
Caledon Downstream of WWTW	2015	30	June	7.34	155	3.3	67.4	510	510	10
Caledon Downstream of WWTW	2015	28	July	7.29	89.5	2.3	60.3	2000	2000	13
Caledon Downstream of WWTW	2015	28	September	7.7	103	2.5	47.4	24	24	23
Caledon Downstream of WWTW	2015	27	October	8.12	91	1.5	21.2	500	500	4
Caledon Downstream of WWTW	2016	4	February	7.45	119	2.5	73.6	2200	2200	27
Caledon Downstream of WWTW	2016	25	February	8.29	260	15.9	171	4000	4000	5
Caledon Downstream of WWTW	2016	24	March	7.66	146	11.2	123	780	780	29

*Shaded data represent maximum and minimum positive values for each water quality parameter. Empty cases mean no values were obtained for that specific water quality.

Appendix D: Kolmogorov-Smirnov Tests of Normality

Tests of Normality				
	es	Kolmogorov-Smirnov		
		Statistic	df	Sig.
pH	Caledon Source	.388	46	.000
	Caledon Downstream	.344	48	.000
	Caledon Upstream	.346	48	.000
Conductivity	Caledon Source	.252	46	.000
	Caledon Downstream	.241	48	.000
	Caledon Upstream	.181	48	.000
Ammonia	Caledon Source	.203	46	.000
	Caledon Downstream	.223	48	.000
	Caledon Upstream	.377	48	.000
COD	Caledon Source	.204	46	.000
	Caledon Downstream	.195	48	.000
	Caledon Upstream	.267	48	.000
Total Coliforms	Caledon Source	.470	46	.000
	Caledon Downstream	.478	48	.000
	Caledon Upstream	.424	48	.000
E-Coli	Caledon Source	.359	46	.000
	Caledon Downstream	.355	48	.000
	Caledon Upstream	.346	48	.000
TSS	Caledon Source	.225	46	.000
	Caledon Downstream	.241	48	.000
	Caledon Upstream	.287	48	.000

*The mean difference is significant at the 0.05 level.