ASSESSMENT OF THE IMPACT OF WASTEWATER TREATMENT PLANT DISCHARGES AND OTHER ANTHROPOGENIC VARIABLES ON RIVER WATER QUALITY IN THE eTHEKWINI METROPOLITAN AREA.

By

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PREFACE

All of the work presented henceforth is ultimately based on the experimental work conducted in the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Durban (South Africa) – from January 2012 to December 2014 under the supervision of Dr. Srinivasan Pillay.

This dissertation comprises the original intellectual product of the author, Jayseelan Naidoo, and has not been submitted in substance for any other degree or award at this or any other learning institution, nor is it being submitted concurrently for any other degree or award. Information sources and the work of others are duly acknowledged as such.

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DECLARATION - PLAGIARISM

I, Jayseelan Naidoo, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.
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DECLARATION-PUBLICATIONS

The author of this document will be working towards the production of individual research papers from this dissertation, as well as the submission of these papers to the relevant journals for publication.

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ABSTRACT

On a global scale the deterioration in riverine water quality is of great concern since water is one of the most valuable and essential resources that forms the basis of all life.

For South Africa, the declining water quality is of even more importance since the country is located in a semi-arid part of the world with scarce water supplies. The quality of water in many rivers in South Africa continues to deteriorate at unprecedented rates, which affects its availability and use. This situation is quite the same for rivers in the eThekwini Metropolitan Area which is located in Kwazulu-Natal, a coastal province of South Africa.

This study assesses the qualitative impact of wastewater plant discharges from the uMhlatuzana; Northern and KwaMashu Wastewater Treatment Works, on the uMhlatuzana River; uMgeni River and uMhlangane River, respectively. Samples were collected from identified points upstream and downstream of the wastewater discharges and the results were analysed in terms of the t-test statistical technique to identify any significant change in water quality between the upstream and downstream sites. In addition, the samples collected were analysed for physico-chemical and microbiological parameters as respects compliance with the Target Water Quality Guideline Range for aquatic ecosystems (DWAF, 1996); as well as in comparison with the general requirements for purification of wastewater (DWAF, 1984).

The results from the t-test statistical analyses indicated that there was significant difference between the upstream and downstream water quality for the following parameters and sites: pH and permanganate value at the uMgeni River sampling sites; for dissolved oxygen at the uMhlatuzana and uMgeni River sampling sites ; for total dissolved solids, conductivity, chlorides, ammonia; nitrite and nitrates at all sampling sites.

In 50% of the instances there was compliance with the Target Water Quality Guideline Range for aquatic ecosystems (DWAF, 1996). The majority of sites did not meet the general requirements for purification of wastewater (DWAF, 1984); and the results indicate that negative impacts from wastewater discharges occurred in 76% of the instances, while other anthropogenic influences adversely affected water quality in 23% of instances. This study has identified the extent; nature and source of water quality impacts on the rivers and it could serve as a useful tool for rehabilitation and monitoring since it identifies the major source of adverse water quality impacts.

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LIST OF ABBREVIATIONS

COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
E.coli	Escherichia coli
KWWTW	Kwamashu Wastewater Treatment Works
ML/day	Megalitres per day
NWWTW	Northern Wastewater Treatment Works
NWA	National Water Act (No. 36 of 1998)
NWRS	National Water Resource Strategy
pH	Potential of Hydrogen
TDS	Total Dissolved Solids
UKZN	University of KwaZulu-Natal
US-EPA	United States – Environmental Protection Agency
UWWTW	uMhlatuzana Wastewater Treatment Works
WHO	World Health Organization
WISA	Water Institute of South Africa
WRC	Water Research Commission
WWTW	Waste Water Treatment Works

UNITS

cm	Centimetre
km	Kilometre km2 Square kilometre
L	Litre
m	Metre
mg/l	Milligrams per litre
°C	Degrees centigrade
<	Less than
>	Greater than

CHAPTER ONE

INTRODUCTION

1.1 RATIONALE FOR THE STUDY

Without water, life as we know it would not be possible (Ahuja, 1986). Virtually all our daily activities involve the consumption of water in one form or another. However over 80 countries in the world suffer from a water deficit, and an estimated 1.2 billion people drink unclean water (Ahuja, 2009); and global trends indicate that by the year 2025, nearly two billion people will live in regions or countries with absolute water scarcity (Seckler *et al.,* 1999).

South Africa is a water scarce country with complex hydrological conditions that make it very challenging to secure sufficient water for economic growth (Schreiner and Hassan, 2011). Approximately 60 percent of the region is regarded as arid to semi-arid (Nomquphu, 2005). It is the 30th driest country in the world and the intensity of South Africa's water use at 31 percent of the available resources is high by world standards and far greater than other countries in the region (DWAF, 2011). About 65% of the country receives less than 500mm rainfall on average per year, and about 20% receives less than 200mm per year with desert conditions on the far western parts (DWA, 1986). Also, the water quality of rivers in South Africa has deteriorated to the extent that they have been deemed to be of poor quality for human consumption and of limited associated uses. The poor quality is largely due to the discharges of inadequately treated industrial; agricultural and domestic wastewater into rivers as well as other indiscriminate activities. Constitutionally, South Africa has legally enshrined the right to minimum amounts of water as a human right, but supplying this amount to all citizens is turning out to be a difficult task (Rogers and Leal, 2010). This has necessitated the transfer of water into South Africa from neighboring countries. Transferring water from areas having a surplus to those with a deficit has provided a solution to water scarcity (Cyrus *et al.,* 1999). However augmenting water supplies for South Africa from neighboring countries through inter-basin transfers attracts high costs and continued supply is not sustainable, since international arrangements on shared rivers are expected to become a matter of key concern and tension as these countries development needs for more water expand (Schreiner and Hassan, 2011).

These national challenges with respect to water quality, its availability and utilization in South Africa necessitate urgent interventions. Water quality concerns have led to an increasing demand for monitoring of water quality (Antonopoulos *et al.*, 2001). The deterioration in water resources needs to be controlled through effective and feasible concepts of water management (Nhlapi and Gijzen, 2005). Mechanisms to achieve this include, water resource management, the promotion of more efficient municipal, agricultural and industrial water usage and protect the water resource from pollution; however implementation of these reforms is proving to be challenging, given the diverse and complex nature of the country's water resources and their use (DWAF, 2011). There is thus a need to use the existing water supplies effectively and efficiently and changes are needed to sustain urban water and resource management services (Daigger, 2009). The Department of Water Affairs is the custodian of South Africa`s water resources and has initiated various monitoring programs and promulgated a series of laws that regulate all water matters to ensure efficient; effective and sustainable utilization thereof. Compliance with sewage standards is currently a major challenge. These are discussed in the literature survey.

In addressing the national challenges with respect to water availability and utilization in South Africa extensive research has been conducted on the water quality of many rivers in South Africa (DWAF, 2001; Harris *et al.*, 1991; Van Wyk, 2001; Naidoo, 2005; Bezuidenhout *et al.*, 2002). 'The State of the Rivers Report' for the Crocodile, Sabie-Sand and Olifants River System (DWAF, 2001), 'The evaluation of water quality in the Mvoti River' (Harris *et al.*, 1991) and the study of the water quality of the Palmiet River (Naidoo, 2005) also noted that factors and processes influencing water quality are best understood when the catchment is considered as an inter-related system, where catchment activities continuously influence naturally dynamic river systems. With reference to the deteriorating riverine water quality, Bezuidenhout *et al.,* (2002), indicated that continuous fecal pollution in source water is a global problem that is particularly debilitating to rural communities that are directly dependent on untreated source water for all their domestic and other purposes. This baseline study assesses the impacts of wastewater treatment plant discharges and other anthropogenic impacts on the water quality of three specific rivers in the eThekwini Municipal Area namely: the uMhlangane River; the uMgeni River and the uMhlatuzana River. Furthermore this study serves as a tool in proposing remediation and mitigation measures to improve the riverine water quality by identification of pollution impacts and sources. By quantifying the impacts of pollution sources essential information to formulate and implement appropriate pollution strategies can be provided (Van Wyk, 2001).

1.2 RESEARCH AIM

The aims of this study are:

- To determine the impact of wastewater treatment plant discharges on the water quality of the uMhlangane River; the uMgeni River and the uMhlatuzana River and to identify other anthropogenic variables that have an influence on the water quality of these rivers.

1.3 RESEARCH OBJECTIVES

The research objectives are to:

- identify the water quality legislation as promulgated by the Department of Water Affairs and Forestry and compliance thereto;

- determine the water quality upstream and compare it with the water quality downstream of the wastewater treatment works discharge point and further compare these result with the wastewater treatment works discharge permit;

- conduct assessments of activities along the course of the river to determine the point source and non-point source anthropogenic activities necessitating the use of land and water adjacent to the rivers and the impact thereof on water quality and

- propose rehabilitative measures for rivers with compromised water quality.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses wastewater; water quality and anthropogenic activities. Wastewater is described in terms of its origins; composition; treatment processes and impacts on water quality. Water quality impacts; physico-chemical and microbiological parameters to quantify water quality impacts as well as water quality legislation are identified. The nature and extent to which anthropogenic activities influence water quality are also discussed in this chapter.

2.2 WASTEWATER

Wastewater originates from domestic, commercial and industrial sources (Tempelton and Butler, 2011). It is a reference to any water that has been adversely affected in terms of its quality by anthropogenic influences and is defined as an amalgam of water-conveyed wastes from the sanitary conveniences of dwellings; commercial; institutional and industrial facilities. From the standpoint of sources of generation, wastewater may be defined as a combination of the liquid or water-carried wastes removed from residences, institutions, and commercial and industrial establishments (Tchobanoglous *et al*., 2004).

The constituents of wastewater include a varying range of potential contaminants such as silt; sand; chemical residues; industrial cooling waters; industrial process waters; biodegradable organic wastes; detergents; pesticides; fats; oil; greases; solvents; phenols; cyanides; nutrients (nitrogen, phosphates, ammonia); metals (Hg, Pb, Cd, Cr, Cu, Ni) and microorganisms (pathogenic bacteria, viruses and worm eggs) (Table 2.1) (Ujang and Henze, 2006).

Table 2.1: Major components of domestic wastewater (Ujang and Henze, 2006).

Major components	Specific items / interest	Environmental and public health effects
Micro organisms	Pathogenic bacteria, viruses and worm eggs	Health risk when bathing and eating shell fish
Biodegradable organics	Oxygen depletion in aquatic systems	Fish death, odours
Other organic components	Detergents, pesticides, fat, oil and grease, colouring materials, solvents, phenols, cyanides	Toxic, aesthetically unacceptable, bioaccumulation in food chain
Nutrients	Nitrogen, phosphorus, ammonium	Eutrophication, oxygen depletion in aquatic system
Metals	Hg, Pb, Cd, Cr, Cu, Ni	Toxic, bioaccumulation in food chain
Other inorganics	Acids, bases	Corrosion, toxic
Thermal effects	Heating water	Change aquatic conditions for flora and fauna
Odour and taste	Hydrogen sulphide	Aesthetically unacceptable, toxic
Radioactivity		Toxic, accumulation

As well as containing fecal material, domestic and industrial wastes carry a range of naturally occurring and xenobiotic organic compounds, including bioactive pharmaceuticals (Lindqvist *et al.*, 2005); and a diverse range of lipids, proteins, carbohydrates, and bacterial cells (Gray, 2005). With reference to wastewater constituents, Orugai (2003) included the need to remove or reduce the numbers of many pathogenic enteroviruses known to be excreted in feces, some of which are present in very high numbers. Wastewater consists primarily of pure water (more than 95%), with less than 5% impurities and there are numerous processes that can be employed for treatment depending on the nature and extent of contamination (Figure 2.1) (Tempelton and Butler, 2011).

The treatment of wastewater is not only important for our own health but also to keep our environment clean and healthy. According to Khopkar (2004), the objective of treatment is to produce a disposable effluent without causing harm to the surrounding environment and, to prevent pollution. Without the proper wastewater treatment, many ecosystems would be severely damaged once the inadequately treated water gets recharged back into the environment. Untreated wastewater usually contains numerous pathogenic or disease-causing, microorganisms that dwell in the human intestinal gut or that may be present in certain industrial waste (Tchobanoglous and Burton, 1991).

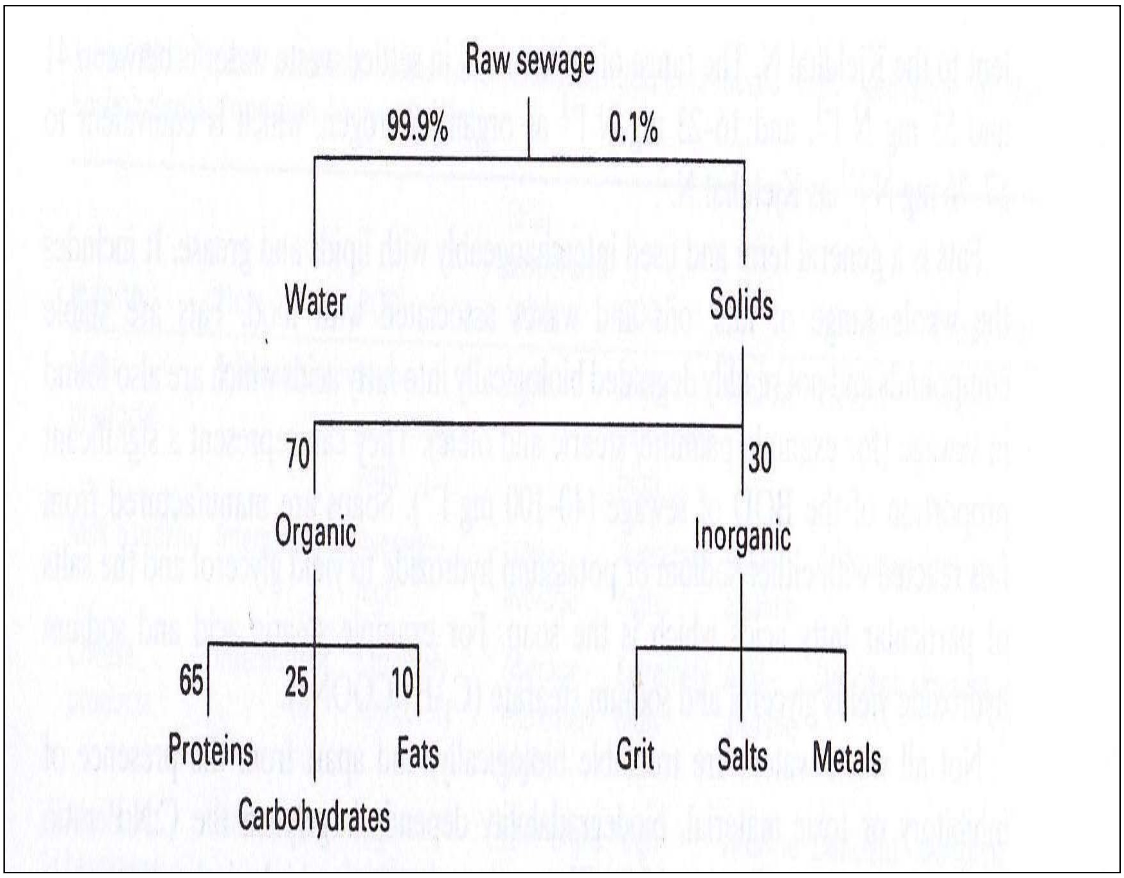

Figure 2.1: Composition of raw sewage (Tempelton and Butler, 2011).

The traditional aim of wastewater treatment is to enable wastewater to be disposed safely, without being a danger to public health and without polluting watercourses or causing other nuisance (Tempelton and Butler, 2011). From the perspective of the treatment works, the primary objective of wastewater treatment process operation is to meet the permit requirements or, if the facility is non-discharging, the applicable requirements of the regulatory agencies for groundwater protection (Boyd and Mbelu, 2009).

Wastewater treatment involves sequential processes for removal or conversion of the harmful constituents present in wastewater. Treatment is broadly categorized into the following stages: preliminary treatment; primary treatment; secondary treatment; tertiary treatment and solids treatment (Figure 2.2) (Tempelton and Butler, 2011).

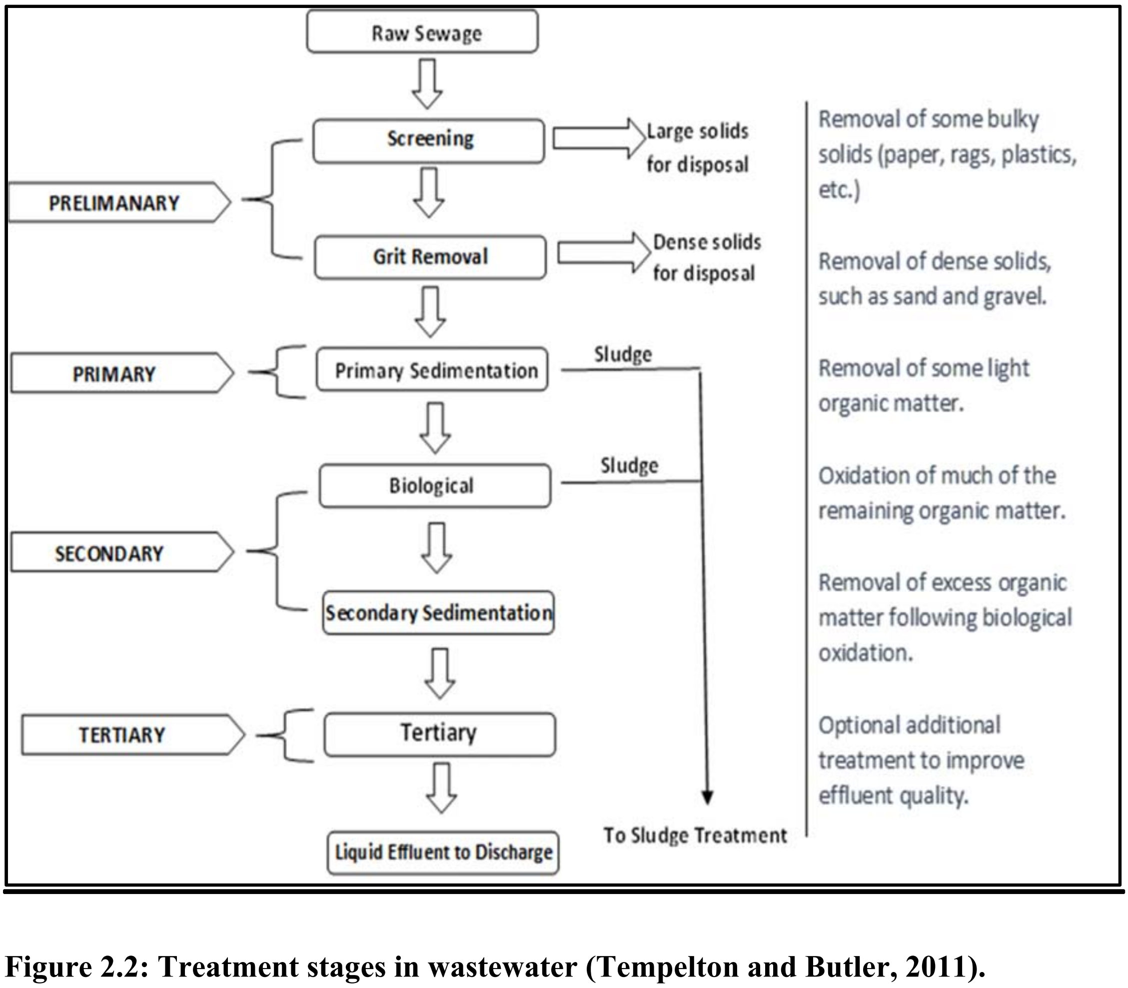

Figure 2.2: Treatment stages in wastewater (Tempelton and Butler, 2011).

2.2.1 Preliminary Treatment

The first unit process in any treatment plant is the preliminary treatment unit (Water 21, 2013). Preliminary treatment is defined as the removal of wastewater constituents that may cause maintenance or operational problems with the treatment operations, processes, and ancillary systems (Tchobanoglous *et al.*, 2004). According to WISA (2002), preliminary treatment is important for:

- screening and removal of solids that could cause blockages in pumps and piping as well as damage equipment;
- removal of grit and sand that could cause pipe blockages and abnormal pump wear through abrasion as well as reduce downstream tank volumes through grit settlement in tanks and;
- inflow measurement which is invaluable in managing the treatment process in addition to budgetary and future expansion planning.

Preliminary treatment of wastewater occurs at the head of the works and generally includes screening, grit removal and flow measurement as indicated in figure 2.3, below.

2.2.1.1. Screening

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). These items include the removal of large solid components which are entrapped by coarse screens. These coarse screens are generally constructed of heavy, parallel rectangular or round steel bars spaced 50-150mm apart in the channel and are sloped at an angles ranging from 30 to 45 degrees from the vertical position. The influent sewage water passes through a bar screen to remove all large objects like cans, rags, sticks, plastic packets etc. carried in the sewage stream (London, 1999). Fine screens are located after the coarse screens to remove the finer solids such as rags and paper (WISA, 2002). Substances typically removed include wood, cardboard, rags, plastic, grit, grease and scum (WEF, 1996). If gross solids are not removed, they become entrained in pipes and moving parts of the treatment plant, and can cause substantial damage and inefficiency in the process (EPA, 2004). In addition, floating material can encourage the development of odours and breeding of flies and other organisms (DWAF, 2002).

2.2.1.2. Grit Removal

The preliminary treatment stage concludes after the heavier solids such as grit and sand is allowed to settle out in channels for removal to a landfill site (WISA, 2002). Grit channels or chambers, by design allow the grit and sand particles to settle out for removal to a landfill site. Removal volumes of grit vary (4 to 200ml/m3 is typical) (Tchobanoglous *et al.*, 2004). There are 3 general types of grit chambers:

- Horizontal- flow chamber either of a rectangular or square configuration where the flow passes through the chamber in a horizontal direction and the straight line velocity of flow is controlled by the dimensions of the unit, special influent distribution gates and the use of special weir sections at the effluent end;
- Aerated chamber which consists of a spiral-flow aeration tank where the spiral velocity is induced and controlled by the tank dimensions and quantity of air supplied to the unit or
- The vortex-type which consists of a cylindrical tank in which the flow enters tangentially creating a vortex-flow pattern; centrifugal and gravitational forces cause the grit to separate (Tchobanoglous *et al.*, 2004).

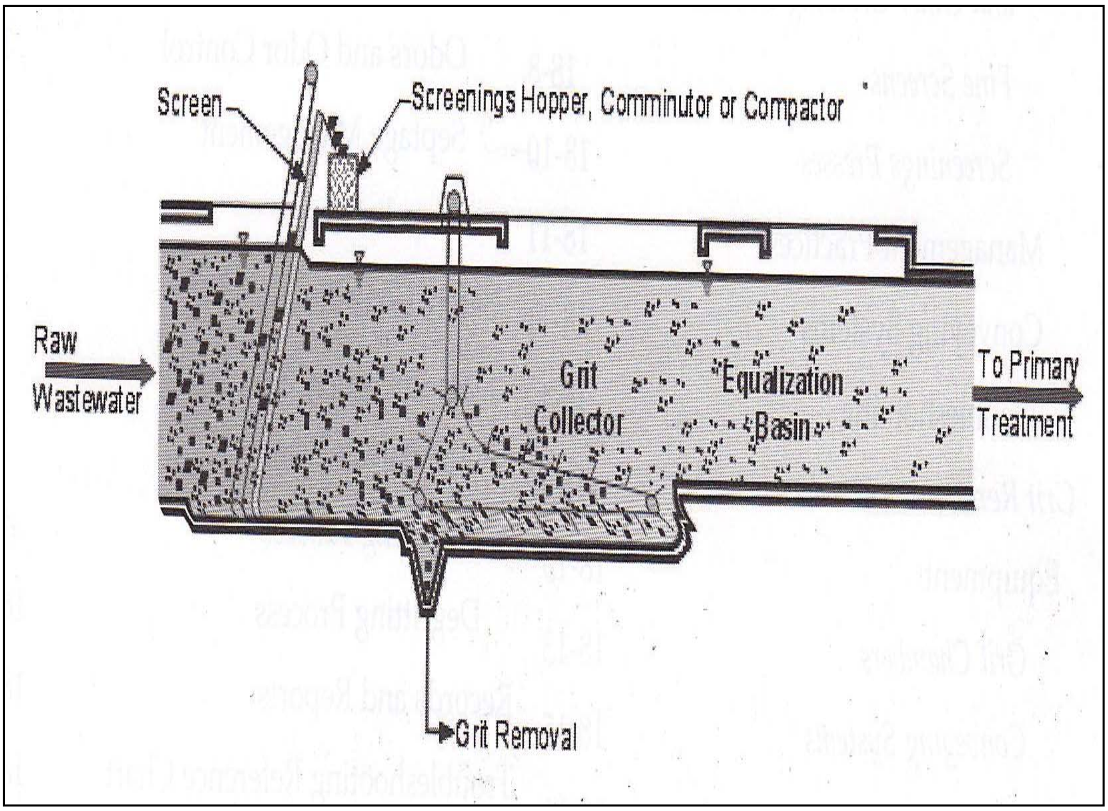

Figure 2.3: Preliminary treatment schematics (WEF, 2008a).

Whereas the process of degritting is costly and difficult to operate (Ujang and Henze, 2006); it is important for treatment. According to Tempelton and Butler (2011), grit removal is an important preliminary treatment process for several reasons:

- To protect mechanical equipment and pumps from abrasive wear;
- To prevent pipe clogging by deposition of grit, and
- To reduce accumulation of grit in settling tanks and digesters.

2.2.1.3. Flow Measurement

There are many flow measuring devices but the open channel flow measurement using a venturi flume is possibly the most widely used system for waste waters (WISA, 2002). Other flow measuring devices include venturi meters, flow nozzles or orifice meters (WRC, 2006). Flow measuring devices are usually located downstream of the screens, and their primary function is to accurately measure the amount of wastewater entering the treatment works. In addition, regular flow recordings provide warnings on blockages or pump failure in sewer reticulation (DWAF, 2002). Records of this nature aid in determining the nature and extent of future treatment works expansions and are invaluable for plant operation and process control.

2.2.2 Primary Treatment

Primary treatment is predominantly a physical removal process. Following preliminary treatment, primary treatment removes suspended and floating material (WEF, 1996). The main purpose 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 solids separation reduces the organic loading on downstream processes and also reduces the suspended solids load on subsequent processes. The rationale for separation is explained by WISA (2002), as follows: "when a liquid, containing solids(mostly organic) in suspension, is placed in a relatively quiescent state, those solids having a higher specific gravity than the liquid will tend to settle and those with a lower specific gravity will tend to rise". Hence, the majority of organic and suspended solids separate from the liquid and settle at the bottom of the settling tank and is subsequently transferred to the sludge digester tank. This reduces the load on the biological aerobic liquid stage and allows sludge to be treated anaerobically (WISA, 1999).

Primary treatment involves the utilization of large settling tanks to facilitate this separation. The tank configuration could be rectangular in shape with horizontal inflow from one end of the tank to the other and scrapers moving back and forth pushing sludge at the bottom of the tank into a sludge hopper; circular in shape where the inflow enters at the centre of the tank and dissipates to the perimeter while sludge is scraped to a central point at the bottom of the tank for removal or square shaped. These tanks (square shaped) remove settled solids and floatables in a manner similar to that of circular tanks (Figure 2.4) (WEF, 2008a). In most wastewater treatment plants the efficiency of the primary and secondary clarifiers in removing and concentrating sludge controls the volatile solids loadings to anaerobic digesters (Gerhardi, 2003).

Figure 2.4: Circular Shaped Primary Sedimentation Tank (http://en.ekoton.com/about us).

2.2.3 Secondary Treatment

Secondary treatment is effected predominantly by biological means. Following primary treatment, the next treatment stage is termed secondary treatment. Secondary treatment provides for the oxygenation of the liquid fraction flowing from the primary settling tanks (WISA, 2002). This oxygen is consumed by microoganisms as they reduce the organic substances in the wastewater. Secondary treatment reduces the concentrations of dissolved and colloidal organic substances and suspended matter in the wastewater (WEF, 1996). Secondary treatment includes the processes of aeration in an activated sludge system or treatment in biological filtration (also known as trickling filters) and secondary settling.

2.2.3.1 Aeration and Activated Sludge Treatment

For secondary treatment the conventional and most popular process is activated sludge (WATER 21, 2013). The activated sludge process is the most commonly used system for the treatment of municipal wastewater, and it is probably the most versatile and effective of all wastewater treatment processes (Gerhardi, 2003). This secondary treatment begins with aeration or oxygenation of primary tank effluent in a large basin or tank. The primary tank effluent flows into aerated basins, wherein it is mixed with a mass of microorganisms that reduce the organic matter by their metabolic activity (Figure 2.5). The activated sludge process contains a large number and a large diversity of organisms (Gerhardi, 2008). This process essentially involves an aeration tank, that is, a biological reactor where the biomass is kept in suspension by aeration (Orhon *et al.,* 2009). The activated sludge process is a biological process of developing an activated mass of microorganisms capable of stabilizing waste aerobically (Boyd and Mbelu, 2009).

Biological treatment is an ingenious system where pollutants in wastewater serve as substrate for the microbial community sustained in a reactor and microorganisms are grown in a controlled environment at the expense of organic and inorganic pollutants in the feed stream through a complex sequence of biochemical reactions (Orhon *et al.,* 2009). The principle in an activated sludge plant is that a mass of active sludge is kept moving in wastewater by stirring or aeration (Ujang and Henze, 2006). Because the sludge is aerated, and the bacteria become very active during aeration, the term 'activated sludge' is used to describe the process where bacterial solids are active in the purification of the wastes within the aeration tank (Gerhardi, 2003). Aeration facilitates the dissolving of oxygen in the effluent; mixes and keeps the effluent mass in suspension and is vital for the activity of aerobic microorganisms in the aeration basin. This results in a stable effluent that will cause limited future oxygen demands on the receiving waters (WISA, 1999).

The two basic methods of aerating wastewater are (1) to introduce air or pure oxygen into the wastewater with submerged diffusers or other aeration devices or (2) to agitate the wastewater mechanically so as to promote solution of air from the atmosphere (Tchobanoglous *et al.*, 2004). Diffused air aeration is enabled either by passing fine bubbles or air through it, providing strong agitation or as a result of percolation through a thin stream of sewage (WISA, 2002).

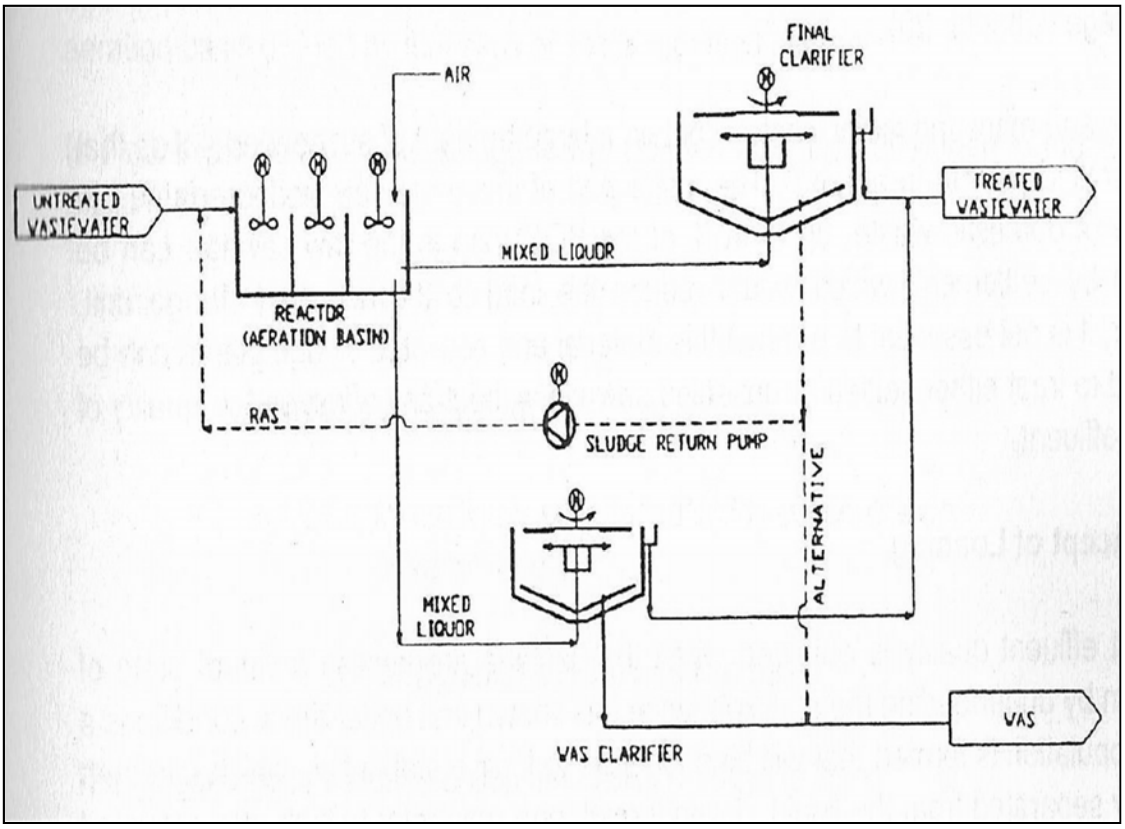

Figure 2.5: The Activated Sludge Process (WEF, 2008a).

There are two groups of mechanical aerators differentiated according to their axis and location configuration namely: surface or submerged vertical axis aerators and surface or submerged horizontal axis aerators. In surface aerators, oxygen is entrained from the atmosphere; in submerged aerators, oxygen is entrained from the atmosphere and, for some types, from air or pure oxygen introduced in the tank bottom (Tchobanoglous *et al.*, 2004). Typically, the effluent is oxygenated in a large basin which may range in depth from 1.5 to 5.0 metres and use motor-driven aerators floating on the surface of the wastewater (Beychok, 1971). New configurations have been adopted (multistage plants for nutrient removal) and new technologies are being developed (membrane bioreactors, biofiltration, sequencing batch biofilm reactors) but all derive from the traditional activated sludge process (Tandoi *et al.,* 2005).

2.2.3.2 Biological Filtration

Since the late 1880`s secondary treatment has been effected by biological filtration with the use of trickling filters (also termed biofilters). Trickling filters attempt to duplicate the natural purification process that occurs when polluted wastewater enters a receiving stream and trickles over a rock bed or rocky river bottom (Figure 2.6) (WEF, 2008a).

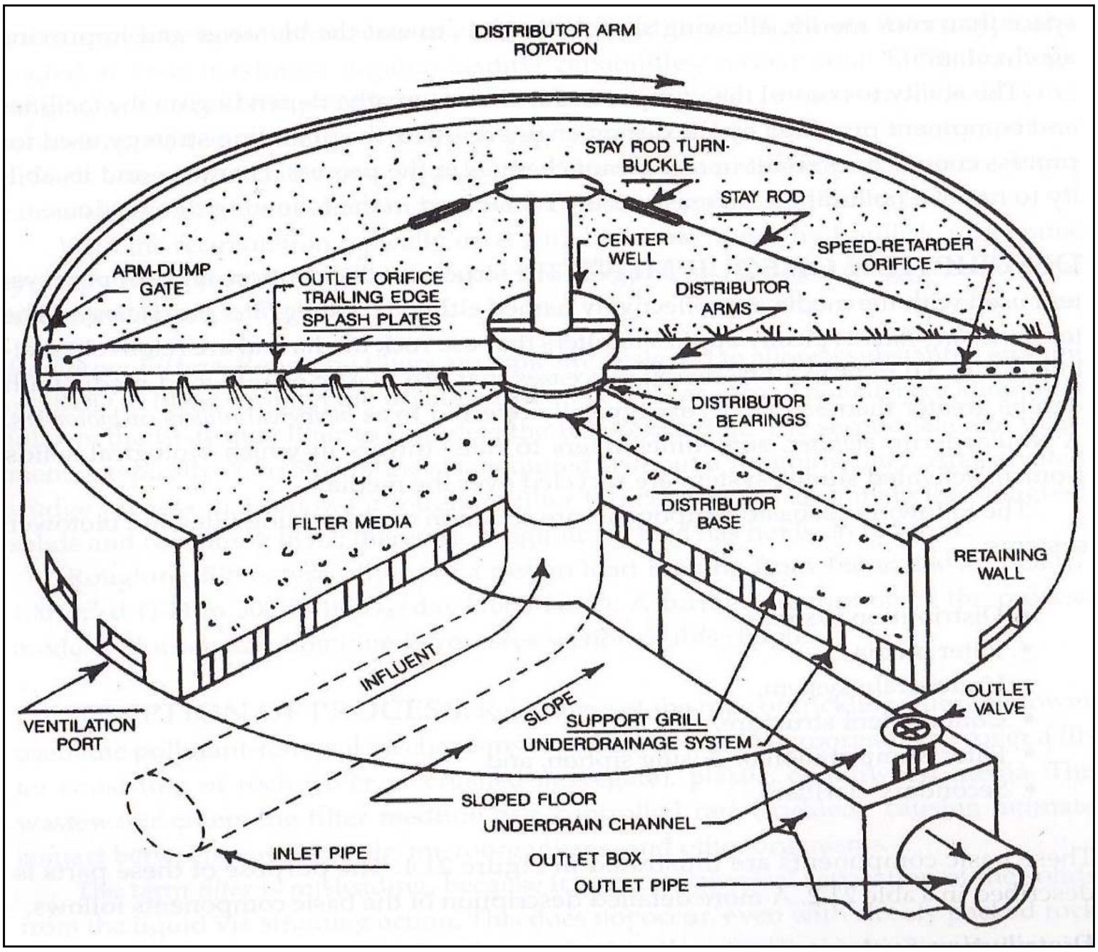

Figure 2.6: A Typical Trickling Filter (WEF, 2008a).

The trickling filter is a non-submerged fixed-film biological reactor using rock or plastic packing over which wastewater is distributed continuously and treatment occurs as the liquid flows over the attached film. at the top of the packing through distributor arms that extend across the tricking filter inner diameter and have variable openings to provide a uniform application rate per unit area and are rotated by the force of the water exiting through their opening or by the use of electric drives (Tchobanoglous *et al.*, 2004).

Biofilters are based on the ability of the bacteria to attach and develop on a solid medium (Ujang and Henze, 2006). The attachment medium is a slime layer. A slime layer develops on the rock or plastic packing in the trickling filters and contains the microorganisms for biodegradation of the substrates to be removed from the liquid flowing over the packing. (Tchobanoglous *et al.*, 2004). Hence biofilters sustain attached microbial systems or biofilms (Orhon *et al.,* 2009). Biological filtration oxidizes carbon and ammonia nitrogen fractions in wastewater and is achieved by passing the wastewater over or through fixed surface media to which bacteria attach themselves (DWAF, 2002).

2.2.3.3 Secondary Settling

Secondary settling processes follow both the activated sludge system as well as biological filtration. Clarifiers are used for secondary settling of activated sludge and humus tanks are used for settling of biofilter effluents. The quality of the final effluent from an activated sludge system is determined by the efficiency of activated sludge separation in secondary clarifiers (Tandoi *et al.,* 2005). Hence, following aeration, the effluent flows into settling tanks termed "clarifiers", which as the name suggests, have the objective of clarifying the effluent by gravitational settling and separation of solids from the effluent. The remaining organic solids, settle at the bottom of the tank for subsequent removal to the sludge digester tank (WISA, 2002). For successful wastewater treatment using activated sludge the biomass must be able to flocculate and settle and thicken by gravity sedimentation because the treated wastewater is separated from the activated sludge in secondary clarifiers (secondary settling tanks) where the main driving force for separation is gravitation (Tandoi *et al.*, 2005). The overflow from the clarifier is the clear treated effluent from the process, and the underflow, which contains settled sludge solids, is the sludge return or recycle stream (WISA, 1999). The sludge is returned to the aeration basin as it contains a mass of microorganisms that will mix with incoming effluent and once again effect reduction of organic matter. A portion of the sludge is removed as waste sludge from the aeration basin and transferred to the digester while the overflow from the clarifier undergoes disinfection before being discharged to the receiving environment (Tandoi *et al.,* 2005).

For secondary settling of biofilter effluent, the effluent flows into the humus tank from the biofilter underdrain. Humus tanks are required to remove the solids present in the effluent discharged from biological filters (biofilters) by sedimentation (WISA, 2002). All the sludge from trickling filters settling tanks is sent to sludge processing facilities or returned to the primary clarifiers to be settled with primary solids (Tchobanoglous *et al.*, 2004).

2.2.4 Tertiary Treatment

Tertiary treatment generally includes some form of chemical treatment. The purpose of tertiary treatment is to provide a final treatment stage to further improve the effluent quality before it is discharged to the receiving environment and can include nutrient removal processes; final polishing of effluent in stabilization ponds and disinfection. According to Tempelton and Butler (2011), tertiary treatment is the further removal of suspended solids or nutrients and/or disinfection before discharge to the receiving watercourse. Usually tertiary treatment at a sewage works involves a series of ponds, wetlands or reed beds that are installed to provide a degree of polishing of the treated effluent discharged from the mechanical treatment process (DWAF, 2002).

2.2.4.1 Stabilization Ponds

Waste stabilization ponds are by design usually about 1.5 m deep basins with earthen sides, and usually arranged in a series in which wastewater flows from one pond to the following pond by gravity, with an incremental improvement in quality as the flow moves from one pond to the next.

According to Ujang and Henze (2006), the advantages of waste stabilization ponds, which come from their unique combination of physical simplicity and biological complexity, include:

- Low cost;
- Simplicity of construction;
- Excellent pathogen removal;
- Ability to treat a variety of wastes;
- Toleration of organic and hydraulic shock loads;
- Low maintenance requirements;
- Low sludge production;
- Reliability of operation and
- Simple land reclamation

2.2.4.2 Disinfection

A critical aspect of tertiary treatment is disinfection. Ideally water destined for human consumption should be free from microorganisms, however, in practice this is an unattainable goal (Gray, 1999). The goal of water disinfection is to remove or inactivate pathogenic microorganisms (WISA, 2002); and disinfection of wastewater treatment plant effluent inactivates or destroys pathogenic bacteria, viruses, and amoebic cysts commonly found in wastewater (WEF, 1996). In addition to destruction of pathogens, a further advantage of disinfection is that the general microbiological quality of the water is also improved (WRC, 2006). Biological effluents from domestic wastewater treatment are required to be disinfected before reuse because they still contain microorganisms of intestinal origin, such as helminth ova and fecal coliform bacteria such as *Escherichia coli* (Liberti *et al.,* 2000) (Table 2.2).

Table 2.2: Types and numbers of Microorganisms found in raw domestic sewage (Tchobanoglous *et al.*, 2004).

Organism	Concentration number $m\ell^{-1}$
Total coliform	10^5 - 10^6
Faecal coliform	10^4 - 10^5
Faecal streptococci	10^3 - 10^4
Enterococci	10^2 - 10^3
Salmonella	10^0 - 10^2
Pseudomonas aeriginosa	10^1 - 10^2
Clostridium perfringens	10^2 - 10^3
Mycobacterium tuberculoses	Present
Protozoan cysts	10^1 - 10^3
Giardia cysts	10^{-1} - 10^2
Cryptosporidium cysts	10^{-1} - 10^1
Helminth ova	10^{-2} - 10^1
Enteric virus	10^1 - 10^2

Since the numbers of pathogenic present in wastes and polluted waters are usually few and difficult to isolate and identify, microorganisms which are more numerous and easily tested for, are commonly used as surrogate (i.e., an indicator) organisms for the target of pathogens (Metcalfe and Eddy, 2004). The presence of *Escherichia coli* indicates the presence of fecal pollution. *Escherichia coli* is a bacterium of enteric origin and its occurrence and abundance allows for its use in defining the sanitary quality of water and wastewater. The World Health Organization has established a maximum level of 1000 fecal coliform units (FCU)/100 mℓ for Category "A" water quality (Liberti *et al*., 2000).

There are many disinfection techniques in use (Table 2.3) (Ahuja, 2009), The commonly used disinfectants include chlorination; UV irradiation and ozonation. Apart from these, other forms of disinfection include the application of calcium hypochlorite (DWAF 2002).

2.2.4.2. a. Chlorination

Chlorine has been the dominant disinfectant of wastewater (WISA, 2002). For many years, wastewater treatment plant designers selected chlorine because of its ability to disinfect wastewater with relatively low doses, its simple feed and control procedures, and its low cost compared with other substances (WEF, 2008a). It is also relatively easy to handle and cost effective (Gray, 1999). Disinfection is effected as chlorine oxidizes cellular material and causes destruction of proteins when critical enzymes are inactivated.

2.2.4.2. b. Ultraviolet Radiation

With the proper dosage, ultraviolet radiation has proved to be an effective bactericide and vircide for wastewater, while not contributing to the formation of toxic products (Tchobanoglous *et al*., 2004). The mode of disinfection is by ultraviolet light which inhibits cellular replication by alteration of cellular genetics and thereby inactivating bacteria and viruses. At a wavelength of 253.7 nm, ultraviolet light can inactivate microorganisms without significantly altering the effluent`s physical and chemical properties and unlike chlorine, UV light leaves no residual that can affect receiving waters; it adds nothing but energy, which produces some heat (WEF, 2008a).

2.2.4.2. c. Ozonation

Ozone is an extremely reactive oxidant, and it is generally believed that bacterial kill through ozonation occurs directly because of cell wall disintegration (Tchobanoglous *et al.*, 2004). At a dosage rate of 1ppm, ozone destroys all bacteria within ten minutes. The bacteria are destroyed as a result of protoplasmic oxidation, which causes disintegration of the bacterial cell wall. When ozone decomposes in water, it results in the formation of the free radicals hydrogen per-oxy and hydroxyl which have great oxidizing capacity and play an active role in disinfection (WEF, 2008a).

Ozone is generated on site by photochemical or electrical excitation methods; is more costly when compared to the cost of chlorination and it has to be manufactured on site.

Table 2.3: Characteristics of commonly used disinfectants (Ahuja, 2009).

Consideration	Disinfection Agent				
	Free Chlorine	Combined Chlorine	Ozone	Chlorine Dioxide	Ultraviolet Light
Effectiveness	Excellent	Fair	Excellent	Excellent	Good
Cost	Low	Moderate	High	Moderate	High
Size of plant	All sizes	All sizes	Medium to large	Small to medium	Small to medium
Safety concern	High	High	Moderate	High	Low
Toxicity at operating temperatures	High	High	High	High	High
Residual	Long	Long	None	Moderate	None
Odor removal	Moderate to high	Moderate	High	High	N/A
Contact time	Moderate	Moderate	Short	Moderate	Short
pH dependency	High	High	Low	Low	None
Regulatory limit on residuals (USEPA, 2007)	4 mg/L	4 mg/L	0.8 mg/L	N/A	N/A
Solubility	Moderate	High	High	High	Moderate
Frequency of use as primary disinfectant	High	Moderate	Moderate	Low	Low, but increasing
Stability	High	Moderate	Low	Low	N/A

2.2.5 Solids Treatment

Primary tank sludge usually undergoes thickening to increase its solids content prior to subsequent sludge treatment processes of anaerobic digestion and dewatering. This is necessitated since untreated sludge from the primary and secondary sedimentation tanks have a high water content (Tchobanoglous *et al.*, 2004). Thickening also aids in reducing the cost of sludge treatment. Sludge produced in wastewater treatment plants amounts to a small percentage (1%) of the volume of treated wastewater, while the processes for sludge treatment and disposal represent from 20% to 60% of operating costs, incorporating manpower, energy and sludge disposal costs (Foladori *et al.,* 2010).

Following primary sedimentation and thickening, wastewater solids are treated in anaerobic digesters. The anaerobic digestion of sludge is a tertiary treatment stage that stabilizes surplus sludge generated through the sewage treatment process (DWAF, 2002). Enabled by biological degradation of organic compounds, anaerobic digestion destroys a major portion of the volatile solids in sludge (thereby reducing the sludge volumetrically) and minimizing putrefaction. This process of digestion converts the raw sludge from a smelly putrescible nature to a substance that is relatively odour-free, readily dewaterable and sufficiently stabilized to be disposed of without causing nuisance conditions, (Boyd and Mbelu, 2009).

Anaerobic digestion can be described as a multistage biochemical process comprising of a series of bacterial events for sludge stabilization in the absence of molecular oxygen. According to Gerhardi (2003), these events are commonly considered as a three-stage process:

- The first stage of the process involves the hydrolysis of solids. The hydrolysis of these wastes results in the production of simplistic, soluble organic compounds (volatile acids and alcohols);

- The second stage of the process, acetogenesis, involves the conversion of the volatile acids and alcohols to substrates such as acetic acid or acetate and hydrogen gas that can be used by methane-forming bacteria and

- The third and final stage of the process, methanogenesis, involves the production of methane and carbon dioxide.

Enhanced by elevated temperatures and extended detention time, anaerobic digesters facilitate a significant reduction in solids and hence decreased sludge handling and disposal costs and reductions in the number of pathogens. The solids are kept for 20 to 30 days in the digesters (Rogers and Leal, 2010) and the anaerobic digestion of liquid organic wastes requires temperatures above 20°C to ensure the bacteria are active enough for subsequent waste degradation (Ujang and Henze, 2006). These solids require relatively long digestion periods (10-20 days) to allow for the slow bacterial processes of hydrolysis and solubilisation of solids (Figure 2.7) (Gerhardi, 2003).

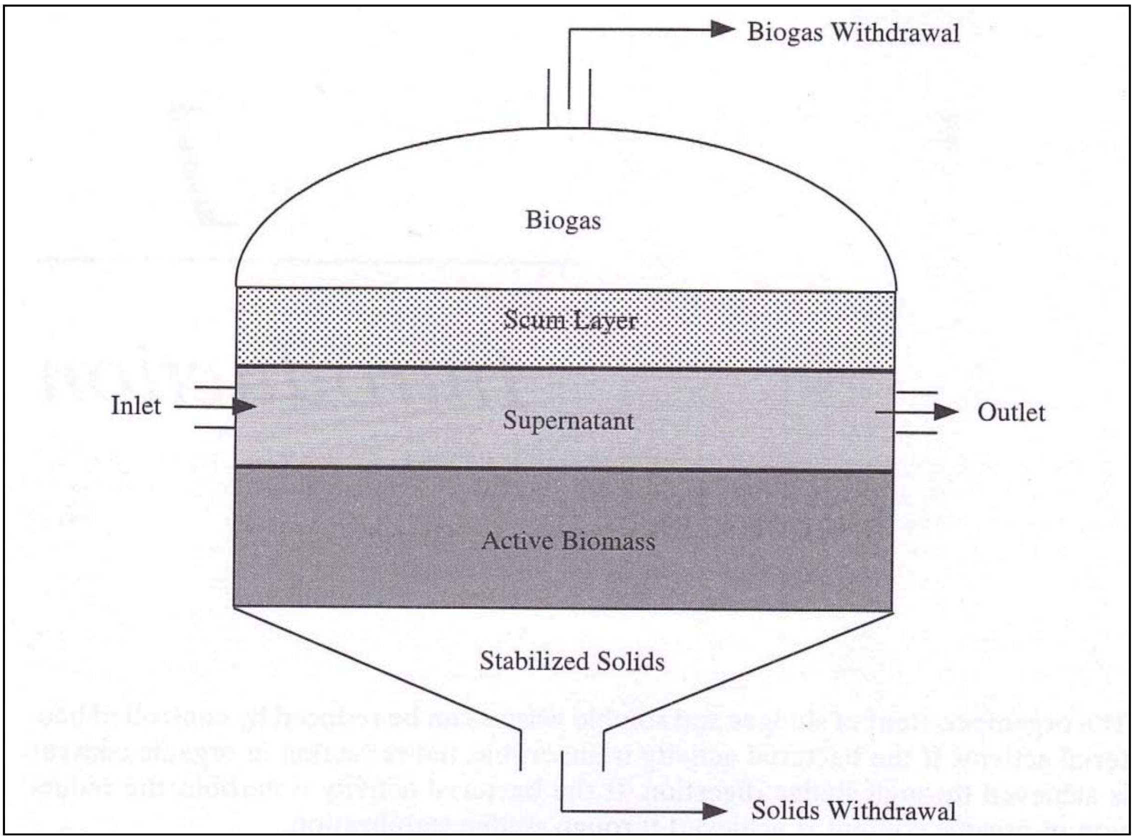

Figure 2.7: Anaerobic digester with depiction of sludge layers (Gerhardi, 2003).

Apart from generating stabilized sludge solids, anaerobic digestion produces a mixture of gases which are collectively termed digester gas or biogas which consists mostly of methane and carbon dioxide. The gases produced in largest quantities are methane and carbon dioxide and by volume, methane is 60% to 65%, and carbon dioxide is 35% to 40% (Gerhardi, 2003).

Of significant value in terms of energy generation, is methane since it is a flammable, odourless gas and can be used as a fuel source. Most municipal wastewater treatment plants use biogas to heat digesters to 32-35°C (Gerhardi, 2003). Furthermore, anaerobic digestion of wastewater sludge can, in many cases, produce sufficient digester gas to meet most of the energy needs for plant operation (Tchobanoglous *et al.*, 2004).

Following anaerobic digestion, the stabilized sludge needs to be dewatered for disposal. One of the major destinations for sludge in many areas, especially in the past, was the nearby ocean, although recently many countries have introduced laws for marine pollution control, which do not permit sea dumping (Foladori *et al.,* 2010). Options for safe and beneficial disposal include agricultural use, landfill and incineration. The sludge is digested or broken down to a stable mass by the action of microorganisms and thereafter it is dried and stored on site or disposed of at a landfill site (WISA, 2002).

Dewatering is carried out by mechanical means such as a filter press and by non-mechanical methods which include application on drying beds (Figure 2.8). The main aim of dewatering is to eliminate as much water as possible to produce a non-fluid material whose solid concentration is higher than 20% of total solids. (Ujang and Henze, 2006).

Drying beds are the cheapest and simplest form of dewatering (Gray, 1999). They consume less energy but require greater land extension, and more manual labour, mainly to handle the sludge cake (Ujang and Henze, 2006).

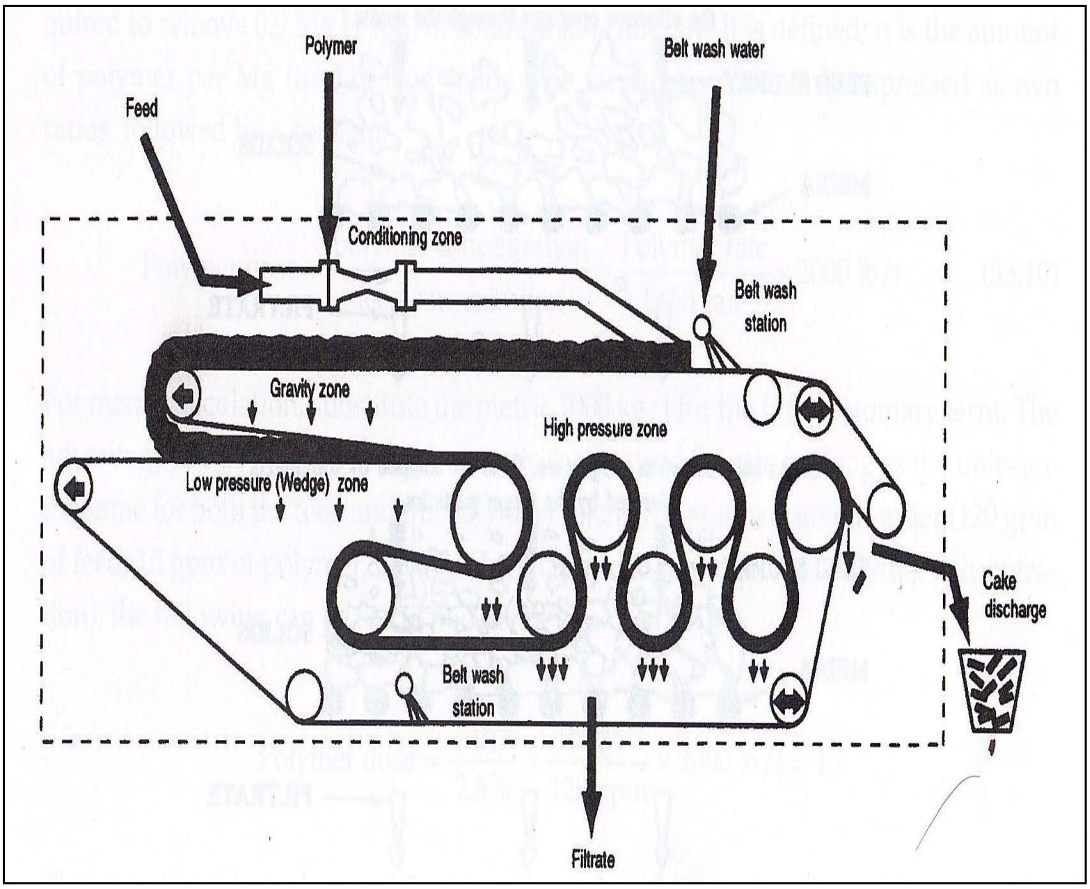

Figure 2.8: Belt filter press process flow diagram (WEF, 2008b).

2.3. WATER QUALITY

According to Boyd (2000), the term water quality describes the physical, chemical and microbiological properties of water and its fitness for use and ascertaining its quality is crucial before use for various intended purposes such as potable water, agricultural, recreational and industrial water uses (Sargaonkar and Deshpande, 2003). Water quality is a measure of the condition of water relative to the requirements of one or more biotic species or to any human need or purpose (Johnson *et al*., 1997). Water quality is only meaningful when evaluated in relation to the use of the water, since water of a certain quality may be fit for a specific use, but completely unfit for another use (WRC, 2006).

From a human perspective water quality has implicit reference to safety, since safe drinking water and sanitation is an essential human right (WATER 21, 2013).

Water quality is impacted upon by human activities which include agricultural activities, urban and industrial development, mining and recreation as well as by natural processes such as seasonal variation, climatic changes and the types of soils, rocks and surfaces through which it flows. These impacts influence the water use potential and hence, it is important to ascertain the quantities and the proportional presence of different types of impurities in water which are determined by the nature of the water source (Figure 2.9) (Polasek *et al*., 2005). Water availability, its quality and its suitability has been ever deteriorating due to climate change and direct human impacts on water resources Jähnig, (2010).

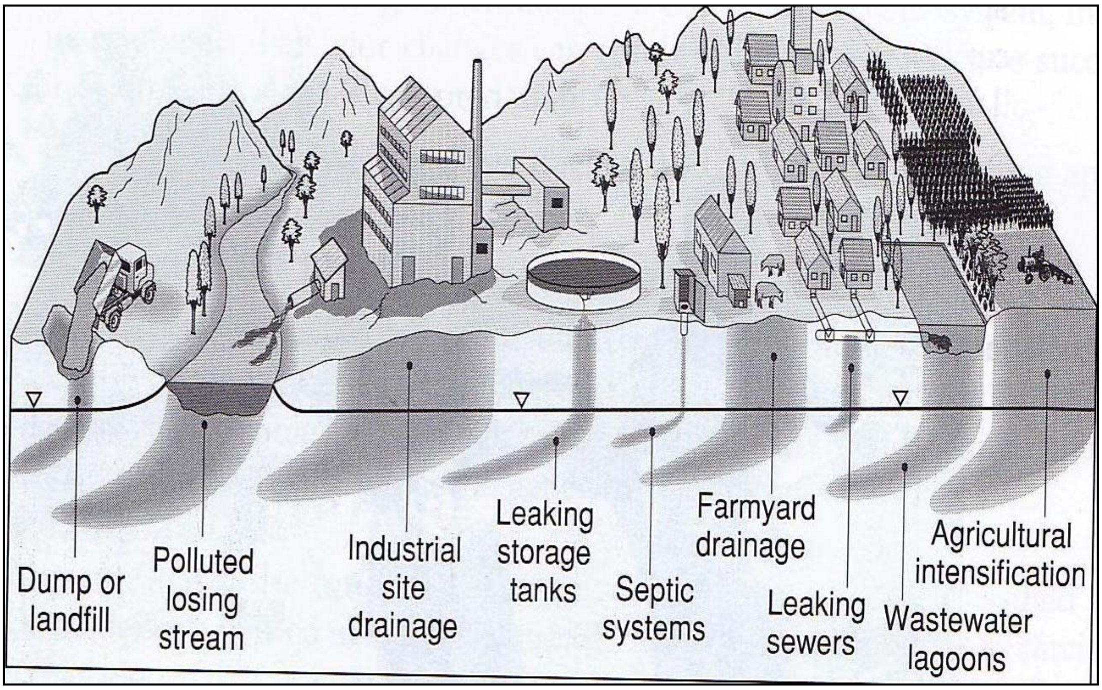

Figure 2.9: Land use activities generating a groundwater pollution threat (Kresic, 2009).

Deteriorating water quality increases treatment costs of potable and industrial process water, and decreases agricultural yields as a consequence of increased impurities in irrigation water. The effects of consumption of water of poor quality on human health, on the aquatic ecosystem (aquatic biota, and in-stream and riparian habitats) as well as various sectors of the economy, including agriculture, industry and recreation, can have disastrous consequences. Toxic substances coupled with high populations of certain microorganisms such as cyanobacteria may present a health hazard for non-drinking purposes such as irrigation, swimming, fishing, rafting, boating, and industrial application (Table 2.4). Cyanobacteria are commonly found in freshwater systems that are the source waters for the production of drinking water. This is of special importance to the drinking water suppliers as several genera of cyanobacteria can produce cyanotoxins that can affect human health (Water SA, 2007).

Table 2.4: Diseases generally transmitted by contaminated drinking water (Gray, 1999).

Agent	Disease	Incubation time
Bacteria		
Shigella spp.	Shigellosis	1–7 days
Salmonella spp.		
S. typhimurium	Salmonellosis	6–72 hours
S. typhi	Typhoid fever	1–3 days
Enterotoxigenic *Escherichia coli*	Diarrhoea	12–72 hours
Campylobacter spp.	Gastroenteritis	1–7 days
Vibrio cholerae	Gastroenteritis	1–3 days
Viruses		
Hepatitis A	Hepatitis	15–45 days
Norwalk-like agent	Gastroenteritis	1–7 days
Virus-like particles <27 nm	Gastroenteritis	1–7 days
Rotavirus	Gastroenteritis	1–2 days
Protozoa		
Giardia lamblia	Giardiasis	7–10 days
Entamoeba histolytica	Ameobiasis	2–4 weeks
Cryptosporidium	Cryptosporidiosis	5–10 days

2.3.1 Water Quality Parameters

Since water is one of the most valuable and essential resources that form the basis of all life, accurate monitoring and assessment of our water resources is necessary for sustained water resource management (Hodgson and Manus, 2006). Assessment of water quality is critical for pollution control and the protection of surface and ground waters (Gray, 1999). The regimen of monitoring and assessment is enabled by comparison with established water quality parameters which are broadly categorized as physical; chemical and microbiological parameters. The quality of water is typically determined by monitoring microbial presence, especially fecal coliform bacteria, and physico-chemical properties (Gray, 1994). Water quality is determined by measurement against a set of standards or scientifically determined parameters by which compliance can be assessed. The parameters for water quality are determined by its intended use.
Traditional approaches to assessing water quality are based on a comparison of experimentally determined parameter values with existing guidelines (Boyacioglu, 2007). Water quality guidelines for South Africa are grouped according to potential user types (e.g. domestic, industrial) in the 1996 Water Quality Guidelines (DWAF, 1996). Drinking water quality is subject to the South African National Standard (SANS) 241 Drinking Water Specification (Hodgson and Manus, 2006).

2.3.1.1 Physico-chemical Parameters

These parameters, as the name suggests, refer to physical or chemical quality effects on water. Physico-chemical constituents include: chemical oxygen demand; dissolved oxygen; electrical conductivity; pH; dissolved/suspended solids; turbidity; ammonia; chlorides; permanganate value; nitrites and nitrates.

2.3.1.1.a. Chemical Oxygen Demand (COD).

COD is a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant (DWAF, 1996c). According to

King *et al.,* (2003) COD is a measure of the oxidation of reduced chemicals in water. COD is determined by means of a test which measures the amount of oxygen consumed to chemically oxidize organic water contaminants to inorganic end products. The test is based on the chemical decomposition of substances that are dissolved or held in suspension in water. The results of this test indicates the amount of dissolved oxygen that was consumed and consequently the higher the COD, the higher the presence of contaminants in the sample and vice versa.

2.3.1.1.b. Dissolved Oxygen (DO)

Dissolved oxygen is a relative measurement of the amount of oxygen dissolved or carried in a given sample. It is a measure of the amount of gaseous oxygen that is dissolved in water. Oxygen enters the water body through diffusion, from the surrounding atmosphere by aeration and by photosynthesis. Adequate DO is a requisite for good water quality. Most aquatic organisms depend wholly on the oxygen dissolved in water for their survival. Hence, maintaining adequate dissolved oxygen levels is crucial for the survival and functioning of these organisms. A well-mixed water body is generally fully saturated at approximately 10mg/l of DO at 15 degrees celsius. Generally, a lack of DO in natural waters creates the most problems, specifically an increase in tastes and odours as a result of anaerobic decomposition (Ritter, 2010). Insufficient DO in water results in a condition known as hypoxia which is caused by decomposing organic matter. Insufficient oxygen in water negatively impacts on the aquatic organisms including fish. When DO levels drop to below 5mg/l, aquatic organisms are put under stress. DO levels that remain below 1-2mg/l for a few hours can cause major fish kills. Oxygen depletion (low DO) is also sometimes experienced in eutrophic conditions accompanied by turbid conditions, algal blooms, pathogens, and habitat loss (Obeng, 2010).

2.3.1.1.c. Electrical Conductivity (EC).

Electrical conductivity is a measure of the ability of the water to conduct an electric current (WRC, 2006); and it is a measure of the total amount of dissolved material in a water sample (Dallas and Day, 2004). Additionally, conductivity measurements are used to establish the degree of mineralization of water to assess the effect of the total concentration of ions, which is particularly relevant to corrosion rates; and to evaluate variations in the concentration of dissolved minerals in a water source (Ritter, 2010). This test measures the salinity derived from the total dissolved inorganic compounds as well as other substances that have a potential to carry an electric charge, such as nitrates and phosphates. It is a general indicator of water quality change. Conductivity increases in direct proportion to dissolved ion concentrations (Boyd, 2000). Hence the higher the inorganic dissolved solids concentration of water, the higher the conductivity and vice versa. Conductivity may also increase naturally when metals within the bedrock are dissolved and taken up by the river current (Kadewa, *et al.,* 2005). However, rivers with granite bedrock have a lower conductivity than rivers with runoff containing clay particles since the minerals in clay ionize more readily in water. A decrease in conductivity may also result from high rainfall as a result of the natural dilution potential caused by the additional rainfall.

2.3.1.1. d. pH

pH is a measure of the acidity or alkalinity of a solution. pH is dependent on the carbonic acid equilibrium of water as explained by Cooke (2006): " when carbon dioxide from the air enters freshwater, small amounts of carbonic acid are formed which then dissociate into hydrogen ions and bicarbonate ions". This hydrogen ion concentration is measured as pH. pH controls many chemical reactions, including coagulation; disinfection; water softening; corrosion; biochemical reactions and ammonia removal (Ritter, 2010). Variation in pH has wide ranging effects of water chemistry and hence on the aquatic ecosystem. Human induced pH variation can arise from industrial discharges; mining activities and farming. Extensive research has been done on the toxic effects of pH on fish, (Ingersoll *et al.,* 1985); (Wendelaar *et al.,* 1986); (Henriksen *et al.,* 1987) and (Hall, 1987). 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). At a pH level of 9 and above the membranes of fish are denatured. pH levels below 4.5 renders the water unsuitable for aquatic organisms since at low pH levels release of metals that could contain toxins is accelerated from rocks in and around the river and this could be toxic to aquatic organisms. Also, organic substances like plant debris will not undergo decomposition and fish eggs will not hatch. Hence the ideal pH range for most surface water is 6 to 8 (Dallas and Day, 2004); (DWAF, 1996).

2.3.1.1. e. Total Dissolved Solids (TDS)

TDS a measure of all the compounds dissolved in water and is directly proportional to electrical conductivity. TDS represents the total quantity of organic and inorganic dissolved material in the water (Dallas and Day, 2004). In natural waters, the biggest contributor of such compounds is inorganic ions. TDS is likely to increase as water moves downstream as salts are being added both naturally and by human intervention. In natural waters, the biggest contributor of such compounds is inorganic ions such as calcium; magnesium; sodium and potassium. Many human activities have induced increased TDS levels in water. Apart from the obvious effects of discharging saline industrial effluents into rivers or lakes, increasing TDS levels may be caused by irrigation; clear felling and return of large quantities of sewage effluent to inland waters (Dallas and Day, 2004). Storm flows have a tendency to decrease the concentration of TDS by its dilution effect. The presence of salts affects plant growth in three ways:

- Osmotic effects, caused by the total dissolved salt concentration in the soil water;
- Specific ion toxicity, caused by the concentration of individual ions; and
- Soil particle dispersion, caused by high sodium and low salinity (Tchobanoglous *et al.*, 2004).

With aquatic organisms, physiological adaptation to changes in salt concentrations are enabled when these changes occur slowly. It is often the rate of change rather than the final salinity that is most critical (Dallas and Day, 2004).

2.3.1.1. f. Suspended Solids

Suspended solids are defined as solids that are relatively large and settle easily under quiescent conditions (WRC, 2006). This is a measure of the amount of solid sediments carried in suspension by the water. Usually, the higher the sediment concentration, the poorer the water quality is. Sediment alone, diminishes water suitability especially for urban supply, recreation, industrial consumption and aquatic life. As suspended solids settle out they may smother or abrade benthic fauna and impair gill function and foraging efficiency in fish (Dallas and Day, 2004). Additionally chemicals and wastes attach onto suspended solid particles. Wash off, and hence a reduction of suspended solids may result from storm flows.

2.3.1.1. g. Turbidity

Turbidity measures the light-transmitting properties of water and is an indication of the cloudiness or clarity of water. In South Africa, turbidity is still considered to be the most important pollution indicator, which is used exclusively in most waterworks for monitoring their performance and for control of the required dosing rate of destabilization agents (Water SA, 2005). The removal of turbidity by any treatment process is important for subsequent treatment processes (WRC, 2013). Waters showing very little light scattering produce low-turbidity measurements; those with a great deal of light scattering have high turbidity. It is an indication of the extent of suspended matter in water and influences the microbial water quality. Turbidity is commonly quantified by the use of instruments that project a beam of light into a small volume of water, with the amount that is reflected at a 90 degree angle measured. This process is termed nephelometry, and the units are called nephelometric turbidity units (NTU`s). Turbidity, usually reported in Nephelometric Turbidity Units is largely a function of suspended particulate material concentrations in the water sources (African Journal of Aquatic Science, 2007). The majority of natural waters have turbidities less than 50 NTU`s, but values can range from 1 NTU to 1000 NTU or more (Boyd, 2000). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites, and some bacteria. High turbidity reduces water clarity and impedes light penetration which is essential for photosynthesis. Hence the activity of primary producers such as peryphyton and macrophytes decreases as a result of reduced light penetration and consequently the food availability for organisms higher in the food chain is reduced. According to Wood and Armitage (1997), fish are adversely affected by elevated turbidity and suspended sediment concentrations by impairment of gill function; reduced resistance to disease; reduced spawning habitat; reduced food availability and interference with hunting efficiency. Elevated turbidity levels are caused by overgrazing; non-contour ploughing removal of riparian vegetation; industrial discharges; mining activities and flooding.

2.3.1.1. h. Ammonia; Nitrites and Nitrates

The most common and important forms of nitrogen are ammonia; nitrite; nitrate and nitrogen gas. The nitrogen cycle starts with the absorption of nitrates by microscopic and aquatic plants as certain bacteria in the soil and water convert atmospheric nitrogen into nitrate, a process called nitrogen fixation (Miller, 2005). The nitrogen cycle involves losses and gains that are physically related to use of fertilizers, farm wastes, sewage and industrial activities (Hall, 2003). Sources of ammonia include: sewage discharges; industries using ammonia or ammonium salts; industrial discharges and commercial fertilizers. In surface or ground water ammonium generally results from the decomposition of nitrogenous organic matter, and is one of the constituents of the nitrogen cycle (Table 2.5) (Dallas and Day, 2004). Ammonia is a common pollutant and is one of the nutrients contributing to eutrophication (DWAF, 1996).

Table 2.5: Major potential sources of Nitrogen and Phosphorus (Dallas and Day 2004).

Sources		
Climatic	Weathering of rocks and soil	
	Erosion	
	Rainfall	
	Variability of runoff	
Catchment characteristics	Surface geology	
	Land form	
Anthropogenic	Point sources	Sewage effluent
		Industrial discharge
		Intensive animal enterprises
		Detergents
	Diffuse sources	Agricultural surface runoff
		Disturbance of soil mantle
		Addition of fertilizers
		Manure
		Urban runoff
	Atmospheric deposition	Gases released from agriculture
		Burning of fossil fuels

Nitrite is formed under oxidizing conditions where nitrate is converted to nitrite. It is the intermediate in the conversion of ammonia to nitrate (Dallas and Day, 2004). Nitrite exists naturally as an anion in saline and fresh water and its concentration is increased with discharges that originate from organic industrial waste; treated sewage containing excreta of humans and animals and surface runoff in which fertilizers are dissolved. Although present in low concentrations, nitrite can be very important in wastewater or water pollution studies because it is extremely toxic to most fish and other aquatic species (Tchobanoglous *et al.*, 2004).

Nitrates are produced when nitrogen or ammonia is oxidized. Nitrates are the end products of aerobic stabilization of organic nitrogen (Dallas and Day, 2004). Owing to their soluble nature, nitrates are easily transported in rivers and groundwater (Murphy, 2006). Hence nitrates are ubiquitous in aquatic environments. However, nitrate removal by conventional physico-chemical water treatment technologies is usually very expensive and/or very energy consuming (Rocca *et al.,* 2007). Nitrates are generated by both natural and human sources. In South Africa the most extreme nitrate concentrations are caused through point-source pollution (Holtzhausen, 2005). Non-point sources include, excessive fertilization of agricultural land which has generally been reported as one of the key factors influencing the nitrate groundwater pollution (Yu *et al.*, 2012). Nitrates stimulate plant growth however, elevated nitrate concentrations in the aquatic environment results in eutrophication. Nitrate and phosphate nutrients can lead to eutrophication of waterways (Cheesman, 2005). High nutrient concentration in surface water bodies, nitrogen and phosphorus in particular, is an increasing environmental concern worldwide because it is a major reason for eutrophication of lakes and rivers (Yu *et al.,* 2012). The blanket term "eutrophication" refers to a collection of symptoms caused by an overabundance of nutrients entering fresh, estuarine or marine waters (Burkholder, 2001). Epidemiological studies in Canada and South Australia have shown a statistically significant increase in congenital malformations associated with nitrate-rich well water (AWA, 1992). Generally, the discharge of nitrogen (the forms of which are ammonia, nitrite and nitrate) to receiving waters leads to significant effects on water quality, causing phytoplankton blooms and resulting in eutrophication of water bodies (Xia, 2008).

2.3.1.1. i. Chloride

Chloride is an anion of chlorine and they are essential components of living systems, being involved in the ionic, osmotic and water balance of body fluids (Dallas and Day, 2004). Chloride ions are quite often the result of salt deposits that dissolve in water. These salts may include: sodium chloride and magnesium chloride. Chloride inputs to surface waters can arise from irrigation return flows, sewage effluent discharges and various industrial processes (DWAF, 1996). Chloride is also found naturally in groundwater because of leaching from rocks and soils in contact with the water body. Chlorides in natural water result from the leaching of chloride-containing rocks and soils with which water comes into contact, and in coastal areas from saltwater intrusion (Tchobanoglous *et al.*, 2004). Chloride is an aesthetic parameter, and as such may have impacts on the taste; smell or colour of water. At high concentrations, chlorides cause corrosion of piping and metals; causes water to have an unpalatable taste and in extreme cases, may cause death in aquatic organisms. The extent of the presence of chloride may also serve as an indication of deterioration in water quality.

2.3.1.1. j. Permanganate Value (PV4)

Potassium permanganate is utilized to quantitatively determine the total oxidisable constituents in a water sample. Applications of potassium permanganate exploit its oxidizing properties (Reides, 2002). The PV4 assesses the available oxygen or oxidizing capacity of the water body and the extent of organic pollution. PV determines the chemically oxidisable organic matter in a sample (Tamime *et al.,* 1999). This assessment is important in that when aquatic organisms, including microorganisms consume the dissolved oxygen in water as part of their metabolism, the reduction in dissolved oxygen may cause death in some of these organisms as well as cause other negative impacts on water quality, as a result of reduced oxygen availability.

2.3.1.2. Microbiological Parameters

Microbiological assessment of water quality is essential in identifying the presence of microorganisms associated with the transmission of water-borne diseases and the presence of fecal pollution. Continuous fecal pollution in source water is a global problem that is particularly debilitating to rural communities that are directly dependent on untreated source water for all their domestic and other purposes (Bezuidenhout *et al.*, 2002). Ideally water destined for human consumption should be free from microorganisms, however in practice this is an unattainable goal (Gray, 1999). In water bodies contaminated by human and animal wastes, pathogenic microbes are often widely present (Naidoo, 2005). It is impractical to monitor all types of microorganisms in wastewater on a regular basis; therefore indicator organisms are measured as surrogates. (Tempelton and Butler, 2011). In addition, the tests required to detect specific pathogens are still considered time intensive and expensive (Ritter, 2010). Indicator organisms are used to give an indication of the possible presence of pathogens (WRC, 2006); and provide evidence of fecal contamination from humans or warm-blooded animals (Ritter, 2010). The most common indicator organisms are total and fecal coliforms (Tempelton and Butler, 2011). Therefore, if these organisms are found in water, this is an indication of fecal contamination and renders the water unsafe to consume without adequate disinfection. Fecal indicator bacteria are considered to be useful indicators of fecal contamination of the aquatic environment, generally associated with an increased risk of contracting gastrointestinal and respiratory illness (Haile *et al*., 1999). *Escherichia coli (E.coli)* is used as a bacterial indicator of fecal pollution by warm-blooded animals (generally interpreted as human fecal pollution). *E.coli* may comprise up to 97% of coliform bacteria in human feces. It is a bacterium of enteric origin whose occurrence and abundance allows for its use in defining the sanitary quality of water and wastewater (Liberti *et al*., 2000). The presence of *E.coli* is an indicator of the potential presence of other microbial pathogens including viruses and parasites, as well as bacterial pathogens such as *salmonella spp., Shingella spp., Vibrio cholerae spp., campylobacter jejuni ., Campylobacter coli* and *Yersinia enterocolitica.* These bacteria are responsible for gastrointestinal diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever (DWAF, 1996e).

2.3.2 Water Quality Legislation

Water is one of the most valuable and essential resources that form the basis of all life (Govender *et al.*, 2007). However it is the most poorly managed resource in the world

(Kadewa *et al.,* 2005); and humans have a habit of using water as if there is an unlimited supply (Rogers and Leal, 2010). The self-purification capacity of many rivers has been exceeded, and they now serve as wastewater collectors in many cities around the world. The most obvious effect is growing water stress (insufficient water supplies) occurring broadly around the world (Daigger, 2009). It was predicted in 1989 that in the continent of Africa by 2025, there would be a significant water crisis with two-thirds of the population being water stressed (Showers, 2002). A recent study commissioned by the Water Research Commission describes South Africa's freshwater ecosystems as "in a shocking state" with 82%, 65% and 57% of estuarine, wetland and river ecosystem types respectively threatened (WRC, 2011). These problems are further compounded by the zero dilution capacity of many rivers in South Africa which means that all pollutants and effluent streams will increasingly need to be treated to ever higher standards before being discharged into communal waters or deposited in landfills (Turton, 2008). In the absence of water management related regulation or lack of effective and efficient regulation, water quality will deteriorate to critical levels. This deterioration of water resources needs to be controlled through effective and feasible concepts of urban water management (Nhlapi and Gijzen, 2005). In addressing water quality management, South Africa has revised its water policy to facilitate the protection; sustainable utilization; conservation; management and regulation of its limited water resources. To give effect to this endeavour, water quality management in South Africa is governed by a hierarchical suite of environmental legislation, which include: The Constitution of the Republic of South Africa Act No. 108 of 1996, which is the supreme law of the country; framework environmental legislation such as the National Environmental Management Act No. 107 of 1998; as well as sectorial environmental legislation such as The National Water Act No 36 of 1998; The National Water Resources Strategy and The South African Target Water Quality Guidelines(TWQGR).

2.3.2.1. The Constitution of the Republic of South Africa Act No. 108 of 1996.

The Bill of rights, embodied in the Constitution includes the following water related principles:

- Achieving of equitable access to water, which includes equity of access to the provision of water services; the utilization of water resources and to the benefits derived from the use of water resources.

- Achieving sustainable water utilization through progressive adjustments to water use in order to achieve a balance between water availability and water requirements and by taking steps to protect water resources.

- Achieving effective and efficient water utilization to optimize social and economic benefit.

In South Africa water is treated, first and foremost, as a social commodity to which people and the aquatic environment have a legal protected right (Du Plessis, 2003). Section 24 of the Constitution prescribes that every person shall have the right to an environment which is not detrimental to his or her well-being. The Constitution also refers to measures for preventing pollution and ecological degradation; promoting conservation and ecologically sustainable utilization and development of natural resources. This creates imperatives for pollution prevention; prevention of ecological degradation and sustainable utilization of aquatic resources.

2.3.2.2. The National Water Resources Strategy (NWRS).

The NWRS divides the country into 19 water management areas, each being managed by a catchment management agency. This serves as a framework for the protection; utilization; conservation; management and regulation of South Africa`s water resources. According to Section 5(4)(a) of the NWRS, its purpose is to set out the strategies, objectives, plans, guidelines and procedures of the minister and institutional arrangements relating to the protection, use development, conservation, management and control of water resources within the framework of existing relevant government policy to achieve:

- The purpose of this Act
- Any compulsory national standards prescribed under Section 9(1) of the Water Services Act, 1997 (Act No 108 of 1997); (W&S AFRICA, 2012).

2.3.2.3. The National Water Act (NWA) No. 36 of 1998.

The NWA supplies the regulatory background for water resource management. The concepts of Resource Quality Objectives and Resource Quality that were introduced by the NWA necessitate that water quality management also takes responsibility for the management of the aquatic ecosystem quality (in-stream and riparian habitat, and aquatic biota quality). Protection of basic human and ecological needs, economic efficiency and social equity are the most important pillars guiding water resource allocation and use under the new National Water Act of South Africa (Water SA, 2005. It is a challenge to balance economic and social development with sustainable use of water resources. This challenge is referred to in the NWA as the aim to balance long-term protection of water resources. Chapter 14 of the NWA provides for the monitoring of the quality of South Africa's water resources, since what cannot be measured, cannot be managed (Schreiner and Hassan, 2011). Section 26(1) of the NWA provides for the use of water resources to be monitored, measured and recorded; the prohibition of any activity for the protection of a water resource as well as the requirement for waste treatment before discharge into a water resource. The objective of the NWA is to ensure that the country's water resources are protected, utilized, developed, conserved, managed and regulated in accord with the following considerations:

- Meeting the basic needs of the present as well as future generations;
- The promotion of equitable access to water;

- Redress of past racial and gender discrimination;
- The promotion of efficient, sustainable and beneficial utilization of water in the public interest;
- Facilitation of social and economic upliftment;
- Provision for increasing demands for water use;
- Protection of aquatic and related ecosystems as well as their biological diversity;
- Reduction and prevention of pollution and degradation of water resources;
- Honoring international obligations and
- Promotion of dam safety and management of flood and drought situations.

The NWA introduced Water Management Areas; Catchment Management Agencies; Integrated Catchment Management and Catchment Forums to facilitate the objectives listed above.

2.3.2.4. The National Environmental Management (NEMA), Act No. 107 of 1998.

NEMA provides umbrella legislation by establishing principles and determining procedures for co-operative governance and co-ordinated environmental functions exercised by organs of the state. It identifies institutions that promote cooperative governance and determines the procedures to co-ordinate environmental functions of state departments.

2.3.2.5. The South African Water Quality Guidelines (TWQGR).

A target range for water quality has been set by the Department of Water Affairs, as a response to increasing deterioration of South Africa`s water resources. The water quality guideline approach is based on the principle that receiving waters have a capacity to assimilate pollution up to a point at which it becomes detrimental towards specified water users (Fruggle and Rabie, 2003). The natural assimilative capacity of river water is breached when there is excessive discharge of undesirable substances in the river water. TWQGR provides for the acceptable level or range at which a substance may be found in water so as not to compromise the water quality and cause a detrimental effect on water quality. This "no effect range" is the range of concentrations or levels at which the presence of a constituent would have no known or anticipated adverse effect on the fitness of water for a particular use or on the protection of aquatic ecosystems (DWAF, 1996). The TWQGR applies to water use for irrigation; livestock watering; domestic use; aquatic ecosystems; industrial and recreational use.

2.4. ANTHROPOGENIC IMPACTS

Anthropogenic impacts are a reference to those human activities that have an influence on water quality. Eutrophication is often a consequence of human activities such as agriculture; urbanization and industrialization (Varioli *et al.,* 2005). Domestic and commercial activities contribute synthetic organic chemicals to wastewater discharges; agricultural runoff; urban runoff and leachate from contaminated soils and such organic contaminants include pesticides (such as atrazine and aldicarb), solvents and metal degreasers (such as trichlorobenzene; tetrachloroethylene; trichloroethylene and trichloroethane) and a family of compounds formerly in wide use, the polychlorinated biphenyls (Ritter, 2010). Land based activities in the various river catchments greatly affect the natural variation of water quality.

2.4.1. Agricultural; Forestry and Mining Activities

Related activities such as land clearance; irrigation; ploughing of fields; spreading of fertilizers and pesticides on farmlands as well as livestock farming have significant impacts on the quality of water. Soil disturbance accompanying forest ploughing, drainage, road works and harvesting operations has the potential to cause large quantities of sediment to enter the stream or river, resulting in increased turbidity and siltation (Nisbet, 2001). The employment of poor farming methods (such as non-contour ploughing), coupled with the injudicious or excessive application of fertilizers such as urea, ammonium nitrate or ammonium phosphate may result in a washout of these fertilizers into adjoining rivers periods of heavy rainfall, causing elevated concentrations of nitrate, ammonium and phosphorus in receiving waters. Pressure to increase productivity of agricultural systems in order to meet domestic and international demand has resulted in the intensification of agriculture, exploitation of more land and greater reliance on pesticides, fertilizers and imported animal feedstuff (Shabalala and Combrink, 2012). Typical sources of water pollution associated with agricultural systems include livestock grazing, nitrates and phosphates in fertilizers, metals, pathogens, sediments and pesticides (Shabalala and Combrink, 2012). Wastes discharges from livestock grazing are rich in nitrogen and phosphorus and are bacteriologically contaminated (Shabalala and Combrink, 2012). Excessive influx of fecal materials from anthropogenic sources and animal farms can pose major problems due to the potential adverse health impacts when the waters are to be used for potable, recreational and shellfish harvesting purposes (Reeves *et al*., 2004). Impacts from forestry include removal of large canopy trees and soil disturbance. Removal of forest cover reduces evapotranspiration of rainfall and increases surface storm-water runoff, causing erosion and suspended sediment pollution of receiving waters (Lee *et al*., 2004). Mining operations alter the land topography, thereby causing high runoff rates; high turbidity and soil erosion. They produce increased quantities of heavy metals in streams and such operations may also release a toxic mix of metals and ore-extracting substances such as cyanide. Acids from mine drainage severely affect water quality. Receiving waters from acidic coal mine drainage normally have a very low pH (down to 2) and a high total dissolved solids (Dallas and Day, 2004).

2.4.2. Industrial Activities

Waste products from the oil and petrochemical industries include oils and oil emulsions as well as chemical process effluent. Effluents from chemical industries often have high loads of suspended solids and high oxygen demand (as a result of biodegradable organic content and reducing chemicals such as sulphides), in addition to elevated concentrations of trace metals, toxic inorganics (egg cyanides and fluorides) organic compounds and nutrients (Dallas and Day, 2004). The lignin in wastewater from the pulp bleaching process in the paper industry results in surface foaming. Textile industries discharge dyed or discolored effluents which may contain chemicals that are toxic to aquatic organisms. Various pollutants from power stations, waste disposal sites and agricultural lands potentially can contaminate groundwater (Sargaonkar *et al.,* 2008).

2.4.3. Urbanization

Urbanization entails the construction of buildings; roads; and sidewalks and the use of chemicals for landscaping, which results in the increase of impervious surfaces that accelerate runoff and pollution of the receiving water body. As urbanization occurs, soils are covered by increasing quantities of impervious surfaces such as parking lots; roads; sidewalks and rooftops which greatly reduces the ability of the earth to infiltrate rainwater, turning much of it into storm water runoff (Ahuja, 2009). Some of the numerous adverse effects on receiving waters from urban runoff include physical effects such as flooding, erosion, sedimentation; physico-chemical effects such as elevated temperatures, dissolved oxygen depletion, nutrient enrichment; toxicity and biological effects such as reduced biodiversity (Marsalek *et al.,* 2002). Ongoing urbanization in recent decades has led to significant changes in both volume and quality of storm water runoff (Figure 2.10) (Walsh *et al.,* 2004). Urbanization affects flood runoff as it produces impermeable surfaces and the construction of sewage and storm drains accelerate runoff. Storm water runoff contains pollutants such as toxic chemicals; fecal contaminants; metals and nutrients that accelerate eutrophication.

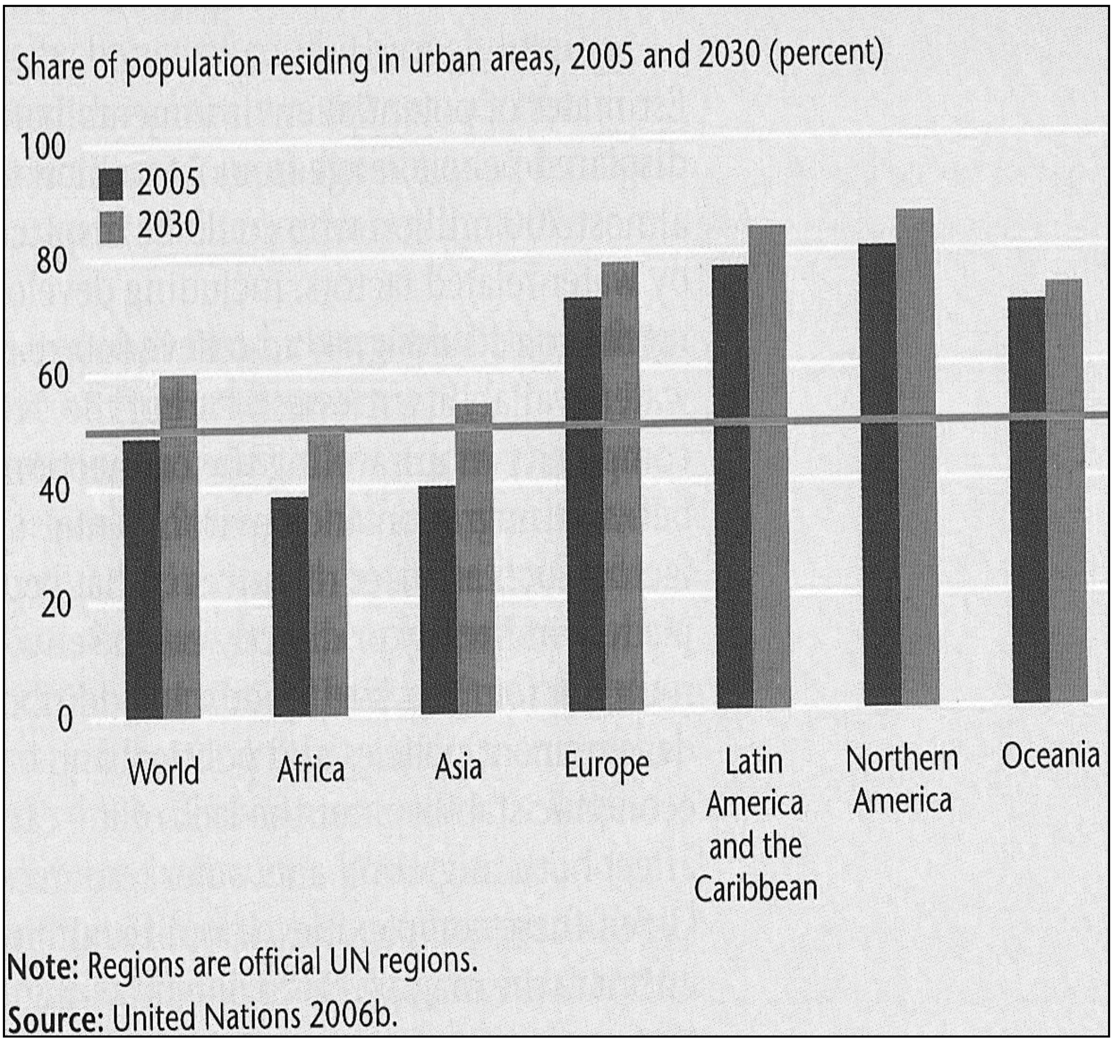

Figure 2.10: World's urban population prediction for 2030 (WWAP, 2009).

Surface runoff (and consequently non-point source pollution) contributes significantly to high level of pathogens in surface water bodies (Sagardoy, 1993). As it moves further downstream, runoff water accumulates more chemical constituents such as heavy metals; organometallics; polycyclic aromatic hydrocarbons; lubricant oils and greases which impact on the riverine water chemistry and are deleterious to biological and aquatic ecosystems (Dallas and Day, 2004). Rapid urbanization results in the proliferation of informal settlements as the demand for housing and services exceeds the provision thereof. On a global scale informal settlements are a significant problem especially in third world countries housing the world`s disadvantaged (May *et al.,* 1998). In 1994, approximately 1.06 million households comprising 7.7 million people lived in informal settlements (Statistics South Africa, 1997). Informal settlements are characterized by a dense proliferation of small make-shift shelters built from diverse materials, degradation of the local ecosystem and by severe social problems (Mazur, 1995). Often informal settlements are constructed close to rivers, for access to water supplies and waste discharges. In many instances sewage and excreta from these informal settlements are discharged into storm water drainage pipes, which directly flow into nearby rivers (Paulse *et al.,* 2007). Fecal contamination from non-point agricultural pollution can also cause deterioration of water quality by emitting significant levels of fecal bacteria and nutrients to waterways (Monaghan *et al*., 2007). Fecal contamination of water catchments occurs from natural wildlife as well as from anthropogenic sources (Mudge and Duce, 2005).

2.5. CONCLUSION

Wastewater, generated from human activities has many negative impacts if it is inadequately treated. Adequate treatment necessitates various processes to ensure compliance with discharge requirements and no adverse effects on the water quality of the receiving water system. Processes for wastewater treatment are sequentially categorized as physical; biological and chemical methods. The quality of water is determined by comparison of the physico-chemical and microbiological assessment with the legislated water quality guidelines. Water quality legislation in South Africa facilitates holistic water management which includes its protection; sustainable utilization and conservation. Anthropogenic activities are predominantly land based human activities which result in a severe decline in water quality when the environmental impacts are overlooked. These impacts include: washout of pesticides and fertilizers; industrial waste discharges; runoff from informal settlements and impervious surfaces.

CHAPTER THREE

THE STUDY AREA

3.1. INTRODUCTION

The study area comprises three river systems of the eThekwini Municipality, each of which receives a discharge exceeding 4 million litres per day from wastewater treatment works located within their catchments, namely:

- uMhlangane River into which the KwaMashu Wastewater Treatment Works discharges (KWWTW);
- uMgeni River into which the Northern Wastewater Treatment Works (NWWTW) discharges, and
- uMhlatuzana River into which the uMhlatuzana Wastewater Treatment Works (UWWTW), discharges.

Using the location of discharge from these wastewater treatment works as the reference point, the study area for each river is further subdivided as the riverine area upstream of the discharge point and the riverine area downstream of the discharge point.

3.2. DESCRIPTION OF THE eTHEKWINI MUNICIPALITY (EM).

EM is located in the province of KwaZulu-Natal, which is one of nine provinces in South Africa. The municipality operates 27 wastewater treatment works with a cumulative treatment volume of 460 million liters of wastewater daily (WSDP, 2012). The region is characterized by a typical warm sub-tropical climate of KwaZulu-Natal with an average winter temperature of 16°C between the months of May to July and an average summer temperature of 27°C between the much warmer months of January to March, coupled with an average annual rainfall of 1054 mm mainly during the summer months (MER/ERM, 2011). Approximately 80% of the annual rainfall is received in the warmer summer months, resulting in regular catchment flooding and high river flow velocities (Tinmouth, 2009). The predominant natural vegetation types within the catchments comprise of coastal forest, thornveld, bushland and grassland, which cumulatively account for 23% of the natural vegetation within the broader catchment and are mainly restricted to recreational parks and nature reserves (MER/ERM, 2011). In terms of its geology, the area predominantly comprises granites and gneisses of the Basement Complex, sandstones of the Natal Group, glacial tillite and shales of the Dwyka and Ecca Groups and minor Karoo dolerite intrusions (MER/ERM, 2011).

3.3. THE uMHLANGANE RIVER AND KWWTW

The uMhlangane River into which the KWWTW discharges, is located upstream from uMgeni Estuary (Figure 3.1). The uMhlangane River is a tributary of the uMgeni River and has a length of 50 km (MER/ERM, 2011).

Along its banks are located the residential areas of Phoenix, Kwamashu, Avoca and Effingham; the industrial areas of Phoenix, River Horse Valley and Springfield Park; as well as several informal settlements and some agricultural plots (WSDP, 2012).

Figure 3.1: Location of KWWTW and uMhlangane River (EWS, 2011).

In the upstream areas of Phoenix and Kwamashu, a portion of the river is canalized in the vicinity of the Phoenix Industrial Zone. The KWWTW is located on the South bank of the river, immediately downstream of the Phoenix Industrial Zone. Some of the up-catchment informal settlements are located in this area and all have inadequate access to proper sanitation facilities. Some residents in this vicinity have livestock and the cattle and goats from these settlements frequent the river for drinking water and grazing along the banks. Subsistence farming is practiced along the river in close proximity to the WWTW. Flow volumes increase appreciably downstream of the WWTW due to the discharge from the plant. KWWTW has been designed to treat 59 million liters of wastewater per day (ML/day). The current dry weather inflow to the works averages 67 ML/day. The site is currently being expanded to treat 84 ML/day to accommodate the anticipated 2030 flows and 100 ML/day for the ultimate flow (WSDP, 2012) (Figure 3.2).

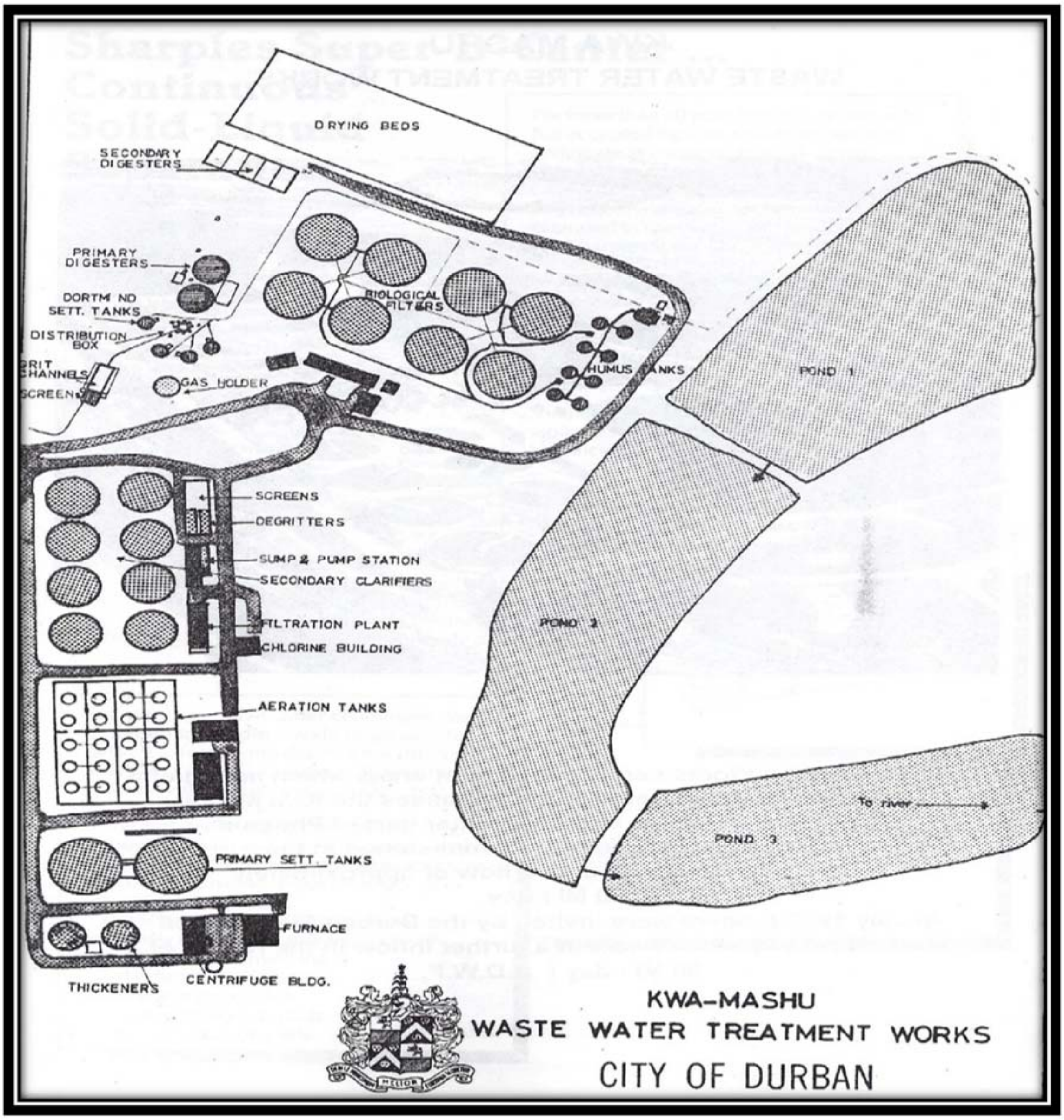

Figure 3.2: KWWTW Flow and Process Diagram (EWS, 2011).

The nature and extent of treatment is prescribed by the General Standard and Exemption Permit 1523 B, which is issued by the Department of Water. In terms of treatment standards, KWWTW has been granted an Exemption Permit, No.1523B, which provides increased discharge volumes and *E.coli* Limits of 1000cfu/100ml.

3.4. THE uMGENI RIVER AND NWWTW

The uMgeni River into which Northern Wastewater Works discharges has a catchment of 4416 km2 and a length of 255 km (WRC, 2002) (Figure 3.3). The river rises in the Dargle Range at an altitude of about 1830 meters above sea level (Begg, 1989). At this point the river flows through an undisturbed region.

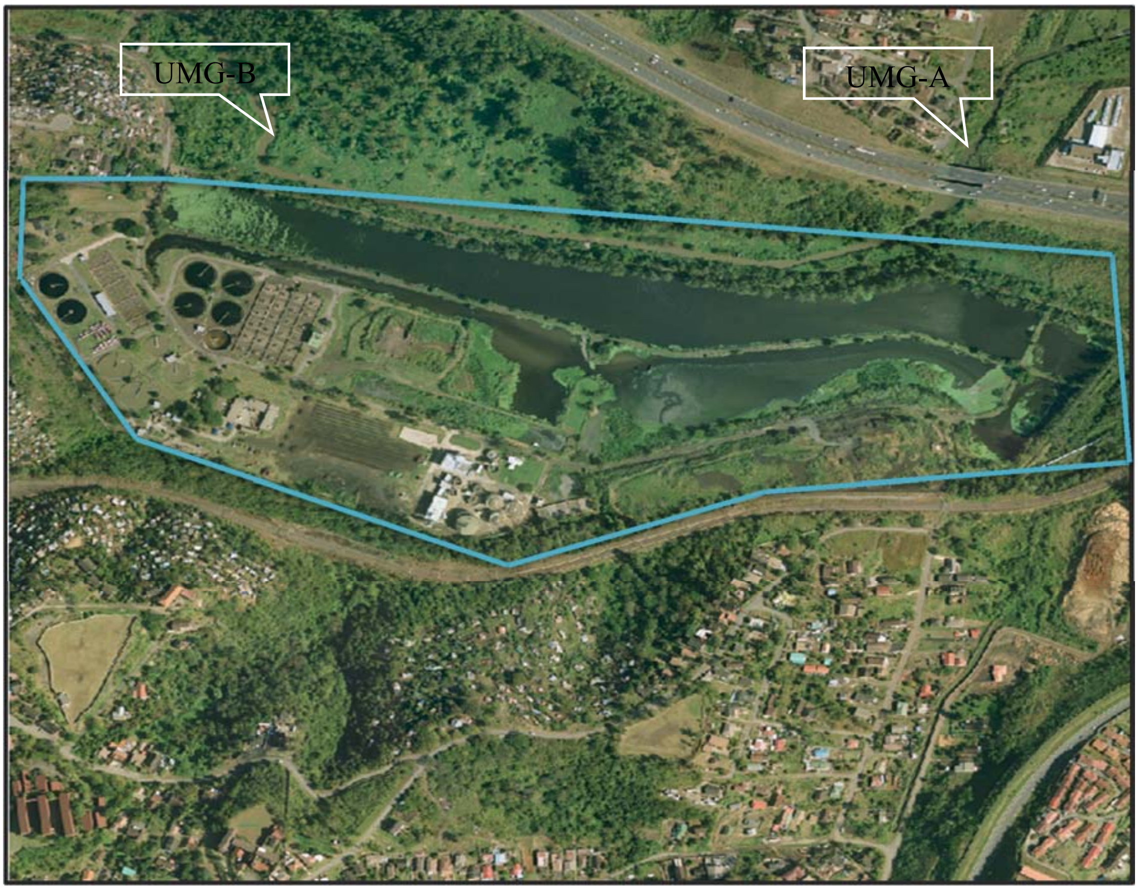

Figure 3.3: Location of NWWTW and uMgeni River (EWS, 2011).

From Inanda Dam, the uMgeni River flows through the Valley of a Thousand Hills with a gentle gradient for 24 km before it flows out to the sea at Durban (WRC, 2002). This section of the river has undergone significant modification to accommodate human activities including intensive, large scale urbanization and modification of the river course (WRC, 2002).The river flows through the valley , flanked by vast residential. Commercial and industrial areas with tributaries draining these areas into the uMgeni River.

Land use change resulting from the establishment of Springfield Industrial Park, Springfield Industrial (north of the uMgeni River) and general urbanization has removed the majority of riparian vegetation and to a large extent canalized the system. The uMgeni River provides a large source of building sand and consequently sand winning operations have become a common occurrence at various points along· the river; however these operations have removed the protective riverine vegetation and severely undercut the river bank (Mulder, 1984). No fewer than 2 sand mining operations are found along the banks of the river with resulting exposed soils which exacerbates soil erosion during heavy rainfall periods. The upper reaches of the river close to Reservoir Hills has been found to harbour appreciable amounts of water hyacinth. Water hyacinth is considered one of the world`s worst weeds, invading lakes, canals and rivers (Holm *et al.*, 1977).

NWWTW has a design capacity of 58 ML/day and its current dry weather inflow is 54 ML/day (Figure 3.4). The works has undergone expansion to increase treatment capacity to 66 ML/day and an ultimate flow capacity of 99 ML/day (WSDP, 2012). This treatment works operates under the Department of Water permit 1525B which permits a discharge of *E.coli* not exceeding 1000cfu/100ml.

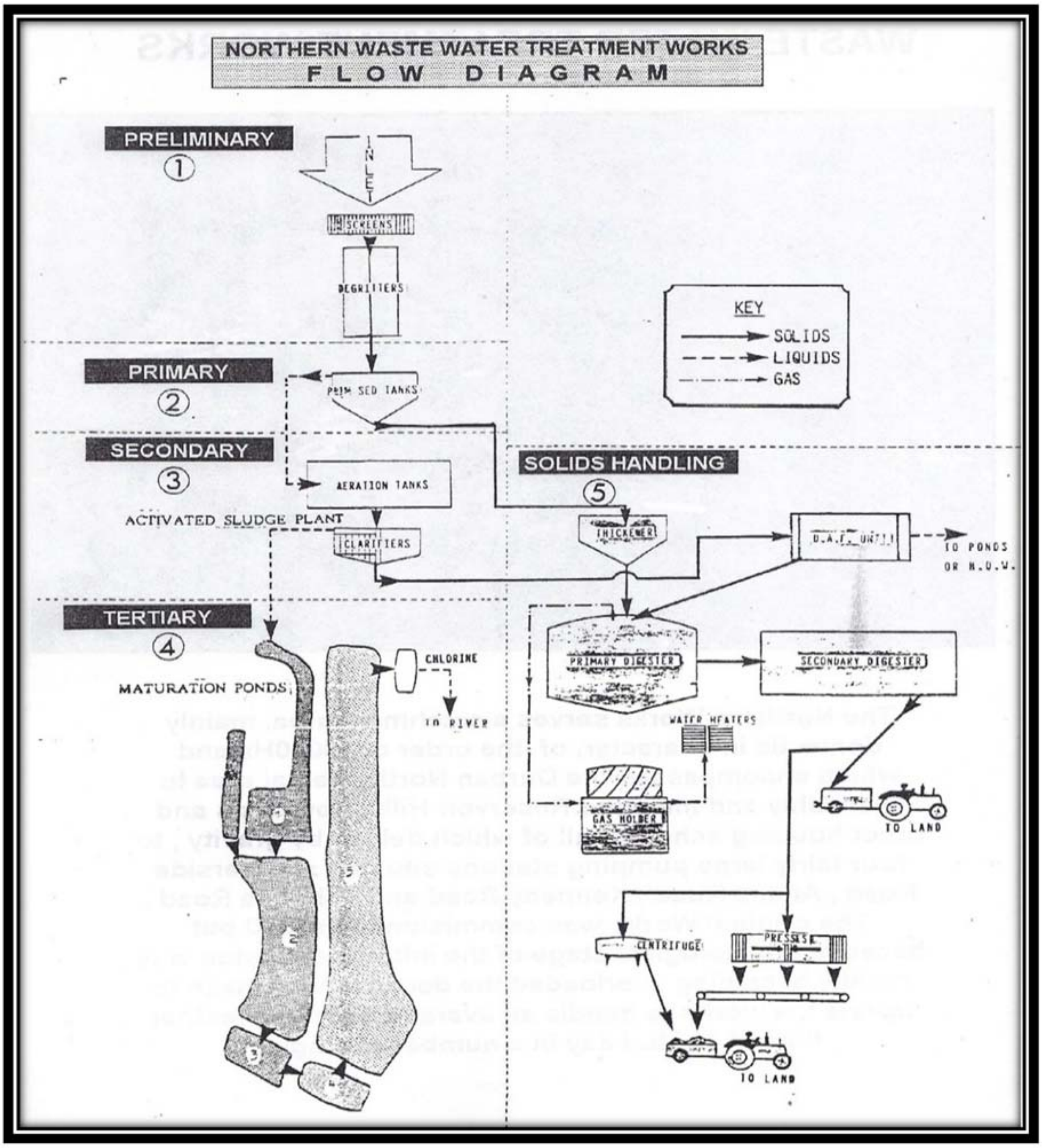

Figure 3.4: NWWTW Flow and Process Diagram (EWS, 2011).

3.5. THE uMHLATUZANA RIVER AND UWWTW.

The catchment area and river length of the uMhlatuzana Rivers is 113 km2 and 50 km, respectively (MER/ERM, 2011). The uMhlatuzana River into which UWWTW discharges (Figure 3.5) carries treated effluent from its upper reaches emanating from the Hillcrest Wastewater Treatment Works. A wastewater pumping station (with evidence of recent overflows) is also located along the river. Further downstream there is evidence of quarrying operations as well as the Marianhill Industrial Area which has a mix of light and heavy industries. Residential areas are located in close proximity to the river, and tend to increase along the area adjacent to UWWTW. Downstream of the uMhlatuzana Wastewater Treatment Works, the discharge from the works tends to dilute and enhance the water appearance. Habitat integrity, riparian and the instream condition of the river are fair, however in the lower reaches the riparian habitat quality deteriorates to poor (WRC, 2002).

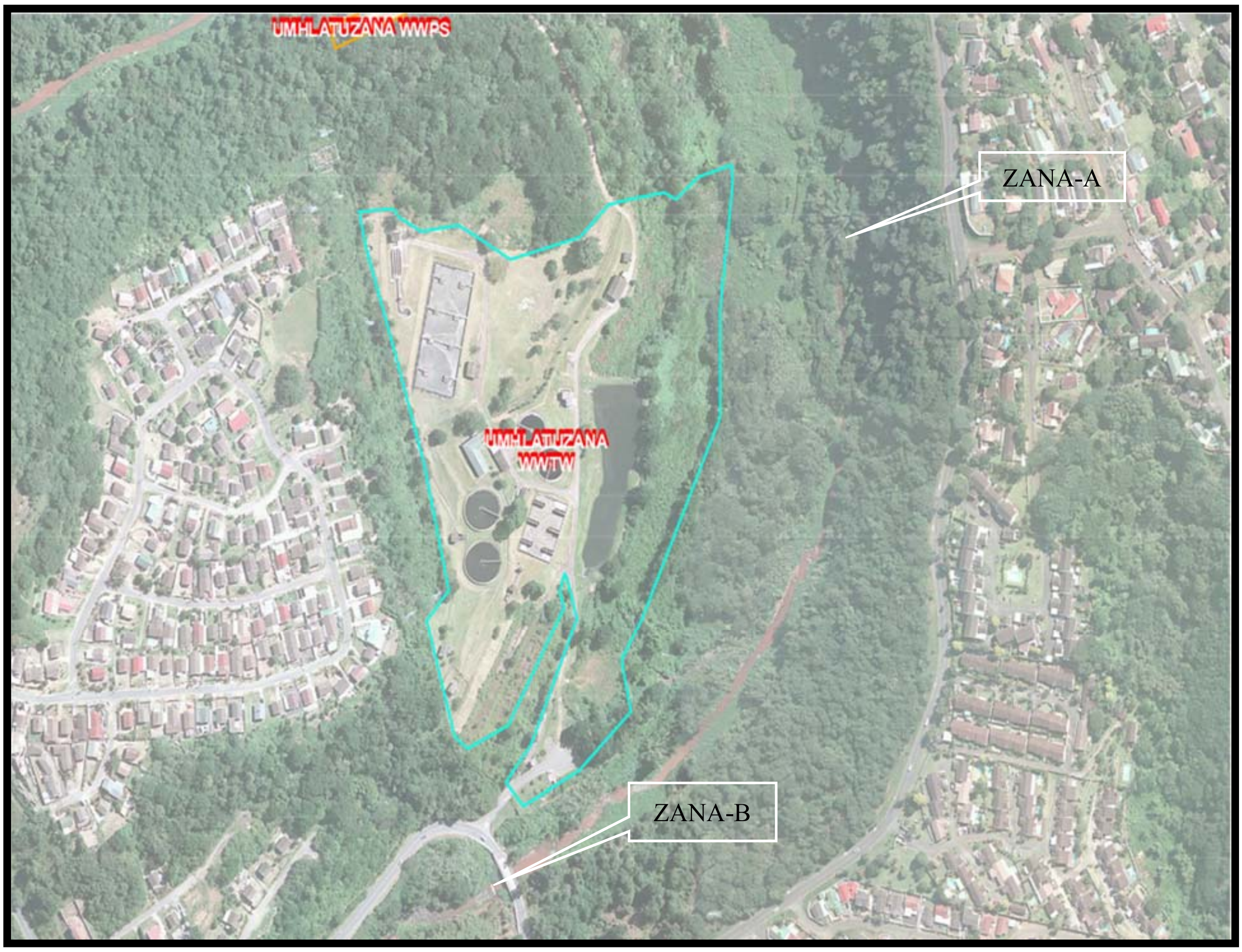

Figure 3.5: Location of UWWTW and uMhlatuzana River (EWS, 2011).

The UWWTW had been designed to treat inflow of 15 ML/day and its current dry weather inflow averages 10.5 ML/day (Figure 3.6). No expansion is planned for this works at this stage. Trunk sewers from Hillcrest to UWWTW are at the Environmental Impact Assessment stage (WSDP, 2012).The nature and extent of treatment is prescribed by permit 651 B, which is issued by the Department of Water and permits a maximum *E.coli* discharge of 1000cfu/100ml.

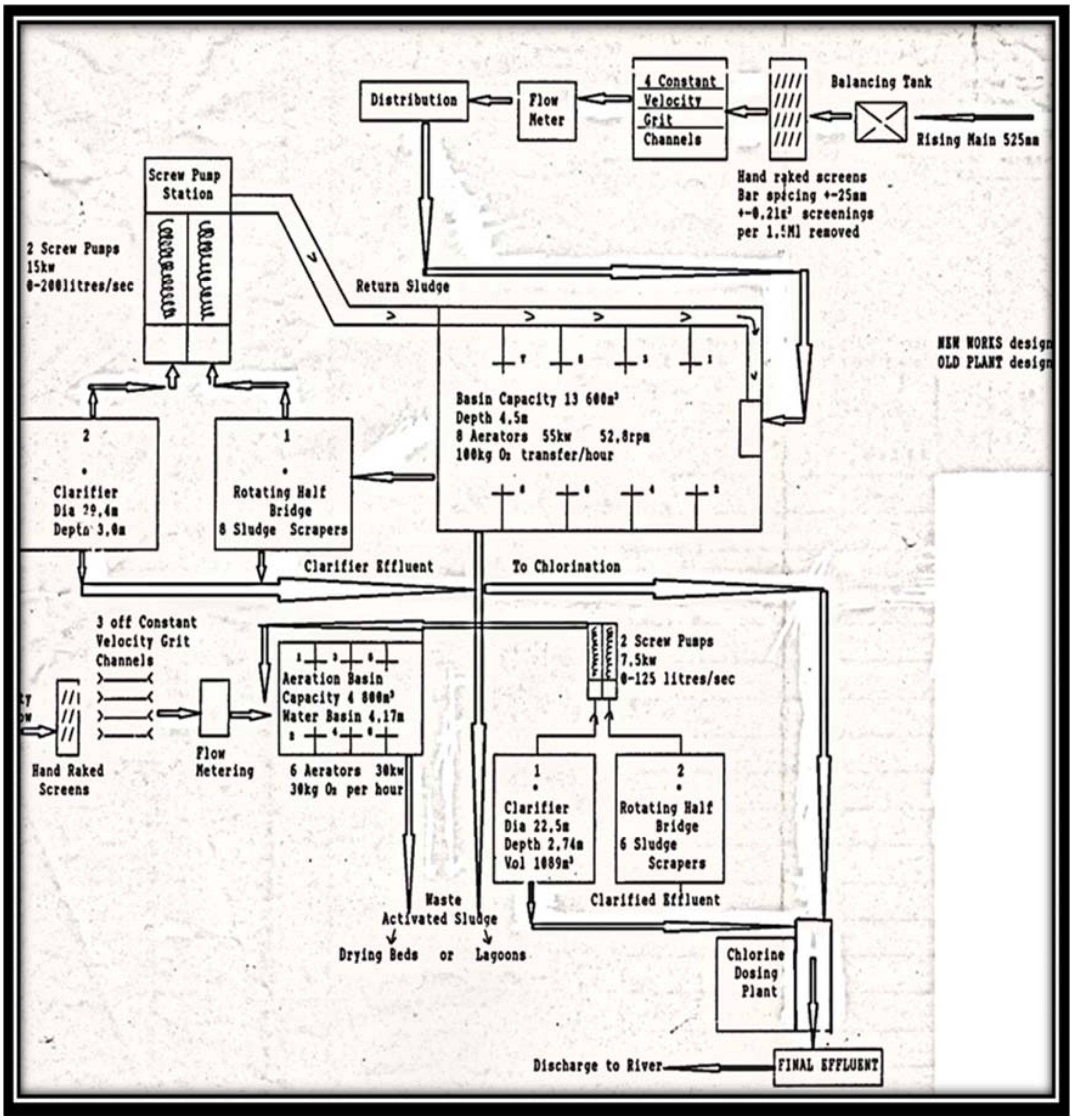

Figure 3.6: UWWTW Flow and Process Diagram (EWS, 2011).

3.6. CONCLUSION

The uMhlangane River; uMgeni River and uMhlatuzana River flow through areas of much activity which include: residential; industrial; agricultural areas as well as sites with informal settlements. The process and flow diagrams for the WWTW present an overview of the nature and extent of wastewater treatment as prescribed by the General Standard and Exemption Permits issued by the Department of Water for the treatment and discharge of wastewater into these rivers.

CHAPTER FOUR

DATA COLLECTION AND METHODOLOGY

4.1. INTRODUCTION

This chapter identifies the sampling site locations and unique names as well as the methodology of sample collection to ensure integrity and authenticity. Also, the nature, location and method of sample analyses are discussed and the comparative guidelines for evaluation of the results obtained are noted.

4.2. LOCATION OF SAMPLING SITES FOR DATA COLLECTION

Water samples were taken from the uMhlangane; uMgeni and uMhlatuzana Rivers at 6 different locations. 2 sampling points were located on each of the 3 rivers with one site located upstream and the other located downstream of the effluent discharge points. The sample sites are identified in Table 4.1 below.

The exact location of the sampling sites were identified on the first reconnaissance survey. The rationale for the choice of these sample sites was to obtain results which could identify the sources and nature of impacts on the riverine water quality.

Table 4.1: Tabulated description of the sample sites (Source: Author).

Unique Site Name	Location Of The Site
Gane 1	uMhlangane River - above the discharge point
Gane 2	uMhlangane River - below the discharge point
Umg 1	uMngeni River - above the discharge point
Umg 2	uMngeni River - below the discharge point
Zana 1	uMhlatuzana River - above the discharge point
Zana 2	uMhlatuzana River - below the discharge point

4.3. METHODOLOGY OF SAMPLE COLLECTION

Water samples were taken in duplicate on a monthly basis from each point from January 2012 to December 2012 to accommodate seasonal representivity - a cumulative total of 144 samples. Prior to sampling, the sample bottles were washed thoroughly with de-ionized water and thereafter thoroughly rinsed with water on site before use. Samples were collected by inserting the cleaned 1 liter plastic bottles into the water at a point that was reflective of the river`s flow regime until the bottle was completely filled with the sample. Immediately after each sample was taken, the sample bottles were capped and sealed. At the following sites: Gane 1; Umg 2 and Zana 2, due to dense riparian vegetation, the collection of samples had to be conducted off the bridge at these respective sites. These samples were collected by lowering a bucket into the water from the bridge, suspended by a rope, thereafter the water sample so retrieved would then be placed into one of the sample bottles which were pre-washed with deionized water and rinsed as previously indicated. The samples collected from the 6 sites were appropriately handled to ensure retention of integrity and were appropriately labelled. Each bottle was tagged to record its location; date and time of sampling and unique site name. Thereafter samples were carefully packed and transported, in a cooler box to prevent possible physical, chemical or biological changes to the samples, to the laboratory for analyses.

4.4. METHODOLOGY FOR ANALYSES OF DATA

A set of the duplicated samples was analysed at the University of KwaZulu-Natal, School of Agricultural, Earth and Environmental Sciences laboratory. Sampling analyses were conducted by using a YSI (Yellow Sprigs Instrument) 6920 Multi-parameter Sonde and the 650 MDS (Multi-parameter Display System) (Figure 4.1), for: chlorides; nitrates; nitrites; ammonia, total dissolved solids (TDS) and dissolved oxygen (DO). The remaining set of duplicated samples was analysed at the eThekwini Municipality's central laboratory in Pinetown for: chemical oxygen demand (COD); conductivity; pH; pv4; turbidity and *E.coli.* The results of the aforementioned analyses were evaluated against the Target Water Quality Guidelines Range (TWQGR) as stipulated by the Department Of Water as well as the discharge permit prescriptions for each of the 3 wastewater treatment works. In addition, the t-test which is a powerful parametric test to establish whether there is a significant difference between the means of two samples at the significance level (in this study a significance level less than or equal to 0.05), was conducted on all samples to identify any significant change in water quality at the sample sites. Tabulated results for each of the parameters as well as extrapolated graphical plots informed these evaluations and assessments.

i) ii)

Figure 4.1: The 650 MDS Multiparameter Display System and ii) The 6920 Multiparameter Sonde (http://www.ysihydrodata.com/products.htm)

4.5. CONCLUSION

The selection of the 6 sampling sites enabled the identification of the source of impacts originating either up streaming or downstream of the discharge point. Sample collection; storage; transport and analyses were done using scientific methods to ensure the authenticity of the process. The sampling was duplicated for analyses at 2 laboratories.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1. INTRODUCTION

The tabulated results and graphical comparisons of the sampling from the uMhlatuzana River (Zana A and Zana B); uMgeni River (Umg A and Umg B) and the uMhlangane River (Gane A and Gane B), at the sample point above (A) and below (B) their respective wastewaster treatment works discharge point, are attached as Appendix A. The results for the water quality parameter are discussed as follows:

- in terms of compliance with the TWQGR for aquatic ecosystems (DWAF, 1996);
- in comparison with the general requirements for purification of wastewater as per Regulation 991 (DWAF, 1984); and
- for the t-test analyses to identify any significant change in water quality upstream and downstream of the WWTW.

The TWQGR for pH; Chloride; Ammonia; TDS and DO for Aquatic Ecosystems are discussed below. There are no specific TWQGR for COD; PV4; Conductivity; Turbidity; *E.coli;* Nitrite and Nitrate as respects Aquatic Ecosystems. The results were further discussed in comparison with the general requirements for purification of wastewater as per Regulation 991 (DWAF, 1984); for pH; Ammonia; DO; COD; Conductivity and *E.coli*. There are no general requirements prescribed by DWAF for the other water quality parameters in this scope of study. The t-test analyses were conducted for all parameters and the results are discussed below.

5.2. Potential of Hydrogen (pH)

The TWQGR for pH as respects Aquatic Ecosystems is 0.5 of a pH unit variation. From Appendix A the results for all sample sites except for 1 at Zana A were within the TWQGR for Aquatic Ecosystems. This compliance indicates the rivers are not significantly impacted by factors that influence pH; however there was a significant increase (0.12) in pH from Umg A to B. As site B is located at the WWTW discharge point, this discharge is likely the cause of the pH increase. The pH of natural waters is influenced by various factors and processes, including temperature, discharge of effluents, acid mine drainage, acidic precipitation, runoff, microbial activity and acid-forming substances released into the atmosphere as well as the geology and geochemistry of the rocks and soils of a particular catchment area (DWAF, 1996a). The average pH for Zana A; B; Umg A; B; Gane A and B was 7.66; 7.68; 7.31; 7.43; 7.66 and 7.63 respectively. These results are normal and within the acceptable range, since according to DWAF (1996b), most fresh waters in South Africa, are relatively well buffered and more or less neutral, with pH ranges between 6 and 8. The waters have remained more or less neutral, while in 2 instances reaching a mildly alkaline and a mildly acidic condition.

In terms of the general requirements for purification of wastewater, regulation 991 specifies a pH of between 5,5 and 9,5 (DWAF, 1984). As indicated above, the average pH at each site meets the general requirements.

From Appendix A the t-test results for pH at Zana and Gane indicate that t.calc < t.crit. This implies that there is no significant difference in the water quality water with respect to pH when one compares the sample point upstream with that downstream of the WWTW ($p \leq 0.05$). However, in the case of Umg the results indicate a significant difference between the upstream and downstream water quality since t.calc > t.crit (2.0217>1.717); ($p \leq 0.05$). As indicated above, the most likely reason for this increase in pH from upstream to downstream is the discharge from the WWTW.

5.3. Total Dissolved Solids (TDS)

The TWQGR for TDS as respects Aquatic Ecosystems is < 15% variation from the normal cycles of the water body. According to DWAF (1996), changes in the long-term shifts in the TDS concentration are more important than single values; therefore, mean or seasonal mean values for the concentrations in a data set should be compared with the TWQGR. From Appendix A, the mean for Zana A; B; Umg A; B and Gane A; B were: 297.58mg/l; 402.08mg/l; 385.75mg/l; 612.66mg/l; 478.91mg/l and 613.33mg/l respectively. In comparing the mean of each of the A sites with its corresponding B site the TDS increased from the A sites to the B sites by 135%; 159% and 128% for Zana; Umg and Gane respectively. These variations far exceed the TWQGR for TDS as respects Aquatic Ecosystems. With 1 exception from Gane A to B; the TDS increased from A to B for all sites. According to DWAF (1996b), salts accumulate as water moves downstream because salts are continuously being added through natural and anthropogenic sources whilst very little is removed by precipitation or natural processes. Domestic and industrial effluent discharges and surface runoff from urban, industrial and cultivated areas are examples of the types of sources that may contribute to increased TDS concentrations. Since there is a significant increase at the discharge point (B), the WWTW effluent is singled out as the cause of this increase. The elevated TDS at sites above the WWTW discharge points is attributed to palaeozoic and mesozoic sedimentary rock formations TDS concentrations are generally in the range of 200 - 1 100 mg/l in water in contact with palaeozoic and mesozoic sedimentary rock formations (DWAF, 1996b).

From Appendix A the t-test results for TDS at all sites indicate there is a significant difference between the upstream and downstream water quality since t.calc > t.crit ($p \leq 0.05$). The most likely reason for this increase in pH from upstream to downstream has already been discussed above.

5.4. CHLORIDES

The TWQGR for Chlorides as respects Aquatic Ecosystems is 400mg/l. The results for chlorides at all site complied with the TWQGR. The average Chlorides for Zana A; B; Umg A; B and Gane A; B was 54.25mg/l; 59.25mg/l; 58.67mg/l; 137.17mg/l; 64.33mg/l and 102.83mg/l; respectively. This is typical for chlorides as concentrations of chloride in fresh water range from a few to several hundred mg/l (DWAF, 1996a). All sites recorded chlorides above 50mg/l and only in one instance at Umg B did the chloride result exceed 200mg/l. The threshold for an increased corrosion rate is approximately 50 mg/l and at chloride concentrations greater than 200 mg/l, there is likely to be a significant shortening of the lifetime of domestic appliances as a result of corrosion (DWAF, 1996a). With 1 exception from Zana A to B; the chlorides increased from A to B for all sites. As indicated in Appendix A, the chlorides remained constant from site Zana A to B; however there was an increase of 233% in chlorides from site Umg A to B, and an increase of 160% from site Gane A to B. This increase is likely a result of the sewage effluent discharges from the 2 WWTW, since the increase is at the discharge site (B site). Chloride inputs to surface waters can arise from irrigation return flows, sewage effluent discharges and various industrial processes (DWAF, 1996a).

From Appendix A, the t-test results for Chlorides at all sites indicate a significant difference between the upstream and downstream water quality since t.calc > t.crit ($p \leq 0.05$). For Zana, a relatively smaller difference (1.875>1.717), in comparison with Umg and Gane, where there is quite a significant difference between the upstream and downstream water quality (6.9602>1.717) and (8.438> 1.717) respectively.
The most likely reason for this increase in Chlorides from upstream to downstream is the discharge from the WWTW which has already been discussed above.

5.5. AMMONIA

The TWQGR for Ammonia as respects Aquatic Ecosystems is 0.007mg/l. As indicated in Appendix A, the results for all sites far exceeded the TWQGR for Aquatic Ecosystems.

With 2 exceptions from Umg A to B; the Ammonia concentration increased from A to B for all sites. The average Ammonia for Zana A; B; Umg A; B and Gane A; B was 0.52mg/l; 0.88mg/l; 0.64mg/l; 1.2mg/l; 0.61mg/l and 1.06mg/l; respectively. The percentage increase in Ammonia from the A site to the B site was 169%; 187% and 173% for Zana; Umg and Gane respectively. Ammonia occurs naturally through gas exchange with the atmosphere; chemical and biochemical transformation of nitrogenous matter and nitrogen fixation; other sources of ammonia include sewage discharges; discharge from industries that use ammonia or ammonium salts and commercial fertilizers containing highly soluble ammonia and ammonium salts DWAF, 1996b). At the A sites (above the discharge point) the source of increased ammonia could be from the informal settlements located upstream of Umg A , in the vicinity of Reservoir Hills and along the embankment at Stonebridge Drive where small scale farming is practiced and fertilizers are used. Zana A is most likely impacted by the effluent from the Hillcrest WWTW and pumpstation overflows. The location of all B sites are below the WWTW discharge point. Hence the increased Ammonia concentration at these sites can be attributed to sewage discharges. At Ammonia concentrations of 0.015mg/l, chronic effects to Aquatic Ecosystems result and at concentrations of 0.100mg/l, acute effects result (DWAF, 1996b). At all sites, the Ammonia results exceeded both the chronic and acute effects value. Acute toxicity to fish may cause a loss of equilibrium, hyper-excitability, an increased breathing rate, an increased cardiac output and oxygen intake, and in extreme cases convulsions, coma and death, while chronic effects include a reduction in hatching success, reduction in growth rate and morphological development, and pathological changes in tissue of gills, liver and kidneys (DWAF, 1996b). As for Ammonia, the general requirements for purification of wastewater, regulation 991 specifies a free and saline ammonia (as N) 1.0mg/l (DWAF, 1984).

As indicated in Appendix A, the average Ammonia for Zana A; B; Umg A; B and Gane A; B was 0.52mg/l; 0.88mg/l; 0.64mg/l; 1.2mg/l; 0.61mg/l and 1.06mg/l; respectively. 2 results at Zana B; 7 results at Umg B; 2 results at Gane A and 6 results at Gane B exceeded the 1.0mg/l prescription. Upstream of Gane A, small scale farming for the local market consumption is practiced and the conservative quantities of fertilizers used is likely to increase ammonia levels through washout into the river. The average Ammonia concentration at sites Umg B and Gane B exceeded the requirement of 1.0mg/l. while the average for the Zana B site was elevated, but within range. As these sites are all located below the WWTW discharge point, the discharges from the WWTW is the most likely contributor to these excesses as already discussed.

The Ammonia results for the t-test from Appendix A at all sites indicates there is a significant difference between the upstream and downstream water quality since t.calc > t.crit ($p \leq 0.05$). For Zana, the difference is significantly high (8.35>1.717); however for Umg and Gane, the difference between the upstream and downstream water quality is significantly lower in comparison with Zana, (2.46>1.717) and (3.08> 1.717) respectively. The most likely reason for this increase in Ammonia from upstream to downstream is the discharge from the WWTW and has already been discussed above.

5.6. Dissolved Oxygen (DO)

The TWQGR for DO, specifies a range of 80-120% DO saturation for Aquatic Ecosystems (DWAF, 1996b).The temperature range for sampling at all sites was 15-20 degrees celsius (°C). Typical saturation concentrations are: 12.77 mg/l at 5 °C; 10.08 mg/l at 15 °C and 9.09mg/l at 20 °C (DWAF, 1996b). From Appendix A, the levels of DO at all sites were extremely low in comparison with these standards and are therefore unacceptable. The average DO and percent saturation (%), for Zana A; B; Umg A; B and Gane A; B was 4.42mg/l (44.2%); 5.6mg/l (56%); 4.21mg/l (42.1%); 3.19mg/l (31.9%); 4.43mg/l (44.3%) and 4.1mg/l (41%); respectively. These were also below the TWQGR for DO for Aquatic Ecosystems. For Zana, the average DO increased from site A to B. For Umg and Gane, there was a decrease in DO from site A to B. Dissolved oxygen concentrations can be increased naturally or induced artificially by aeration at a WWTW. It is likely the increase in DO for Zana was the result of elevated aeration rates at the WWTW. The decrease in DO for Umg and Gane, can be attributed to low aeration rates at these WWTW as well as increased organic matter in the wastewater discharges. Sewage effluents also reduce DO in aquatic systems by introducing into the system organic matter which, as noted by Russell (1996) requires oxygen for its breakdown. The rate of increase of dissolution of oxygen can be accelerated if turbulence of the water increases, causing entrainment of air from the atmosphere, while reduction in the concentration of dissolved oxygen can be caused by re-suspension of anoxic sediments, as a result of river floods or dredging activities. The presence of oxidisable organic matter, either of natural origin (detritus) or originating in waste discharges, can lead to reduction in the concentration of dissolved oxygen in surface waters (DWAF, 1996b). According to DWAF (1996b), as a result of low DO, juveniles of many aquatic organisms are more sensitive to physiological stress a rising from oxygen depletion, and in particular to secondary effects such as increased vulnerability to predation and disease.

In terms of the general requirements for purification of wastewater, regulation 991 specifies dissolved oxygen of at least 75 percent saturation (DWAF, 1984).
As indicated above, the DO saturation for all sites ranged from 31.9% to 56%, which is significantly below the requisite 75 percent saturation. The reasons for this discrepancy were discussed above.

From Appendix A, the t-test result for DO at Zana was 2.1 and 6.38 for Umg. Since t.calc > t.crit for Zana (2.1>1.717) and Umg (6.38> 1.717) this implies that there is significant difference in the water quality with respect to DO when one compares the water upstream with that downstream of the WWTW ($p \leq 0.05$). However, in the case of Gane the results indicate no significant difference between the upstream and downstream water quality since t.calc < t.crit ($p \leq 0.05$). The rationale for the variance in DO was discussed in detail above.

5.7. Chemical Oxygen Demand (COD)

In terms of the general requirements for purification of wastewater, regulation 991 specifies a COD not exceeding 75 mg/l (DWAF, 1984). From Appendix A the average COD for Zana A; B; Umg A; B; Gane A and B was 51.67mg/l; 38.75mg/l; 61.4mg/l; 41.58mg/l; 47.29mg/l and 42.78mg/l respectively. The averages for COD were all within the requirements for a COD not exceeding 75mg/l. However 1 site each at Zana A; Umg A; Umg B and 2 sites at Gane A exceeded the 75mg/l requirement. The irregular elevated peaks at the A sites are most likely a result of rainfall and the consequent increase in runoff. At the B sites the elevated COD was probably as a result of high levels of organic matter contained in the discharge.

As indicated in Appendix A, the t-test results for COD at Zana ($0.139 < 1.717$); Umg ($0.100 < 1.717$); and Gane ($0.375 < 1.717$); Since t.calc < t.crit there is no significant difference in the water quality with respect to COD when one compares the water upstream with that downstream of the WWTW ($p \leq 0.05$).

5.8. Permanganate Value (PV 4)

In terms of the general requirements for purification of wastewater, regulation 991 specifies a PV 4 not exceeding 10mg/l (DWAF, 1984). Appendix A indicates the average PV 4 for sites: Zana A; B; Umg A; B; Gane A and B, was 6.73mg/l; 6.37mg/l; 3.72mg/l; 5.71mg/l; 7.47mg/l and 11.98mg/l respectively. The average PV 4 at Gane B exceeded the general requirement of 10mg/l. 2 sites at Zana A; 1 site at Zana B; 1 site at Gane A and 2 sites at Gane B, were above the general requirement for PV 4. The probable reasons for the increased PV4 are discussed below.

From Appendix A the t-test results for PV 4 at Zana ($0.35<1.717$) and Gane ($0.57< 1.717$), this indicates that there is no significant difference in the water quality with respect to PV 4 when one compares the water upstream with that downstream of the WWTW since t.calc < t.crit ($p \leq 0.05$). However, in the case of Umg the results indicate a significant difference between the upstream and downstream water quality ($p \leq 0.05$), since t.calc > t.crit ($3.23>1.717$). PV 4 provides an indirect measurement of the oxygen content, since according to Tamime *et al (*1999), it is a quick test to determine the chemically oxidisable organic matter in a sample. The most likely reason for this increase in PV 4 from upstream to downstream is the increase in organic matter conveyed by the wastewater discharge from the WWTW. The presence of oxidisable organic matter, either of natural origin (detritus) or originating in waste discharges, can lead to reduction in the concentration of dissolved oxygen in surface waters (DWAF, 1996b). The significant difference in PV4 results for Umg correlate with the low DO results discussed above, for Umg.

5.9. CONDUCTIVITY

In terms of the general requirements for purification of wastewater, regulation 991 specifies Conductivity not exceeding 75mS/m (DWAF, 1984). From Appendix A, the average Conductivity for Zana A; B; Umg A; B; Gane A and B was 33.33mg/l; 38.75mg/l; 39.66mg/l; 144.08mg/l; 55.58mg/l and 61mg/l respectively. The average Conductivity Umg B exceeded the 75mS/m requirement. A total of 6 sites at exceeded the 75mS/m Conductivity prescription and these were all located at Umg B. Generally heavy rainfall increases the dilution capacity and hence lowers the Conductivity and during low rainfall periods (winter) little or no dilution, results in higher Conductivity concentrations. The increases in Conductivity were recorded during the low rainfall months. Since the increased conductivity was recorded at the B site, this suggests the source of the increased Conductivity to be the discharged wastewater.

From Appendix A the t-test results for Conductivity at all sites are: Zana (3.04>1.717); Umg (2.8>1.717) and Gane (2.03>1.717). These results indicate there is a significant difference between the upstream and downstream water quality since t.calc > t.crit ($p \leq 0.05$). The most likely reason for this increase from upstream to downstream is the discharge from the WWTW.

5.10. ESCHERICHIA COLI (*E.coli)*

In terms of the general requirements for purification of wastewater, regulation 991 indicates that the waste water or effluent shall not contain any typical (fecal) coli per 100ml *E.coli* (DWAF, 1984). However as indicated in the literature review the 3 WWTW are exempted from this requirement to the extent that their discharges may not contain more than a 1000 typical (fecal) coli per 100ml *E.coli*.

As indicated in Appendix A, 4 sites at Zana A; 6 sites at Zana B; 4 sites at Umg A; no sites at Umg B; 1 site at Gane A and 2 sites at Gane B met this requirement. The majority of sites far exceeded the 1000 cfu/ml requirement, which indicates the presence of pathogens and poor sanitary quality of the water (WRC, 2006); (Liberti *et al.*, 2000). The source of this contamination for Umg A is the informal settlement with poor sanitary facilities located upstream in the vicinity of Reservoir Hills. Zana A is most likely impacted by the effluent discharges into the river from the Hillcrest WWTW and pumpstation overflows. Gane A is most likely impacted by faecal contamination from livestock grazing along the river. The cause of non-compliance at the B sites is the poor quality of wastewater discharged from the WWTW. Indicator organisms (*E.coli*) provide evidence of faecal contamination from humans and warm-blooded animals (Ritter, 2010).

For *E.coli,* from Appendix A the t-test results are: Zana (0.03 $<$1.717); Umg (0.56$<$1.717) and Gane (0.73$<$1.717); this indicates no significant difference between the upstream and downstream water quality since t.calc $<$ t.crit ($p \leq 0.05$).

5.11. TURBIDITY

From Appendix A the t-test results for Turbidity are: Zana (0.31$<$1.717); Umg (0.54$<$1.717) and Gane (0.13$<$1.717); since t.calc $<$ t.crit. there is no significant difference in the water quality with respect to Turbidity when one compares the water upstream with that downstream of the WWTW ($p \leq 0.05$). There was an anomalous increase in Turbidity at Gane A (434 NTU) and at Gane B (411 NTU). Since the point of origin of the elevated Turbidity was above the WWTW discharge point, the anomalously high Turbidity could be attributed high levels of suspended matter being washed down the river. Turbidity in water is caused by the presence of suspended matter which usually consists of a mixture of inorganic matter, such as clay and soil particles, and organic matter; also the discharge of sewage and other wastes can contribute significantly to turbidity (DWAF, 1996a). There were 11 instances of a decrease in Turbidity from Zana A to B which indicates that the diluting effect of the WWTW discharge at Zana B (which had lowered turbidity levels) resulted in a lowering the overall turbidity.

Elevated turbidity levels accelerate microbial growth since microbial growth in water is most extensive on the surface of particulates and inside loose, naturally-occurring flocs; also river silt (which increases turbidity) readily adsorbs viruses and bacteria (DWAF, 1996a).

5.12. NITRITES AND NITRATES

From Appendix A the t-test results for Nitrites and Nitrates at all sites are: Zana (6.35>1.717); Umg (12.07>1.717) and Gane (4.48>1.717); this indicates a significant difference between the upstream and downstream water quality ($p \leq 0.05$). The most likely reason for this increase in pH from upstream to downstream is the effluent discharges from the WWTW. A significant source of nitrates in natural water results from the oxidation of vegetable and animal debris and of animal and human excrement as well as treated sewage wastes that contain elevated concentrations of nitrate (DWAF, 1996a). In aquatic systems elevated concentrations generally give rise to the accelerated growth of algae and the occurrence of algal blooms which may subsequently cause problems associated with malodors and tastes in water and the possible occurrence of toxicity (DWAF 1996a). Optimum levels for aquatic ecosystem functioning are those below 0.5 mg/L as there are moderate species diversity, low productivity and rapid nutrient cycling and no excessive growth of aquatic plants or algal blooms; but at levels between 0.5 – 2.5 mg/L mesotrophic conditions prevail, which result in high species diversity and high productivity as well as nuisance growth of aquatic plants and blue - green algal blooms (DWAF, 1996a).

5.13. CONCLUSION

In comparison with the TWQGR for Aquatic Ecosystems, the average results for pH; COD and Chlorides were within the range; the average results for TDS and Ammonia far exceeded the TWQGR and the DO results were well below the TWQGR. As respects the general requirements for purification of wastewater (DWAF, 1984), the average pH at all sites complied with the general requirements; the average Ammonia at Umg B and Gane

B exceeded the general requirements while the other sites were compliant; the average DO at all sites was well below the general requirement; the average PV4 at Gane B exceeded the general requirement, while the other site complied; the average conductivity at Umg B exceeded the general requirements, while all other sites met the requirements; and the majority of sites far exceeded the general requirement as respects *E.coli,* despite there being a relaxation in the requirement for *E.coli* compliance.

The t-test results indicated that there was significant difference between the upstream and downstream water quality for the following parameters and sites: pH and PV4 at Umg; for DO at Zana and Umg; for TDS, conductivity, chlorides, ammonia; nitrites and nitrates at all sites.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

This study highlighted the decline in global water availability as well as the challenges in South Africa as respects water scarcity and the deterioration in water quality which has further reduced its availability. The deterioration in water quality necessitates urgent interventions for management of water resources to ensure that the existing water supplies are utilized sustainably.

Water quality deterioration results predominantly from anthropogenic activities. Anthropogenic activities refer to human activities that aggravate or cause the decline in water quality. Wastewater, resulting from human activities often contains pathogenic microorganisms and results in negative impacts when inadequately treated and discharged into rivers. Other impacting anthropogenic activities include: washout of pesticides and fertilizers; industrial discharges and urbanization.

The specific aim of this study was to determine the impact of wastewater discharges from the KwaMashu; Northern and uMhlatuzana Treatment Works on the water quality of the uMhlangane; the uMgeni and the uMhlatuzana Rivers respectively; as well as to identify other anthropogenic variables influencing the water quality of these rivers. The results of sampling from the six sites were compared with the TWQGR for Aquatic Ecosystems, and the average results for pH; COD and Chlorides were within the range. The average results for TDS and Ammonia far exceeded the TWQGR and the DO results were well below the TWQGR and hence non-compliant.

When comparing the results from the six sites with the general requirements for purification of wastewater (DWAF, 1984), the average pH at all sites complied with the general requirements; the average Ammonia at Umg B and Gane B exceeded the general requirements while the other sites were compliant; the average DO at all sites was well below the general requirement; the average PV4 at Gane B exceeded the general requirement, while the other site complied; the average conductivity at Umg B exceeded the general requirements, while all other sites met the requirements; and the majority of sites far exceeded the general requirement as respects *E.coli,* despite there being a relaxation in the requirement for *E.coli* compliance.

The t-test results indicated that there was significant difference between the upstream and downstream water quality for the following parameters and sites: pH and PV4 at Umg; for DO at Zana and Umg; for TDS, conductivity, chlorides, ammonia; nitrite and nitrates at all sites.

There was a decline in water quality from upstream to downstream for the following:

- TDS ; Chlorides; Ammonia; Conductivity ; Nitrites and Nitrates-at all sites;
- DO; PV4; Turbidity-at all sites, except for Zana;
- pH; *E.coli*- at the Umg site.

This is a total of declining water quality on 23 instances from upstream to downstream. The Umg site is has the poorest water quality (for 10 instances of declining quality). The WWTW discharge point is located at the downstream site and the reason for the declining water quality can be attributed to the discharge of inadequately treated wastewater into the river.

There was an improvement in water quality from upstream to downstream for:

- COD –at all sites;
- DO; PV4 -at the Zana site;
- *E.coli* -at sites Zana and Gane.

This is a total of 7 instances of an improvement in water quality from upstream to downstream. The dilution effect of the WWTW discharge containing lower concentrations of the above parameters is likely result in the above improvement in water quality. The poor quality at the upstream sites is the result of anthropogenic activities. For Umg A, the informal settlement with poor sanitary facilities located upstream in the vicinity of Reservoir Hills is the most likely cause of the water quality decline. Zana A is impacted by the effluent discharges into the river from the Hillcrest WWTW; industrial discharges and pump station overflows and Gane A is most likely impacted by fecal contamination from livestock grazing along the river and industrial discharges into the canal. The presence of oxidisable organic matter, either of natural origin (detritus) or originating in waste discharges, can lead to reduction in the concentration of dissolved oxygen in surface waters (DWAF, 1996b). PV 4 provides an indirect measurement of the oxygen content, according to Tamime *et al., (*1999).

6.2. RECOMMENDATIONS

The recommendations for improving the downstream riverine water quality of the uMhlatuzana; uMhlangane and uMgeni Rivers include:

- urgent upgrade of the WWTW discharging into these rivers to meet the Department of Water discharge requirements and consequently reduce the poor water quality impacts on the river;
- upskilling and training of operation staff at the WWTW to ensure efficient process operation;
- the Department of Water to enforce penalties for non- compliance with discharge permit requirements;
- improving the policing of pollution and monitoring of rivers to reduce illegal discharges;
- the provision of proper housing and sanitation facilities and the eradication of informal settlements on and around the river banks.

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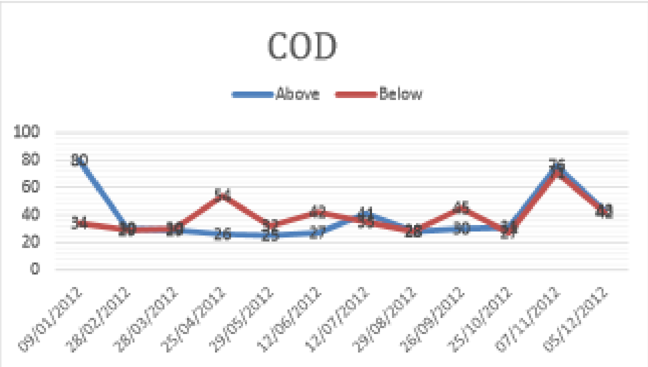
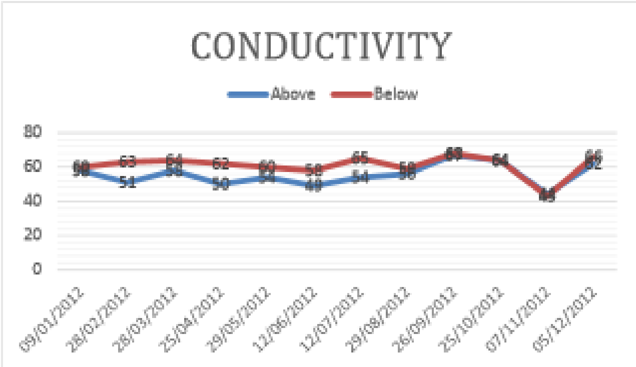
APPENDIX A

R-GANE_04 critical t = 1,717
uMhlangane River

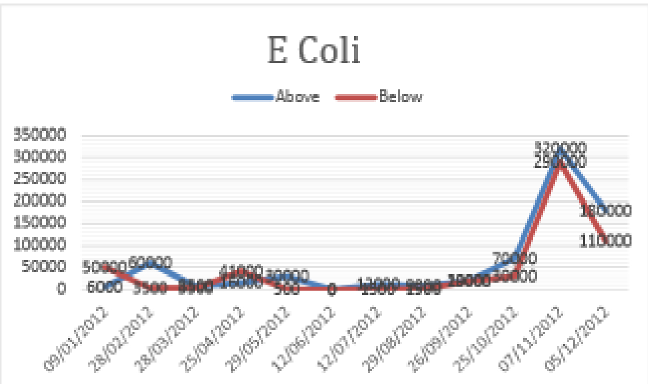
DATE	COD - ABOVE	COD- BELOW	CONDUCTIVITY - ABOVE	CONDUCTIVITY - BELOW
	mg/l	mg/l	mS/m	mS/m
09/01/2012	80	34	58	60
28/02/2012	30	29	51	63
28/03/2012	29	30	58	64
25/04/2012	26	54	50	62
29/05/2012	25	32	54	60
12/06/2012	27	42	49	58
12/07/2012	41	35	54	65
29/08/2012	28	28	56	59
26/09/2012	30	45	67	68
25/10/2012	31	27	64	64
07/11/2012	76	71	44	43
05/12/2012	43	42	62	66
AVERAGE	38,83	39,08	55,58333333	61
T-test calculated	0,375		2,028819899	
Ho	Accepted		Rejected	

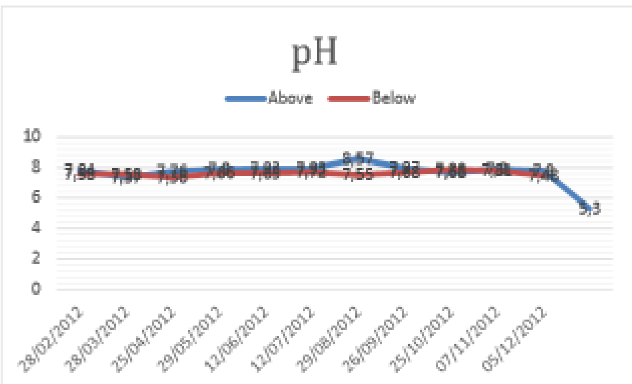




R-GANE_04 critical t = 1,717
uMhlangane River

	E COLI - ABOVE	E COLI - BELOW		
DATE	cfu/100ml	cfu/100ml	Ph - ABOVE	Ph - BELOW
09/01/2012	6000	50000	7,84	7,7
28/02/2012	60000	3500	7,37	7,58
28/03/2012	8500	3500	7,76	7,58
25/04/2012	16000	41000	7,9	7,36
29/05/2012	30000	500	7,93	7,66
12/06/2012	0	0	7,93	7,65
12/07/2012	12000	1500	8,57	7,72
29/08/2012	9000	1500	7,97	7,55
26/09/2012	20000	19000	7,68	7,68
25/10/2012	70000	30000	7,9	7,88
07/11/2012	320000	290000	7,8	7,81
05/12/2012	180000	110000	5,3	7,48
AVERAGE	72958,33333	45875	7,6625	7,6375
t-test calculated	0,727234064		0,107650476	
Ho	Accepted		Accepted	

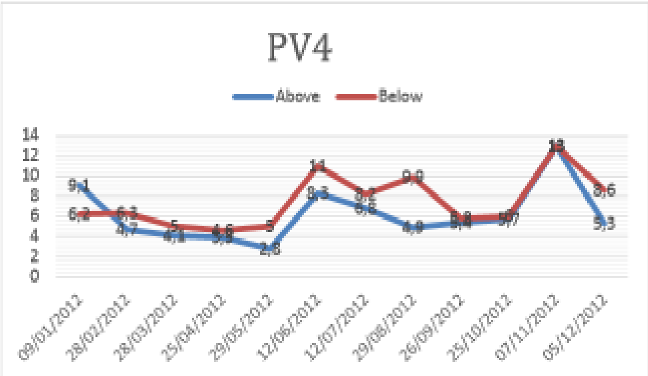


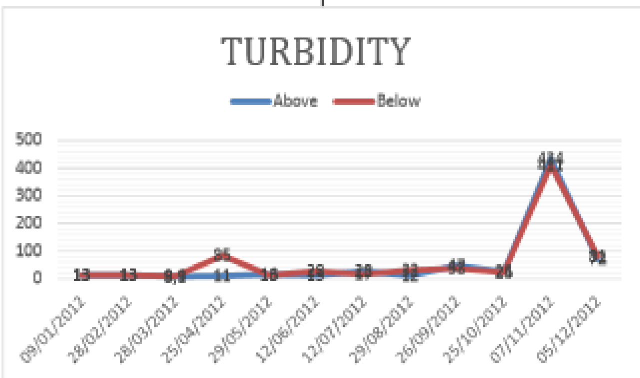


APPENDIX A

R-GANE_04
uMhlangane River

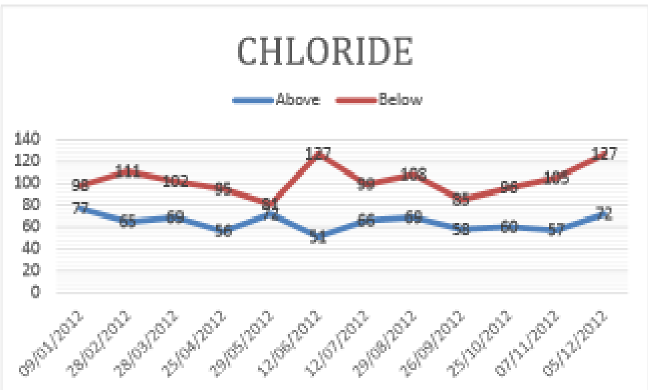
DATE	PV4 - BELOW mg/l	PV4 mg/l	TURBIDITY - ABOVE NTU	TURBIDITY - BELOW NTU
09/01/2012	9,1	6,2	13	13
28/02/2012	4,7	6,3	13	13
28/03/2012	4,1	5	8,1	9,9
25/04/2012	3,9	4,6	11	85
29/05/2012	2,8	5	16	13
12/06/2012	8,3	11	13	28
12/07/2012	6,8	8,2	28	17
29/08/2012	4,9	9,9	12	32
26/09/2012	5,4	5,8	47	38
25/10/2012	5,7	6	25	24
07/11/2012	13	13	434	411
05/12/2012	5,3	8,6	72	81
AVERAGE	**6,16**	**7,466666667**	**57,66**	**63,74**
t-test calculated	**0,565**		**0,128**	
Ho	**Accepted**			

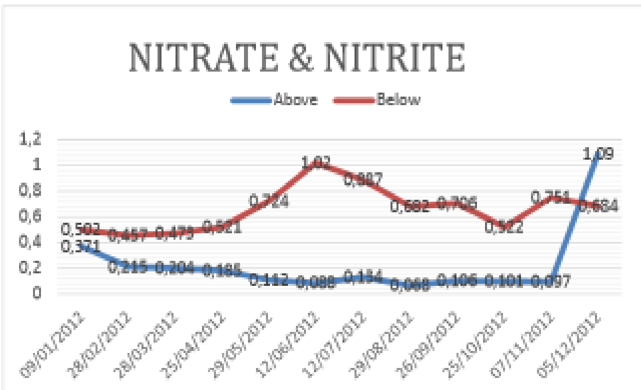




R-GANE_04
uMhlangane River

DATE	CHLORIDE - ABOVE mg/l Cl	CHLORIDE - BELOW mg/l Cl	NITRATE & NITRITE - ABOVE mg/l N	NITRATE & NITRITE - BELOW mg/l N
09/01/2012	77	98	0,371	0,502
28/02/2012	65	111	0,215	0,457
28/03/2012	69	102	0,204	0,473
25/04/2012	56	95	0,185	0,521
29/05/2012	72	81	0,112	0,724
12/06/2012	51	127	0,088	1,02
12/07/2012	66	99	0,134	0,887
29/08/2012	69	108	0,068	0,682
26/09/2012	58	85	0,106	0,706
25/10/2012	60	96	0,101	0,522
07/11/2012	57	105	0,097	0,751
05/12/2012	72	127	1,09	0,684
AVERAGE	**64,33333333**	**102,8333333**	**0,230916667**	**0,66075**
T-test calculated	**8,438395754**		**4,475001219**	
Ho	**Rejected**		**Rejected**	

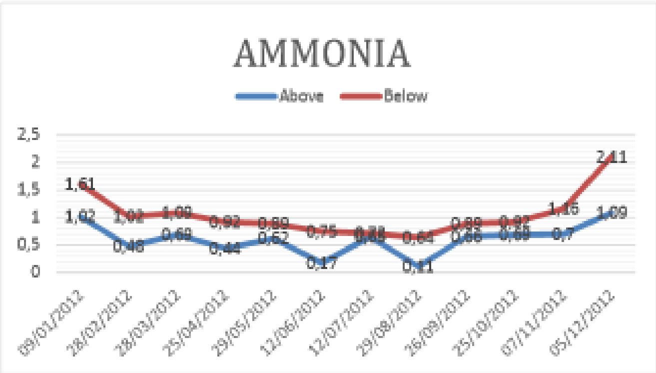


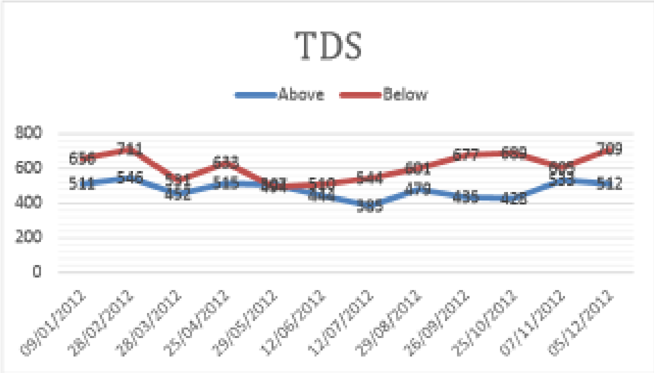


APPENDIX A

R-GANE_04
uMhlangane River

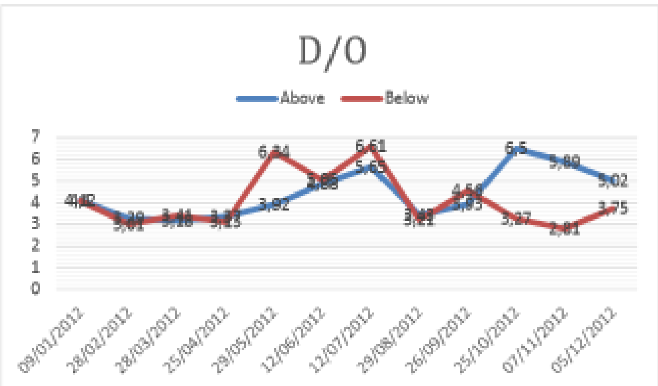
DATE	AMMONIA - ABOVE mg/l NH4	AMMONIA - BELOW mg/l NH4	TDS - ABOVE mg/l	TDS - BELOW mg/l
09/01/2012	1,02	1,61	511	656
28/02/2012	0,48	1,02	546	711
28/03/2012	0,69	1,09	452	531
25/04/2012	0,44	0,92	515	633
29/05/2012	0,62	0,89	507	494
12/06/2012	0,17	0,75	444	510
12/07/2012	0,65	0,72	385	544
29/08/2012	0,11	0,64	479	601
26/09/2012	0,66	0,89	435	677
25/10/2012	0,69	0,92	428	689
07/11/2012	0,7	1,16	533	605
05/12/2012	1,09	2,11	512	709
AVERAGE	**0,61**	**1,06**	**478,9166667**	**613,3333333**
t-test calculated	**3,081158226**		**5,028294812**	
Ho	**Rejected**		**Rejected**	





R-GANE_04
uMhlangane River

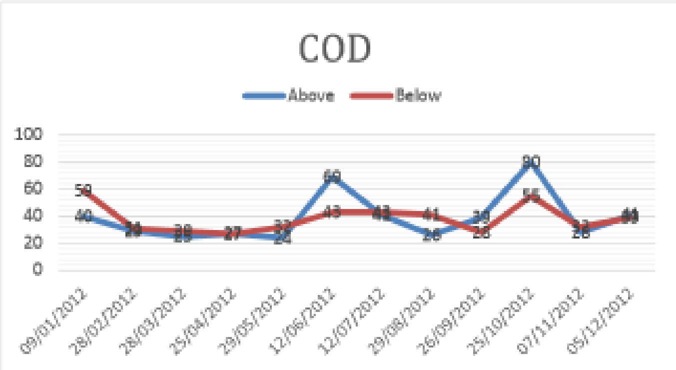
DATE	D/O - ABOVE mg/l	D/O - BELOW mg/l
09/01/2012	4,12	4,1
28/02/2012	3,29	3,01
28/03/2012	3,18	3,41
25/04/2012	3,37	3,13
29/05/2012	3,92	6,34
12/06/2012	4,88	5,05
12/07/2012	5,65	6,61
29/08/2012	3,43	3,21
26/09/2012	3,93	4,56
25/10/2012	6,5	3,27
07/11/2012	5,89	2,81
05/12/2012	5,02	3,75
AVERAGE	**4,431666**	**4,1041666**
t-test Calculated	**0,661530689**	
Ho	**Accepted**	

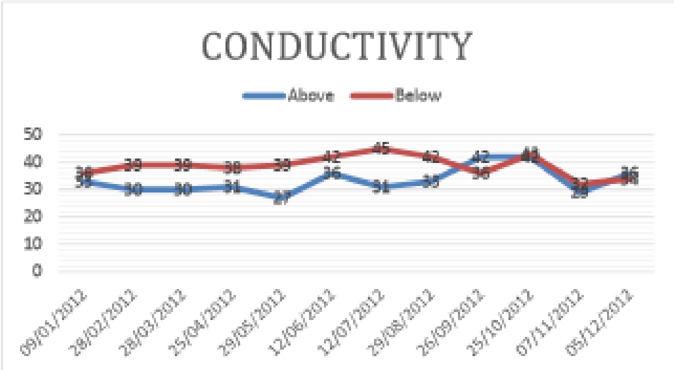


APPENDIX A

R-ZANA_29 Critical t= 1,717
uMhlatuzana River

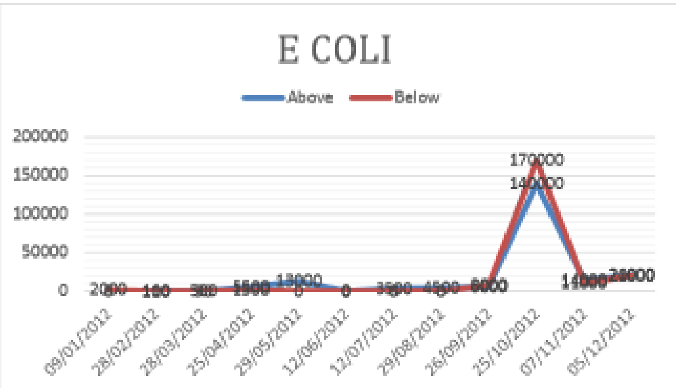
DATE	COD - ABOVE mg/l	COD- BELOW mg/l	CONDUCTIVITY - ABOVE mS/m	CONDUCTIVITY - BELOW mS/m
09/01/2012	40	59	33	36
28/02/2012	29	31	30	39
28/03/2012	25	29	30	39
25/04/2012	27	27	31	38
29/05/2012	24	32	27	39
12/06/2012	69	43	36	42
12/07/2012	41	43	31	45
29/08/2012	26	41	33	42
26/09/2012	39	28	42	36
25/10/2012	80	55	42	43
07/11/2012	28	32	29	32
05/12/2012	41	39	36	34
AVERAGE	39,083	38,25	33,33333333	38,75
T-test calculated	0,139		3,040571755	
Ho	Accepted		Rejected	

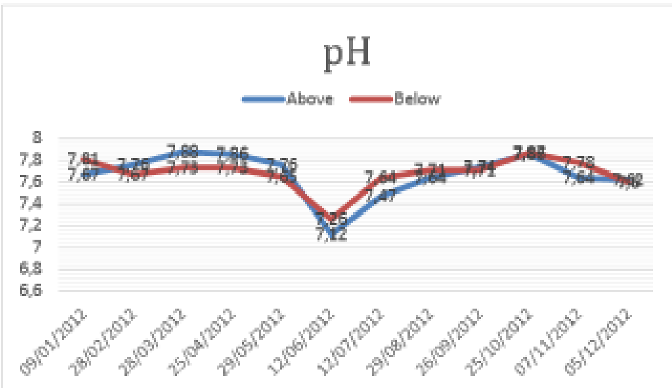




R-ZANA_29
uMhlatuzana River

DATE	E COLI - ABOVE cfu/100ml	E COLI - BELOW cfu/100ml	Ph - ABOVE	Ph - BELOW
09/01/2012	0	2000	7,67	7,81
28/02/2012	110	100	7,76	7,67
28/03/2012	90	500	7,88	7,73
25/04/2012	5500	1500	7,86	7,73
29/05/2012	13000	0	7,76	7,65
12/06/2012	0	0	7,12	7,26
12/07/2012	3500	0	7,47	7,64
29/08/2012	4500	0	7,64	7,71
26/09/2012	6000	8000	7,74	7,71
25/10/2012	140000	170000	7,86	7,87
07/11/2012	14000	11000	7,64	7,78
05/12/2012	21000	20000	7,62	7,6
AVERAGE	17308,33333	17758,33333	7,668333333	7,68
T-test calculated	0,025044239		0,155884823	
Ho	Accepted		Accepted	

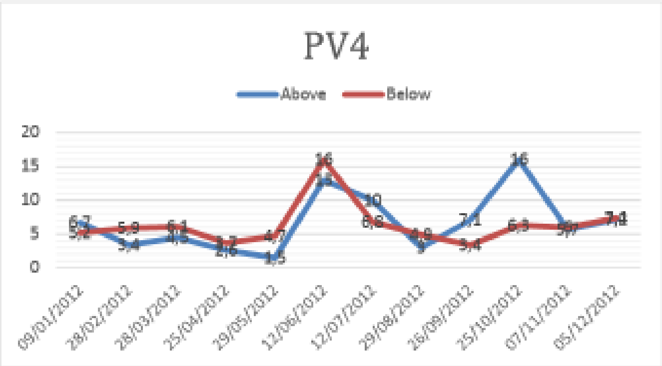


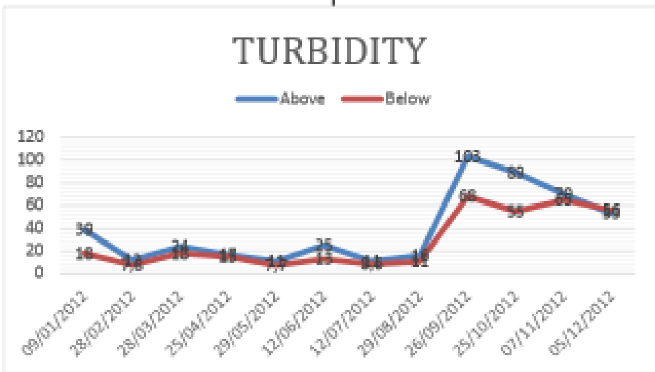


APPENDIX A

R-ZANA_29
uMhlatuzana River

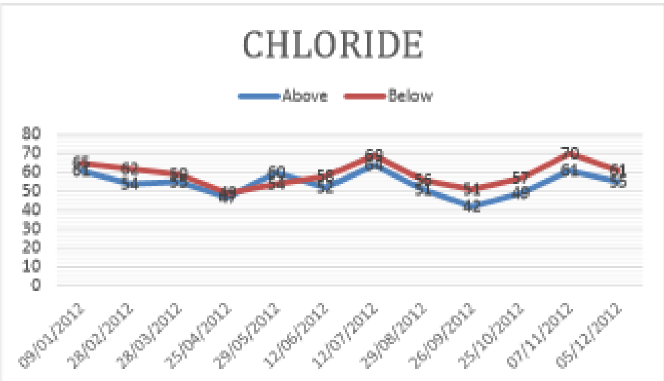
DATE	PV4 - ABOVE mg/l	PV4 - BELOW mg/l	TURBIDITY - ABOVE NTU	TURBIDITY - BELOW NTU
09/01/2012	6,7	5,2	39	18
28/02/2012	3,4	5,9	12	7,8
28/03/2012	4,5	6,1	24	18
25/04/2012	2,6	3,7	17	15
29/05/2012	1,5	4,7	11	7,7
12/06/2012	13	16	25	13
12/07/2012	10	6,8	11	8,6
29/08/2012	3	4,9	16	11
26/09/2012	7,1	3,4	103	68
25/10/2012	16	6,3	89	55
07/11/2012	5,7	6	70	65
05/12/2012	7,2	7,4	53	56
AVERAGE	6,725	6,3666	39,16666667	35,44444444
T-test Calculated	0,353847456		0,308818741	
Ho	Accepted		Accepted	

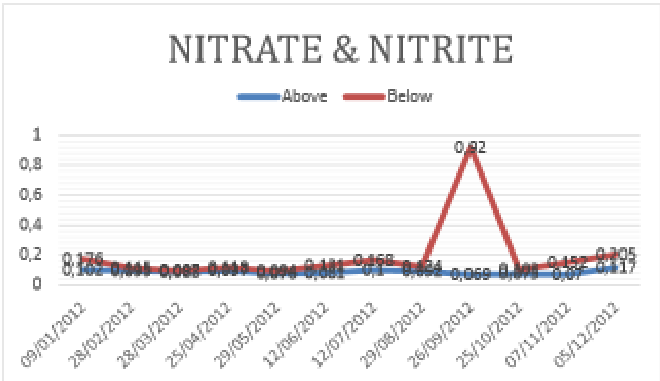




R-ZANA_29
uMhlatuzana River

DATE	CHLORIDE - ABOVE mg/l Cl	CHLORIDE - BELOW mg/l Cl	NITRATE & NITRITE - ABOVE mg/l N	NITRATE & NITRITE - BELOW mg/l N
09/01/2012	61	65	0,102	0,176
28/02/2012	54	62	0,095	0,115
28/03/2012	55	59	0,088	0,097
25/04/2012	47	49	0,097	0,118
29/05/2012	60	54	0,076	0,094
12/06/2012	52	58	0,081	0,131
12/07/2012	64	69	0,1	0,168
29/08/2012	51	56	0,092	0,124
26/09/2012	42	51	0,069	0,92
25/10/2012	49	57	0,075	0,103
07/11/2012	61	70	0,07	0,152
05/12/2012	55	61	0,117	0,205
Average	54,25	59,25	0,0885	0,20025
t-test Calculated	1,875166482		6,345196936	
Ho	Rejected		Rejected	

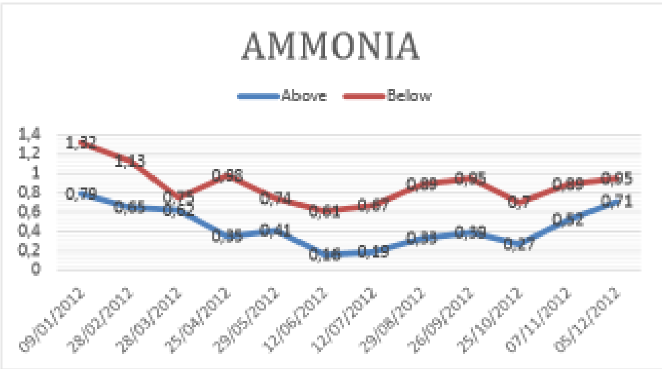


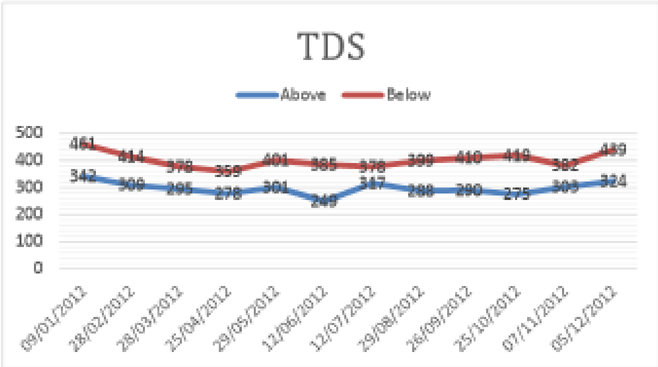


APPENDIX A

R-ZANA_29
uMhlatuzana River

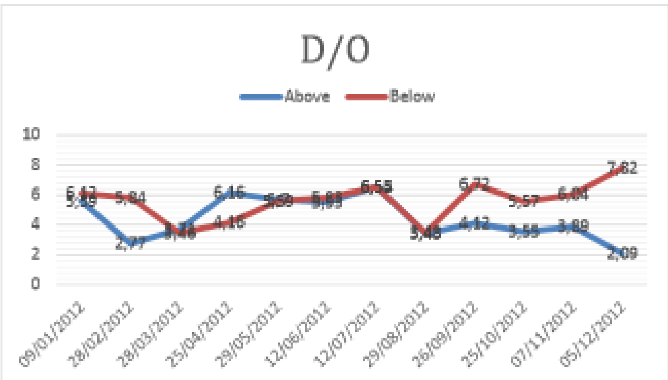
DATE	AMMONIA - ABOVE mg/l NH4	AMMONIA - BELOW mg/l NH4	TDS - ABOVE mg/l	TDS - BELOW mg/l
09/01/2012	0,79	1,32	342	461
28/02/2012	0,65	1,13	309	414
28/03/2012	0,62	0,75	295	378
25/04/2012	0,35	0,98	278	359
29/05/2012	0,41	0,74	301	401
12/06/2012	0,16	0,61	249	385
12/07/2012	0,19	0,67	317	378
29/08/2012	0,33	0,89	288	399
26/09/2012	0,39	0,95	290	410
25/10/2012	0,27	0,7	275	419
07/11/2012	0,52	0,89	303	382
05/12/2012	0,71	0,95	324	439
Average	**0,52**	**0,881666667**	**297,5833333**	**402,0833333**
t-test calculated	**8,346153853**		**9,58932278**	
Ho	**Rejected**		**Rejected**	





R-ZANA_29
uMhlatuzana River

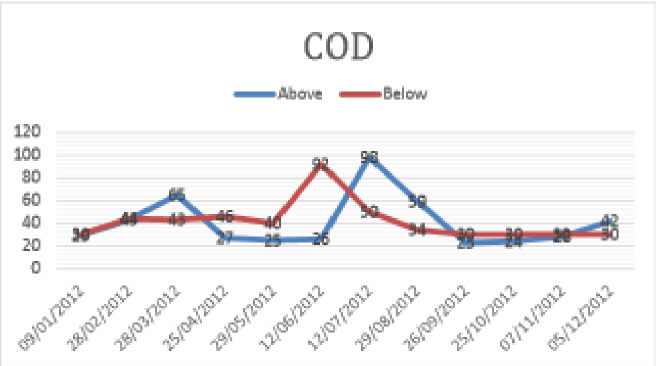
DATE	D/O - ABOVE mg/l	D/O - BELOW mg/l
09/01/2012	5,59	6,12
28/02/2012	2,77	5,84
28/03/2012	3,71	3,46
25/04/2012	6,16	4,16
29/05/2012	5,7	5,59
12/06/2012	5,53	5,83
12/07/2012	6,55	6,54
29/08/2012	3,43	3,48
26/09/2012	4,12	6,72
25/10/2012	3,55	5,57
07/11/2012	3,89	6,04
05/12/2012	2,09	7,82
Average	**4,424166667**	**5,5975**
T-test calculated	**2,096217769**	
Ho	**Rejected**	

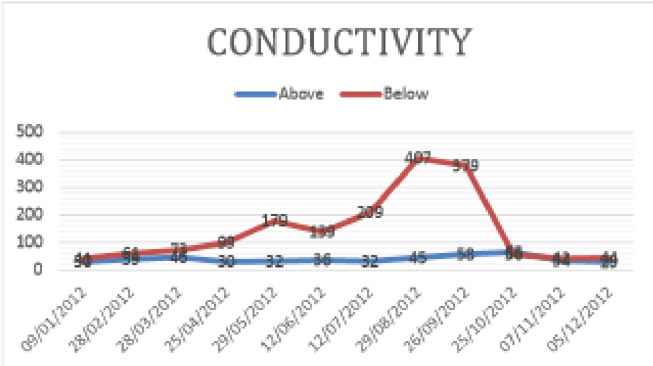


APPENDIX A

R-MGENI_08 Critical t= 1,717
uMgeni River

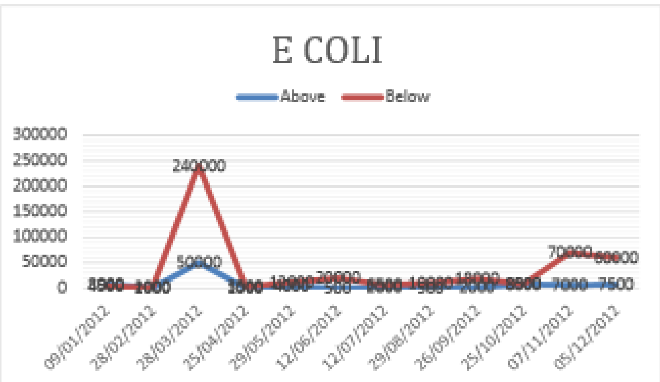
DATE	COD - ABOVE mg/l	COD- BELOW mg/l	CONDUCTIVITY - ABOVE mS/m	CONDUCTIVITY - BELOW mS/m
09/01/2012	29	30	30	41
28/02/2012	43	44	39	61
28/03/2012	65	43	46	73
25/04/2012	27	46	30	99
29/05/2012	25	40	32	179
12/06/2012	26	92	36	139
12/07/2012	98	50	32	209
29/08/2012	59	34	45	407
26/09/2012	23	30	58	379
25/10/2012	24	30	65	56
07/11/2012	28	30	34	42
05/12/2012	42	30	29	44
AVERAGE	41,25	41,58	39,66666667	144,0833333
T-test calculated	0,1		2,796017104	
Ho	accepted		Rejected	

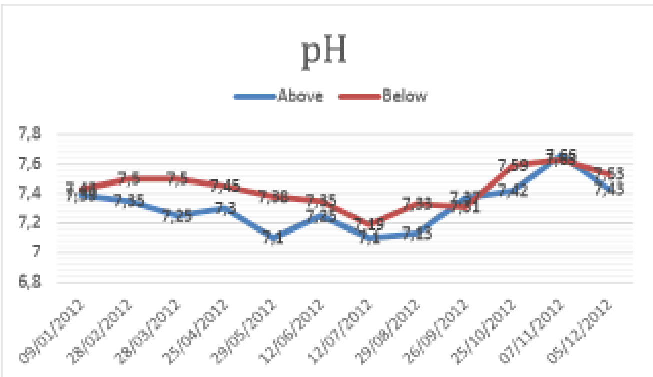




R-MGENI_08
uMgeni River

DATE	E COLI - ABOVE cfu/100ml	E COLI - BELOW cfu/100ml	Ph - ABOVE	Ph - BELOW
09/01/2012	8000	4500	7,39	7,43
28/02/2012	1000	2000	7,35	7,5
28/03/2012	50000	240000	7,25	7,5
25/04/2012	1000	3500	7,3	7,45
29/05/2012	4000	12000	7,1	7,38
12/06/2012	500	20000	7,25	7,35
12/07/2012	2000	6500	7,1	7,19
29/08/2012	500	10000	7,13	7,33
26/09/2012	2000	18000	7,37	7,31
25/10/2012	8500	8000	7,42	7,59
07/11/2012	7000	70000	7,66	7,63
05/12/2012	7500	60000	7,43	7,53
AVERAGE	7667	37875	7,3125	7,4325
t-test calculated	0,562280751		2,021707799	
Ho	Accepted		Rejected	

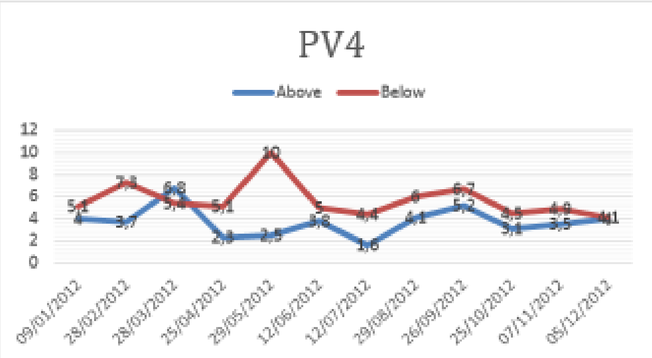


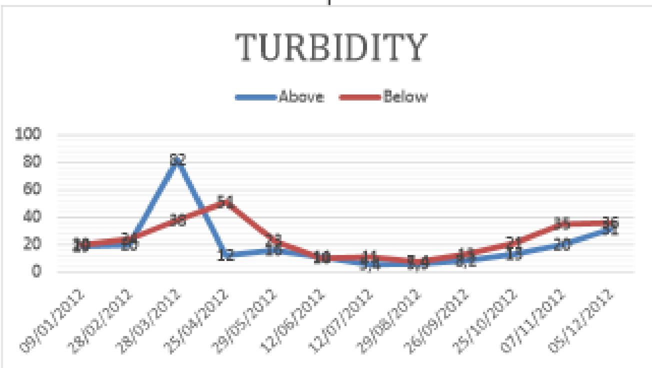


APPENDIX A

R-MGENI_08
uMgeni River

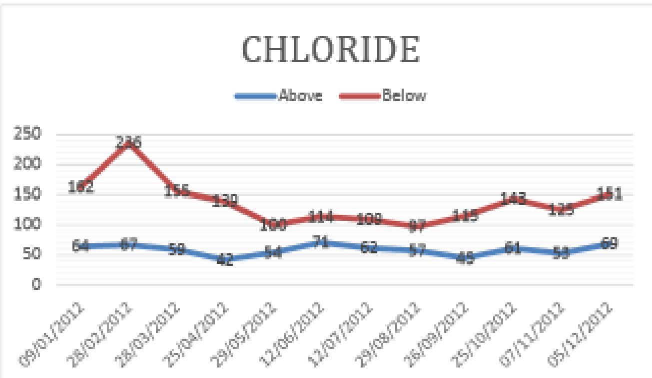
DATE	PV4 - ABOVE mg/l	PV4 - BELOW mg/l	TURBIDITY - ABOVE NTU	TURBIDITY - BELOW NTU
09/01/2012	4	5,1	19	20
28/02/2012	3,7	7,3	20	24
28/03/2012	6,8	5,4	82	38
25/04/2012	2,3	5,1	12	51
29/05/2012	2,5	10	16	23
12/06/2012	3,8	5	11	10
12/07/2012	1,6	4,4	5,4	11
29/08/2012	4,1	6	5,9	7,4
26/09/2012	5,2	6,7	8,2	13
25/10/2012	3,1	4,5	13	21
07/11/2012	3,5	4,9	20	35
05/12/2012	4	4,1	31	36
AVERAGE	**3,716666667**	**5,708333333**	**20,29166667**	**24,11666667**
t-test calculated	**3,230078302**		**0,536741058**	
Ho	**Rejected**		**Accepted**	

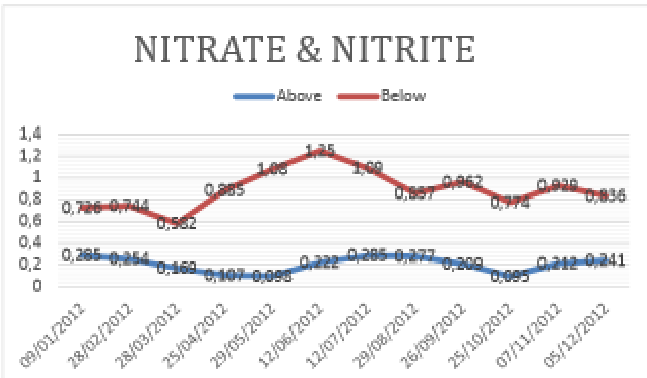




R-MGENI_08
uMgeni River

DATE	CHLORIDE - ABOVE mg/l Cl	CHLORIDE - BELOW mg/l Cl	NITRATE & NITRITE - ABOVE mg/l N	NITRATE & NITRITE - BELOW mg/l N
09/01/2012	64	162	0,285	0,726
28/02/2012	67	236	0,254	0,744
28/03/2012	59	155	0,169	0,582
25/04/2012	42	139	0,107	0,885
29/05/2012	54	100	0,098	1,08
12/06/2012	71	114	0,222	1,25
12/07/2012	62	109	0,285	1,09
29/08/2012	57	97	0,277	0,857
26/09/2012	45	115	0,209	0,962
25/10/2012	61	143	0,095	0,774
07/11/2012	53	125	0,212	0,929
05/12/2012	69	151	0,241	0,836
AVERAGE	**58,66666667**	**137,1666667**	**0,2045**	**0,892916667**
t-test calculated	**6,960284048**		**12,07076162**	
Ho	**Rejected**		**Rejected**	

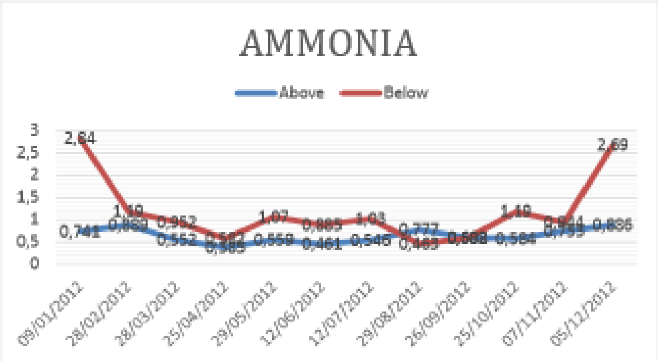


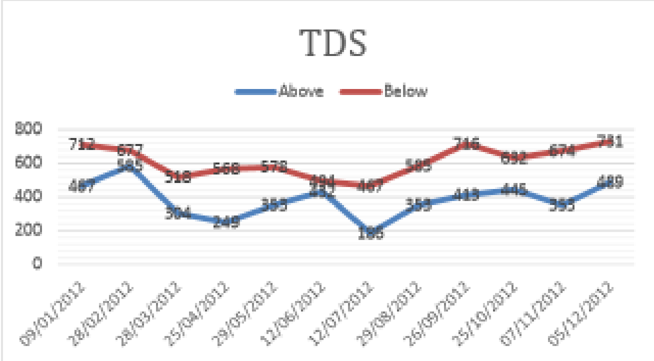


APPENDIX A

R-MGENI_08
uMgeni River

DATE	AMMONIA - ABOVE mg/l NH4	AMMONIA - BELOW mg/l NH4	TDS - ABOVE mg/l	TDS - BELOW mg/l
09/01/2012	0,741	2,84	467	712
28/02/2012	0,889	1,19	585	677
28/03/2012	0,552	0,952	304	518
25/04/2012	0,385	0,582	249	568
29/05/2012	0,559	1,07	353	578
12/06/2012	0,461	0,885	432	494
12/07/2012	0,546	1,03	186	467
29/08/2012	0,777	0,463	353	585
26/09/2012	0,602	0,588	413	716
25/10/2012	0,584	1,19	445	632
07/11/2012	0,753	0,944	353	674
05/12/2012	0,886	2,69	489	731
AVERAGE	**0,644583333**	**1,202**	**385,75**	**612,66**
t-test calculated	**2,46128281**		**12,26561516**	
Ho	**Rejected**		**Rejected**	





R-MGENI_08
uMgeni River

DATE	D/O - ABOVE mg/l	D/O - BELOW mg/l
09/01/2012	5,65	3,48
28/02/2012	2,61	3,01
28/03/2012	2,65	2,67
25/04/2012	2,68	3,16
29/05/2012	5,08	4,02
12/06/2012	6,38	2,68
12/07/2012	5,4	2,55
29/08/2012	7,29	6,92
26/09/2012	3,54	3,58
25/10/2012	4,64	3,11
07/11/2012	3,26	1,96
05/12/2012	1,37	1,17
Average	**4,2125**	**3,1925**
T-test calculated	**6,378483798**	
Ho	**Rejected**