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**THE IMPACT OF THE THABA-NCHU SEWAGE TREATMENT PLANT ON
THE FRESHWATER ECOLOGY OF THE SURROUNDING AREA**

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(2009114477)

Submitted in the fulfilment of the requirements for the degree of
Magister Scientiae

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June 2013

DECLARATION

I declare that this dissertation entitled *The impact of the Thaba-Nchu sewage treatment plant on the freshwater ecology of the surrounding area* is my own independent work, that it has not been submitted for any degree or examination at any other university. I cede copyright of this dissertation in favour of the University of the Free State

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ABSTRACT

Thaba-Nchu is located about 62 km south-east of Bloemfontein, in the Free State Province of South Africa. Sepanespruit is a tributary of the Modder River which drains the Thaba-Nchu area. This area has a population of about 70 000 people and is served by one sewage treatment plant whose hydraulic capacity is 6 Ml/day. This study was conducted to evaluate the effectiveness and the efficiency of the Thaba-Nchu sewage treatment works and the effects of the sewage effluent into the receiving stream; Sepanespruit. Sources of pollution into the stream were identified as the poorly treated sewage effluent, domestic wastes, urban litter and run-off, raw sewage, livestock and human trampling. The municipal truck tankers that disposed-off sewage at the manhole which connected to the sewage treatment plant polluted an area of about 30m in radius with raw sewage, the origin point being the manhole. A canal of raw sewage originated from that area and became a point source of pollution to Sepanespruit.

The sewage effluent caused thermal pollution to the stream, bacterial contamination (measured as total coliform bacteria, faecal coliform bacteria and *E. coli*), and addition of excessive salts (measured as electrical conductivity (EC) and nutrients (PO_4^{3-} and NH_3). Pathogens that occurred in Sepanespruit water were *E.coli*, *Shigella dysenteriae*, *Faecal enterococci* and *Faecal streptococci*; they are all of faecal origin. Endocrine disrupting chemicals such as dyes, herbicides, pharmaceutical and cosmetic compounds were also identified in the sewage effluent; the implication was that the conventional treatment processes did not remove those chemicals from the sewage stream. The sewage effluent was sometimes released in a red-brown coloured state. The colour was attributed to the rich dyes that a meat processing factory dumped at the sewage treatment plant. The most common algal divisions identified in Sepanespruit water were Cyanophyta, Chlorophyta, Bacillariophyta and Euglenophyta. The vegetation along Sepanespruit was classified using JUICE (the computer vegetation classification program) into one community of *Paspalum dilatatum* – *Rumex crispus*. Highly enriched water contributed to the observed vegetation structure; the stream banks were covered by monotypic stands of plant species that are adapted to disturbances such as *Paspalum distichum* and *Rumex crispus*.

The canal water and sewage effluent were the major sources of point pollution to Sepanespruit. Poor sewage quality was a result of poor management, old non-functional unit processes and unskilled operational staff. The section of Sepanespruit that formed part of this study was deemed eutrophic but the dam water was oligotrophic because of the bio-filtration process that the reed beds of *Typha capensis* and *Phragmites latifolia* undertook before water moved into the dam.

Alternative methods of factory dyes' disposal and sludge handling have to be sought in order to reduce water and environmental pollution. The waste management department of the water affairs has been advised to monitor disposal of sewage of sewage at the source manhole and rehabilitate the polluted area.

Key words: sewage effluent, thermal pollution, bacterial contamination, monotypic vegetation, eutrophic water, oligotrophic water, biofiltration

OPSOMMING

Thaba-Nchu is omtrent 62 km suid-oos van Bloemfontein in die Vrystaat Provinsie van Suid Afrika geleë. Sepanespruit is 'n sytak van die Modder River wat die Thaba-Nchu area dreineer. Die area het 'n bevolking van omtrent 70 000 mense, en word deur een riool behandelings-fasiliteit hanteer met 'n hidorliese kapasiteit van 6 Ml/dag. Hierdie studie was aangepak om die effektiwiteit en doeltreffendheid van die Thaba-Nchu riool behandelings-werke te evalueer en ook die effek van die riool afvalwater in die ontvangende stroom-die; Sepanespruit. Bronne van besoedeling in die stroom was ge-identifiseer as swak behandelde riool afvalwater, huishoudelike afval, stedelike rommel en afvalwater, riool, vertrapping deur lewendehawe en mense. Die munisipale trenkwaens wat ontslae raak van riool by die stormwaterpyp wat met die riool behandelings-fasiliteit verbind het is, 'n area van ongeveer 30 m in radius met riool besoedel, met die stormpyp uitlaat as oorsprong. 'n Kanaal van riool het van daardie area ontstaan en 'n punt bron van besoedeling van die Sepanespruit geword.

Die riool-afvalwater het termiese besoedeling in die stroom veroorsaak, bakteriële kontaminasie (gemeet as totale coliform bakterieë, fekale coliform bakterieë en *E. coli*), en die byvoeging van oormatige sout (gemeet as elektriese geleiding (EC) en voedingstowwe (PO_4^{3-} en NH_3). Patogene soos *E. coli*, *Shigella dysenteriae*, *Faecal enterococci* en *Faecal streptococci* wat hoofsaaklik in Sepanespruit se water voorkom, is almal van fekale oorsprong. Chemiese ontwrigtende stowwe sooskleurstowwe, onkruidodders, farmaseutiese en kosmetiese stowwe was ook ge-identifiseer in die riool afvalwater; dit dui daarop aan dat konvensionele riool behandelings prosesse nie hierdie stowwe uit die riool stroom verwyder het nie. Die riool afvalwater is soms vrygestel met 'n rooi-bruin kleur. Die kleur word toegeskryf aan die sterk kleurstowwe wat deur 'n vleis-verwerkings-fabriek in die riool behandelings fasiliteit gestort was. Die mees algemene alg groepe in Sepanespruit sluit in Cyanophyta, Chlorophyta, Bacillariophyta en Euglenophyta. Die plantegorei rondom Sepanespruit is geklassifiseer d.m.v. JUICE (plantegroei klassifikasie rekenaar program) as een gemeenskap van *Paspalum dilatatum* – *Rumex crispus*. Die hoogs verrykte water het bygedra tot die plantegroei struktuur; die stroom oewers was bedek deur monotipiese plantegroei van spesies wat hoogs aangepas is tot versteuring soos *Paspalum dilatatum* en *Rumex crispus*. Monotipiese stande van besoedeling-aangepaste spesies soos *Paspalum distichum* was ook aangemerkt.

Die kanaal water en riool afvalwater was die grootste bronne van punt besoedeling van die Sepanespruit. Swak riool afvalwater was die nagevolg van swak bestuur, ou nie-funksionerende eenheid prosesse en onopgeleide uitvoerende personeel by die riool

behandelings fasiliteit. Die deel van Sepanespruit wat deel van hierdie studie area uitmaak was eutrofies, maar die dam water was oligotrofies as gevolg van die bio-filtrasie proses wat deur riete *Typha latifolia* en *Phragmites capensis* uitgevoer word voor die water by die dam in vloei.

Alternatiewe metodes om van die fabrieks kleurstowwe ontslae te raak en slyk hantering moet geïmplementeer word om water en omgewings besoedeling te verminder. Die afvalbestuur afdeling van die munisipaliteit is veronsterstel om die verwydering van riool by die stormpyp te monitor en die besoedelde area te rehabiliteer.

Sleutel woorde: riool-afval-water, termiese besoedeling, bakterieële kontaminasie, monotipiese plantegroei, eutrofiese water, oligotrofiese water, bio-filtrasie.

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to the following persons and institutions, which made it possible for me to complete this study:

- ❖ The Department of Plant Sciences, University of the Free State for affording me the opportunity to carry out this study
- ❖ My supervisor, Prof. J.P. du Preez for his guidance, assistance and advice
- ❖ My co-supervisor, Me. A. T. Vos for her advice and timeous response to my work
- ❖ The Government of Lesotho through the national Manpower Secretariat for funding this project
- ❖ Inkaba yeAfrika for financial support
- ❖ The Water Cluster, University of the Free State for financial assistance
- ❖ The Centre for Environmental Management for allowing me to use their water quality field equipment
- ❖ The Institute of Ground Water studies for analysing chemical water samples
- ❖ The Centre of Environmental Management for analysing Chlorophyll *a* and identifying algal divisions
- ❖ The Department of Microbial, Biochemical and Food Biotechnology for analysing bacterial samples
- ❖ The Thaba-Nchu sewage treatment plant staff for their co-operation, warmth and willingness to give information and assistance
- ❖ To my colleague, Juan Swanepoel for translation of the abstract into 'opsomming'
- ❖ To my colleagues and the Inkaba students for their encouragements and support
- ❖ To my friends, SDAMS UFS members for their encouragements, support and prayers
- ❖ To my brothers and nephews for their love

.....To God be the glory, great things He continues to do

I DEDICATE THIS THESIS TO MY
MOTHER

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS	Aerobic Activated Sludge
AEC	Anion Exchange Capacity
ARC	Agricultural Research Council
AMD	Acid Mine Drainage
BOD	Biochemical Oxygen Demand
CEC	Cation Exchange Capacity
COD	Chemical Oxygen Demand
DDT	Dichlorodiphenyltrichloroethane
DO	Dissolved Oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
<i>E. coli</i>	<i>Escherichia coli</i>
EC	Electrical Conductivity
EDC	Endocrine Disrupting Chemicals
EPA	Environmental Protection Agency
EWRP	eMalahleni Water Reclamation Project
HAd	Human Adenovirus
GIS	Geographical Information Systems
IPCC	Intergovernmental Panel on Climate Change
NH ₃	Ammonia
NO ₃ ⁻	Nitrate
NO ₂ ⁻	Nitrite
NSW- DEC	New South Wales – Department of Environment and Conservation
NRC	National Research Council
PO ₄ ³⁻	Orthophosphate
RDP	Reconstruction and Development Program

<i>sp.</i>	<i>species</i>
SS	Suspended Solids
SRP	Soluble Reactive Phosphate
TDS	Total Dissolved Solids
TWQR	Target Water Quality Range
wfw	Working for Water
WHO	World Health Organisation
WWTP	Waste Water Treatment Plant
XDR	X-Ray Diffraction

CHAPTER 1

INTRODUCTION

1.1. WATER IS FUNDAMENTAL TO LIFE

Cunningham and Cunningham (2008) stated that water is the most beautiful and precious resource. Water is basic for sustaining lives of all organisms on earth. It is a vital ingredient of everyday life (Best and Ross, 1977). Humans rely almost entirely on freshwater systems for domestic purposes such as cooking and drinking, for economic activities which include agricultural and industrial practices, even for recreation. It is therefore unfortunate that human activities alter and degrade the integrity and health of the Earth's water bodies. The scarcity of good quality freshwater is a common environmental problem in many areas of the world (Welch and Jacoby, 2004). South Africa too, is not exempted from this problem of diminished water quality and quantity (DWAF, 1996a).

Approximately one third of the world's population lives in countries where fresh water is insufficient. Environmental experts have estimated that this number could double by 2033 (Cunningham and Cunningham, 2008). The World Health Organisation (WHO) in 2009 reported that water use has doubled over the past century on a global scale. It is however worth noting that in developed countries, water use is almost stable (Cunningham and Cunningham, 2008). On the contrary, developing nations continue to exploit and mismanage water. In many countries around the world, ground water is being extracted at a rate higher than its natural replenishment rate (Cunningham and Cunningham, 2008).

1.2. LOTIC WATER BODIES

Water is one of the most abundant compounds in nature. Nearly 75% of the earth's surface is covered in water of which above 97% is contained in the oceans and other saline bodies (Wetzel, 1975). Over 2% of the earth's water is tied up in ice caps, glaciers, in the soil and atmospheric moisture. Only about 0.6% of the total water is found in freshwater lakes, rivers and shallow groundwater (Horne and Goldman, 1994). South Africa has limited surface water resources and only receives about 450 mm/year (Funke and Jacobs, 2011). Only about 11% of the total rainfall reaches the rivers, the rest is lost to evaporation and underground resources. The total surface run-off in South Africa is a little more than 49 billion m³/year (DWAF, 2004).

Lotic water bodies are running water ecosystems; they are complex longitudinal systems that appear as a series of sectors, each receiving and discharging water, sediments, organic matter and nutrients (Allan, 1995). In rivers, materials are transported unidirectionally, from the headwaters to the outflow. A river flows between a number of geographical boundaries and introduces factors such as altitude, climate, topology, geochemistry, hydrology and catchment

land-use, all in turn influencing the distribution of species, communities and habitats (Davies and Day, 1998).

Running water systems are particularly susceptible to pollution from the catchment because of their linear, unidirectional nature. Almost any activity that occurs at the catchment has a potential to cause environmental pollution. Any pollutants entering a river system for example have a potential of exerting far-reaching effects downstream. The relatively narrow shape of the lotic systems means that they have an intimate connection with their surrounding catchments. The vegetation that is associated with the water bodies has an important role of buffering the potential negative impacts from the catchment (Malmqvist and Rundle, 2002).

Fresh water ecosystems have been a form of attraction for human settlements since pre-historic times (Malmqvist and Rundle, 2002). They are also extensively exploited for water supplies, irrigation, electricity generation and waste disposal. This explains why there are hydro-power stations, irrigation-based agricultural lands and sewage treatment plants in the immediate catchment of rivers and streams.

Lotic systems have a significant biological value as habitats for an array of animals such as fish, birds and snakes. These systems also contain a diversity of invertebrates, plants and algae. However, zoologists still have a long way to go in terms of naming and classifying zooplankton. There is a gap in taxonomic knowledge because some of the biota in rivers and streams are still undescribed. This makes it difficult to precisely gauge the relative importance of lotic diversity and its ecological significance (Malmqvist and Rundle, 2002). It is also difficult to accurately evaluate the relative damage that has been caused (by pollution and other natural factors) over time.

1.3. WATER CHEMISTRY

The concentration and kind of chemical components in water is a function of climate, geomorphology, geology and soils, and aquatic biota (Horne and Goldman, 1994). In South Africa for example, water chemistry is significantly influenced by the interplay between climate and geology-lithology dynamics. This means that the chemistry of lotic systems differ from place to place. The eastern and southern parts of South Africa have more equitable climatic conditions and the rivers are mostly perennial. The resultant water chemistry is such that the waters are mesic with low concentrations of total dissolved solids (TDS). The interior parts of South Africa are more arid and the rivers are mostly ephemeral or seasonal. During the dry and hot seasons, water becomes high in TDS (Dallas and Day, 2004).

The discharge regimes, precipitation input, the composition of rain and biological activity determine the chemical components of surface water (Allan, 1995). Natural spatial variation

also influences water quality; the type of rocks that weather away and add ions into the water (Hynes, 1970). Igneous rocks such as those of the Transvaal and the Drakensburg Systems contain high amounts of magnesium and calcium, variable amounts of the following nutrients may also occur: phosphates, nitrates and silicates. Water that pass through or over these rocks pick up significant amounts of these elements. The water chemistry in areas that are dominated by these rocks is characterized by high pH values and low conductivity. On the other hand, sedimentary and metamorphosed rocks such as those of the Cape Supergroup leach out very little material to the water. Waters that flow over these rocks have low conductivity values and little nutrients (Dallas and Day, 2004). Sources of precipitation such as the rain and snow add chlorides and sodium to surface waters (Horne and Goldman, 1994).

Water is a very scarce natural resource in South Africa. This scarcity is worsened by the fact that little water that is available for use is susceptible to varying degrees of pollution. Anthropogenic activities such as mining, agriculture, recreational and land developmental activities add variable amounts of chemicals to surface water (DWAF, 1996a). Acid mine drainage is fundamentally associated with coal and gold mining. Pyrite (iron sulphate) is a common waste-product of mining activities. When oxidized in the presence of water, pyrite produces acids and results in pH drop of water resources (Akcil and Koldas, 2006). Acid mine drainages cause very comprehensive and multidimensional water problems because they cause acidification, salinity increase and heavy metal contamination. Acid mine drainages pose health risks to people and animals that may use the contaminated water (DWAF, 1996b). It is also costly to treat water that is polluted by acid-mine drainage (DWAF, 2004).

Land use activities such as construction of roads, building of settlements, excavation developments, mining activities and some agricultural activities deteriorate surface water quality. These activities add high concentrations of suspended solids to water. The presence of sediments reduces the amount of light that gets transmitted into water. This sabotages the development of macrophytes and reduces the abilities of predatory aquatic animals to locate their prey (specifically diurnal hunters). Suspended solids can also be carriers of other nuisance substances such as heavy metals (Horne and Goldman, 1994; DWAF, 1996b).

Surface waters in areas such as Pretoria, Johannesburg and Vereeniging in the Gauteng Province have been reported to particularly contain high concentrations of estrogen and estrogen containing substances. Meintjies *et al.* (2000) reported that South African water resources are burdened with estrogen and estrogen-mimicking substances. They also highlighted that most of the substances responsible for this contamination were of agricultural or industrial origin. Pesticides, herbicides and some household products contain estrogen and estrogen mimicking substances.

Some substances such as dioxins and aldicarbs are estrogen-mimicking substances that have not been identified in South African tap water samples (Meintjies *et al.*, 2000). This calls for much concern because in 2001, South Africa became a signatory of the Stockholm Convention on Persistent Organic Pollutants. Pulp and paper industry are said to produce such chemicals and yet there is no capacity in South Africa to analyse and treat such waste water that contain these chemicals.

The concentration of chemical pollutants such as toxins and nutrients, have increased in rivers over the past century in developing countries (Malmqvist and Rundle, 2002). Pesticide pollution has been profoundly recorded in the rural areas of the Western Cape and many areas of KwaZulu-Natal. The Breede and Fish Rivers have been reported to have had episodes of pesticides pollution in the 1990's (Meintjies *et al.*, 2000). Heavy metal contamination is also a matter of concern in South African aquatic ecosystems. The Umtata River studies showed heavy metal pollution (mainly cadmium and lead) but the sources were not identified. Heavy metals are usually introduced through non-point sources of pollution (Fatoki *et al.*, 2002).

1.4. WATER MICROBIOLOGY

1.4.1. Cyanobacterial poisoning

Oberholster and Ashton (2008) undertook some surveys on South African river systems that were classified as eutrophic or having the potential to become eutrophic. The study indicated that the most important were the Vaal, Crocodile, Mgeni, Orange, Modder (of which Sepanespruit is the tributary) and the Buffalo River systems. Those rivers needed attention with immediate effect pending their hyper-eutrophic states. The most important driving forces that were identified as the causes of water quality degradation in these river systems were the dense rural populations and extensive informal settlements that dominated land use patterns. Other contributing factors were noted as contaminated run-off from rural and urban areas, discharges of raw or partially treated sewage from sewage treatment plants that are overloaded. Poor management of agricultural practices and solid waste dumps that were located on or close to river banks were also noted as contributing factors to diminished water quality. The study further indicated that eutrophic river systems coincided with the spatial distribution of poverty-stricken areas where there was a high HIV prevalence (Oberholster and Ashton, 2008).

The dominance of cyanobacterial blooms in surface waters of hypertrophic reservoirs such as the Roodeplaat, Rietvlei, Hartbeespoort, Smith, Bridle Drift and Laing Dams emphasized the high levels of nutrient enrichment. The dams in the Crocodile and Pienaars River systems were all declared hypertrophic. The water from these sources required rigorous treatment before use. The average population densities in the catchment areas of these hypertrophic reservoirs

exceeded 50 people/km² (which are very dense per unit volume of water). The common water uses were extensive human consumption, recreation and a variety of socio-economic development options (Oberholster and Ashton, 2008).

Oberholster *et al.* (2005) reported that only advanced water treatment methods such as granular activated carbon filtration could appropriately remove cyanobacterial toxins from water. Hurtado *et al.* (2008) calculated that the activated carbon treatment method can remove up to 80% of the microcystins. Another effective method is the photocatalytic degradation of the microcystins using titanium oxide (TiO₂) as a photocatalyst. This photocatalyst is suitable for water treatment because it is non-toxic and photostable. Lawton and Robertson (1999) argued that ozonation is an excellent microcystin-remover. These authors however admitted that advanced water treatment methods are an expensive option. It would be appropriate to implement practices that minimise eutrophication problems in order to avoid financial burdens that they cause.

Most South African water treatment systems are not equipped with these advanced water treatment facilities. Conventional treatment process removes only the cyanobacterial cells and debris but not bio-toxins dissolved in water (Oberholster *et al.*, 2005). It is imperative that cyanobacterial toxins are effectively removed during water purification processes because they pose a serious health hazard to people and animals that consume water. A mixed bloom of *Anabaena* and *Microcystis* species of cyanobacteria were found responsible for a lethal outbreak of gastroenteritis in Brazil. Cyanobacterial toxins that were present in drinking water led to deaths of about 88 children. Over 2,000 cases of gastroenteritis were reported over a period of six weeks (Teixera *et al.*, 1993).

1.4.2 Water pathogens

The primary mode of transmission for intestinal infections is via the faecal - oral route. This kind of transmission can be ascribed to lack of adequate water and sanitation facilities. The toxicity or harmfulness of aquatic pathogens in humans is influenced by the age and state of health of the victim that ingests contaminated water. Children are more vulnerable to infection or poisoning by disease-causing microbes because they drink more water per unit of body weight. They are even more susceptible to physiological damage that pathogens may cause (Falconer, 2005). The elderly people and the immune-compromised citizens are also easy victims of water-borne infections (DWAF, 1996b).

Said *et al.* (2003) investigated the occurrence, prevalence and fate of pathogens in South African surface waters. They embarked on that study project to assess the health risks and associated economic implications that communities who used polluted surface water resources

for drinking purposes, irrigation or recreation were faced with. The authors cited human and animal wastes as the most common sources of pathogenic contamination of surface water. *Salmonella enterica* subsp. *enterica* is a major food and water-borne bacterial pathogen, and as a zoonotic bacterium, has a wide host range. As an organism that is equipped to survive in non-host environments, it occurs in both water and sediment. Microbiology researchers indicate that *Salmonella* is a major cause of gastroenteritis in humans. Viral hepatitis caused water-related deaths in South African metropolitan areas; the well-affected areas were the North West Province and the eastern seaboard of South Africa (Said *et al.*, 2003). A successful catchment management approach to microbial pollution requires an understanding of the origin, fate, survival and transport of pathogens introduced to water bodies (Said *et al.*, 2003).

Vibrio cholerae bacteria are other environmental bacterial pathogens. They spend a significant length of their lifecycle outside human hosts, but when introduced to humans, they cause disease within a short period of time. Oral ingestion of food or water contaminated with *V. cholerae* leads to development of a very contagious disease called cholera. Cholera is also a very common water-borne illness. After comprehensive microbial studies, Said *et al.* (2003) reported that the cholera outbreak in the Kwa-Zulu Natal Province of South Africa in the period from 2000 to 2003 was a compound problem that was characterized by the dynamics of socio-economic status of individuals and environmental conditions. In many incidences, it has been noted that cholera cases are prevalent within disadvantaged communities in which there are sub-standard sanitation facilities, little water supplies and high population densities.

1.5. WATER IN SOUTH AFRICA

1.5.1. The current water situation in South Africa

Helen Keller once said that science has found cure for most evils and yet it has found no remedy for the worst of them – the apathy of human beings. This statement is appropriate to describe the present state of water pollution. Water is arguably the most endangered natural resource in South Africa but still aquatic ecosystems continue to lose value, integrity and health, mostly as a result of human activities (Ahlers, 2006). South Africa's fresh water resources are under increasing stress from an expanding economy, an escalating population growth and inadequate municipal and regional service provision. Almost all of the country's water resources are exhausted (Davies and Day, 1998; Oberholster and Ashton, 2008). The scarcity, poor quality and uneven distribution of water in South Africa is a constraint to development. South Africa does not have surplus water, therefore all future economic developments and social well-being will be compromised in some ways (Turton, 2008). Water scarcity has been directly correlated to hunger, diseases and poverty (Basson *et al.*, 1997). The relatively high temperatures and seasonal rainfall in South Africa account significantly to freshwater scarcity. Most rivers are small and flow only during wet seasons (Davies and Day, 1998).

Venter (2000) highlighted an interesting reality that the present-day scarcity of water in South Africa is a new concept. In the 1800's, water was well-abundant and the riverine systems were almost unpolluted. This is evidenced by the names that were given to certain places and rivers in respect to near-by water bodies. *Amanzimtoti* is a river that runs to the south of Durban in the KwaZulu-Natal. This name 'Amanzimtoti' is Zulu for 'sweet waters'. It is attributed to the famous King Shaka of the Zulus; during one of his tours, he stopped with his army to get some rest. He was served water from the local river in a calabash. He sipped the water and said "Amanz'amtoti' meaning ' the water is sweet' (Gumede, 2003). *Bloemfontein* is Dutch for 'fountain of flowers' or 'flower spring'. Bloemfontein is a city in central South Africa which received its name from the beautiful flowers that surrounded the spring that was located on the farm on which the town was founded in the 1840's (Room, 2006).

1.5.2. South African population

Developing countries are burdened by massive debts, population explosions and increasing urbanization. People in such countries rely heavily on water of questionable quality because there are no better alternatives. This could be attributed to as one of the factors that contribute to shorter life spans in developing countries relative to developed nations. About 20% of urban dwellers and 75% of rural residents in developing countries, on average do not have access to safe water supplies (Igbiosa and Okoh, 2009). With the human population growing at a rate greater than 200 000 people per day, the world's aquatic systems have become more degraded (Welch and Jacoby, 2004).

The Gauteng region is a very populated industrial and metropolitan area of South Africa. However, it is critically short of water. Davies and Day (1998) reported that the northern KwaZulu-Natal, some parts of the Eastern Cape and the Northern Cape Provinces have serious water shortages. The problem of water scarcity has been addressed from different perspectives; scientific, political, social and economic, but many parts of South Africa are still water-short.

The rapid growth of South African population exerts a massive pressure on water resources. The population growth rate in South Africa was reported to have declined from 1.40% per annum between 2001 and 2002, to 1.06% per annum between 2009 and 2010 (Stats SA, 2010). The South African population was reported during the mid-year census that occurred during October 2011 as 51.7 million people (Stats SA, 2011). By 2018, the population of South Africa is extrapolated to be about 80 million people (Stats SA, 2007). The Population Development Programme regards 80 million people as the highest sustainable carrying capacity of South Africa's water and other natural resources. However some health factors such as HIV/AIDS and cancer have a significant negative influence on population growth.

1.5.3. Water use

Since water is a primary requirement for life, meddling with it was one of the earliest human achievements (Davies and Day, 1998). Significant human activities that had adverse effects on the planet earth started when constant agricultural activities were practiced. The movement of livestock from one place to another in search of better grazing lands became intense. Areas that were previously virgin land began to be ploughed. Problems of soil erosion and sedimentation also became significant. However, at that time, these human impacts were localised because the human population was small. Advances in technology led to construction of roads infrastructures, houses and industries. South Africa started experiencing significant environmental pollution during the middle 1900's (DWAF, 1993).

In many cases, water use tends to become water exploitation over time. Water exploitation is not a new concept; it is traced far back in history. Over five thousand years ago, ground water was already excavated in the Middle East. Romans stored rain water in reservoirs and then distributed it to cities. For over a thousand years, people from the East have grown rice in flooded paddles (Davies and Day, 1998). The agricultural sector is the largest water consumer in the world, it accounts for about 69% of fresh water use (van As *et al.*, 2012). South Africa is not exceptional to this, agriculture accounts for around 62% of all water use (DWAF, 1996b). Irrigation is the most popular farming practice and it is used to grow more than 17% of the world's crops which contribute more than one third of the world's food. Horticultural practices such as watering golf courses also use significant quantities of water (DWAF, 1996c). These water uses are so intense that by the year 2005, more than 95% of South Africa's freshwater resources had already been allocated (DWA, 2010),

It is however important to recognise that in high income-countries, the largest water consumer is industry which accounts for about 59% of fresh water (van As *et al.*, 2012). In South Africa, domestic and urban water use (including water for industrial use supplied by water boards) takes only about 27%. Mining, large industries and power generation accounts for 8% of total water use (DWAF, 2004). The domestic water use accounts for about 10% of fresh water in the world. In developing countries, domestic activities use about 11% of their fresh water but developed countries use only 8% for domestic purposes (van As *et al.*, 2012). In South Africa, domestic and urban uses account for around 27% of surface water. Commercial forestry is responsible for about 3% of the total surface water use (DWAF, 2004).

Van As *et al.* (2012) exclaimed that industries use water in an economic way. They calculated that a cubic meter of water that is used for industrial production yields 70 times more revenue (in monetary terms) than when the same volume of water is applied in agriculture. This could explain why the industrial sector is the largest water consumer in high-income countries. Industrial water use accounts for 21% of freshwater use in the world. However industrial

developments have significant negative impacts on South water resources. Many industries release hazardous chemicals as part of their effluent. The effluent may not be directly discharged into water bodies. The waste products that are disposed-off on landfills may release substances that may seep into nearby water courses (Oberholster and Ashton, 2008). These practices make water re-use difficult and expensive.

There is an increasing public concern regarding the quality of South African water resources. The contributions of untreated effluent or poorly treated wastewater discharges aggravate the rate at which the quality of surface water deteriorates. Research has proven that sewage effluents from sewage treatment plants, unskilled operators and inefficient and outdated sewage treatment infrastructures are among the major sources of pollution in freshwater ecosystems (Mema, 2009). Municipal treated sewage effluents are usually discharged from specific point-sources and channeled into receiving waters such as streams, rivers, lakes, ponds, wetlands and ground water. Moreover, point-source pollution also introduces a variety of potentially infectious agents to water. This accounts for massive outbreaks of water-borne diseases (Mema, 2009).

1.5.4. Health and economic implications

South Africa is termed the most advanced country in Africa in terms of economic development and service delivery. Ironically though, in the late months of the year 2000, it suffered one of the most prevalent outbreaks of cholera in the KwaZulu-Natal province. More than 100 000 people were treated for cholera in one month. If only the industrial effluent was properly treated before being disposed-off into the rivers, this dramatic cholera outbreak would have been avoided. Poor sanitary facilities and low levels of food hygiene even in the social environments of the affected areas were recognised and could also have contributed to the cholera outbreak (Dallas and Day, 2004).

Some epidemiological studies that were done in South Africa indicate the prevalence of methemoglobin levels in infants. This condition has been observed in infants that were fed water with nitrate concentrations that exceed 20 mg/l (Osode and Okoh, 2009). Poor water treatment goes beyond pollution, it costs people their lives. On average 30 children per day die in South Africa because of diarrhoeal infections that were mostly caused by exposure to poor drinking water quality (Davies and Day, 1998).

About 50 000 people on average die every day in the world as a result of water-related diseases. About 80% of such diseases are related to drinking water quality. Over 88% of the diarrheal diseases are waterborne or water-related (Jiang, 2006). Diarrhoea is one of the primary symptoms of water-borne diseases such as hepatitis, cholera, dysentery and typhoid. According to the WHO (2000) statistics, about 2.2 million people die each year as a result of

water related diseases. Deaths (that are water-related in this case) are inadequately reported in many rural areas as a result of limited resources and knowledge. Such gaps in information distort the accuracy of reports on water-related illnesses and death cases. Most mortality cases of water-related disease are children who are struck by virulent but preventable diarrheal diseases. In South Africa, diarrhea was reported to be responsible for about 20% of children between 1 and 5 years of age. For children under 5 years of age, diarrhoea is the third most prominent cause of death after HIV/AIDS and low birth weight (DWAF, 2004).

The South African government spends about R15 billion annually, on hospitalisation and treatment of diarrhoea patients (DWAF, 2004). The poor drinking water quality is a serious health threat in South Africa, which when combated, could save the country billions of Rands. This problem will cause serious economic melt-down in the future. Regarding the rate of population growth, the lack of proper sanitation facilities and the inadequate health budget, more health problems should be anticipated. The treatment costs that are associated with these water-related diseases are around R4.3 billion (Hiscock *et al.*, 2002). Oberholster and Ashton (2008) estimated the cost for diarrhoeal treatment in South Africa as about R3.5 billion/anum.

Water contamination is a serious ongoing problem in South Africa. The usual culprits of water pollution are residents of informal settlements who do not have appropriate sanitation services. Some municipal treatment works also do not treat sewage effectively and thereby cause water pollution into the receiving streams and. A series of surveys and technical researches were undertaken in 2004 to study the legislative compliance of wastewater treatment plants. Up to 70% of the assessed treatment plants were found to lack proper maintenance. Furthermore, local authorities were declared incompetent and thus could not cope with constant demand for effective sewage treatment (Osode and Okoh, 2009).

Bourne and Coetzee (1996) investigated the spatial distribution of human mortality in South Africa as a result of water-borne infections. The main objective of the study was to produce an atlas of mortality from potential water-related diseases and to discuss the implications of the observed disease distributions. From their study, Bourne and Coetzee (1996) concluded that in many parts of South Africa, specifically rural areas, water related illnesses were the first or second-ranked cause of death.

In 2009, the World Health Organisation (WHO) reported that 1.4 billion people did not have access to safe drinking water universally. A further 2.9 billion people did not have appropriate sewage disposal facilities. At least 250 million new cases of water borne diseases are reported every year. Around 50% of such reported cases are children under the age of 5 years (Welch and Jacoby, 2004).

1.5.5 Water conservation

Conserving the environment, including water resources is a long-term, perpetual process that needs to be kept in check frequently. Many rivers that flow through the poverty stricken communities are polluted because of poor sanitation and hygiene practices. This results in the spread of diseases such as cholera and typhoid. Countries such as Rwanda, Somalia, The Sudan and Ethiopia are some of the examples of poverty-stricken communities whose water bodies are heavily polluted (Davies and Day, 1998).

Public awareness measures have to be properly strategized and implemented. Water-related issues which include, management, conservation, pollution and distribution need to be effectively communicated to relevant bodies and communities. Social and political concerns on water issues need to be addressed sensitively. In summary, water management requires an integrated approach in which stake holders air their perspectives and a common ground is achieved. This process takes lots of efforts, energy, time and co-operation.

A water conservation initiative such as South Africa's Working for Water program plays a significant role in protecting the environment. It is a program that is aimed at protecting water resources by clearing invasive alien plants (Görgens and Van Wilgen, 2004).

Over the last three decades, the use of natural aquatic processes for wastewater treatment and pollution control has gained much interest globally. Wetlands in particular, have been recognised for their performance in wastewater treatment. Furthermore, the costs, maintenance and running of conventional treatment methods are escalating at high rates. Therefore, establishment of constructed wetlands as an alternative wastewater treatment is a cheaper and yet competent alternative to conventional treatment methods (Gérard *et al.*, 2002). It is an ecologically viable practice that has gained a lot of recognition and popularity around the world.

Water re-use is one viable and substantial method of conserving water. In industrial areas such as Pretoria and Johannesburg, about 50% of the total water requirements are met as return-flows. Water return flows are also helpful in the coastal areas such as Cape Town and the Durban/Pietermaritzburg area. However return flows usually have a profound negative effect on the quality of the receiving waters; they often cause water pollution and degrade the ecosystem's integrity. In cases where water is re-used, advanced wastewater treatment technologies and firm management may be required, depending on the quality of the return flow and its intended use (DWAF, 2004).

Inland water research in South Africa is dominated by researchers that have ecological and zoological interests (Cunningham and Cunningham, 2008). There is therefore a fairly good database of reservoir and river ecosystem studies. There are several gaps in the data bank of

inland water research as a result of the low capacity of the scientific, research community and insufficient financial support for projects. The interaction between researchers and governing bodies or resource agencies was reported weak (Walmsley and Davies, 1991). The co-operation on issues that involve water in southern Africa has been improved by the Protocol on Shared Watercourses in the Southern African Development Community (the SADC Protocol). The SADC Protocol addresses but is not limited to, co-operation between nations on issues of water policies and legislation, collecting and sharing data and information and management of water resources for mutual and equitable benefit of states that share water courses (DWA, 2004).

1.6 PROBLEM STATEMENT

The Thaba-Nchu sewage treatment works has a hydraulic capacity of 6ML/day (DWA, 2011) and serves a population that is in excess of 70 000 people (Stats SA, 2011). There have been reports from personnel, the general members of the public and personal observation during visits that the sewage treatment plant received sewage influent that was beyond its functional capacity. The released effluent was brown-coloured and offensive smelling. The quantity and supply of chlorine to the plant was inconsistent and the chlorine-dispenser was not functional. The level of compliance in terms of sewage effluent quality, the sewage treatment processes and the influent pre-treatment were questionable.

Thaba-Nchu is characterised by large areas of scattered rural settlements that are comprised of about 37 villages (Barbour, 2012) and dispersed informal settlements. Sepanespruit runs through some of these areas and just outside the central business centre. It carried domestic wastes, faecal matter that got swept by rain from the bush toilets (in shack residential areas) and urban run-off. The stream water at this area looked greenish in colour, turbid and slow-flowing with reported periodical foul-smell.

Water is one of the main environmental drivers that significantly influence wetlands and aquatic communities, whether permanently or only for a limited period. Varied hydrological regimes thus go along with wetlands, causing plants to adapt to varying soil wetness (Tiner, 1999). It is therefore imperative to determine the quality of water that the wetland received and the quality of water after the wetland treatment. The wetland receives water in the form of sewage effluent (from the sewage works), urban run-off, overflow from Seroale Dam and raw sewage from manhole overflow. The quality of water that flows in Sepanespruit before it reaches the wetland looked turbid and crude, burdened by visible floating solids. The wetland area is a common grazing site for livestock. The grazing patterns were not monitored and the wetland was at risk of losing its wetland properties; the vegetation and hydric soil characteristics. This study

explored the effectiveness of the Thaba-Nchu sewage works and also the impact of the treated and untreated water on the surrounding environment.

The changes in land and water use, ways and standards are some factors that are not obvious to track in details but that have a significant contribution to water quality in streams. The chemicals that flow in the sewage stream may be influenced by the social and health status of the community served by the sewage treatment plant. Because of the increasing rural and sub-urban population within the Thaba-Nchu area, it was worthwhile to investigate the effects on the stream health, of some cultural practices such as herding livestock within the wetland area. Sub-urban conditions such as lack of running water and sewage systems obliged the municipality to transport raw sewage to the treatment plant. Risks of sewage leakage and spillage in transit and improper sewage disposal are high.

The ecological state of rivers in South Africa is undertaken by the River Health Programme, through its State of Rivers initiative. This initiative involves collecting, storing and interpreting river health data in a systematic and quality-controlled way. The interpretation of river health information guides the process by attaching different river health categories, such as natural, good, fair or poor, to be allocated to each section of the river. This system enables the comparison of the health of one river or section of a river with that of another. Parameters that are considered to indicate the health of a rivers system include flow patterns, the integrity of river habitats and water quality (DWAF, 2004). In many water authorities such as the municipalities and water boards, long-term data collection has become a routine exercise in which data is accumulated and not scrutinised, analysed and interpreted. Such practices put resources such as chemicals, equipment, transport and personnel efforts to waste (DWA, 2011). The Thaba-Nchu sewage treatment was assessed on the basis of sewage effluent quality and compliance in terms of data monitoring and analysis.

The Modder River is not considered one of the largest South African Rivers but it falls under the most polluted South African rivers that need constant monitoring (Grobler and Toerien, 1986) and it was termed highly polluted (Oberholster and Ashton, 2008). It is logical and relevant that the pollution problem in the Modder River was also dealt with through managing water quality and pollution sources in its tributaries, of which Sepanespruit is one.

1.7 RESEARCH QUESTIONS

- The management of sewage treatment in the Thaba-Nchu area and the effectiveness of the Thaba-Nchu sewage treatment works are not up to standard. What are the effects of the sewage effluent on the ecology of the receiving stream?

- What are the threats to the general health of Sepanespruit and the associated wetland's integrity? What are the possible and viable conservative measures?
- Do social transformational issues and cultural habits have an effect on the quality of water in Sepanespruit?

1.8. AIMS

- To determine the water quality of the Sepanespruit upstream from the point of sewage effluent discharge;
- To determine the water quality of the sewage effluent at the point of discharge from the treatment works;
- To determine the water quality of the untreated sewage that flows into the wetland next to the Sepanespruit;
- To determine the treatment efficiency of Thaba-Nchu sewage treatment plant;
- Describe the effects of sewage effluents on the receiving stream;
- Determine seasonal changes in the physico-chemical parameters and phytoplankton of Sepanespruit;
- To determine any anthropogenic sources that threaten water quality and quantity in Sepanespruit and recommend measures to improve the health of this stream;
- To determine the concentration of chlorophyll *a* and algal communities that exist in Sepanespruit; therefore indicate the level of eutrophication;
- Collect and interpret the river health information on the sampling points along Sepanespruit and assign a trophic status to each section;
- Contribute towards compilation of scientific data on South African water bodies for purposes of assessment, monitoring, management and future reference.

CHAPTER 2

LITERATURE STUDY

2.1. WATER QUALITY THREATS IN SOUTH AFRICA

2.1.1. Introduction

Water quality describes the chemical, physical and biological characteristics of water. The chemical components of water include: dissolved oxygen, dissolved salts, nutrients (phosphates and nitrates) and pH. Temperature, taste, odour and clarity are some attributes of the physical component of water. The presence of viruses, bacteria, algae, aquatic plants, invertebrates and fish in water define the biological state of water (Horne and Goldman, 1994). However, the quality of water is described in respect to its suitability for an intended use (DWAF, 1996a).

Water quality deterioration is a result of both natural processes and human activities. Climate, geomorphology, geology, soil types and biotic interactions are some of the natural determinants of water quality in an area. Surfaces through which water moves in the catchment contribute to the composition of water quality in lotic systems (Malmqvist and Rundle, 2002). Therefore, water quality varies from place to place. There are several human activities that cause changes in running water chemistry, ecosystems' composition, physical habitat and aquatic life. These factors include: agriculture, urban and industrial activities, land-use changes, mining and recreational activities (DWAF, 1996a).

There are massive records of the ways in which human activities have polluted and degraded the health of water bodies throughout history. Forms of human-implicated pollution in water bodies have been changing with time. Gross amounts of domestic sewage, industrial effluents, agricultural wastes, mining wastes, pesticides and variable other pollutants were dumped into water bodies in the past. Carrying away all unwanted materials with flowing water was considered appropriate and economical. In more recent years however, that practice has been done away with. Streams are being channelised, stabilised, dewatered (for irrigation) and super-watered (artificially increase flow for other purposes such as drinking and irrigation) (Wetzel and Likens, 1979). Water abstractions in their different forms pose tremendous threats to water quality and quantity in lotic environments (Davies and Day, 1998). The beginning of industrial revolution also marked the increase of running water pollution (Best and Ross, 1977).

Eutrophication is the enrichment of water with plant nutrients especially nitrogen and phosphorus (Horne and Goldman, 1994). Eutrophication is characterised by accumulation of metabolic products, turbid waters, depletion of dissolved oxygen and occurrence of cyanobacterial blooms (Oberholster and Ashton, 2008). Since increased concentration of nutrients results in excessive growth of phytoplankton and macrophytes, eutrophic rivers, dams

or streams lose their aesthetic values because they become covered by large areas of macrophytes. Phytoplankton usually accumulates as algal scums and slicks in water bodies. Macrophytes prevent access to waterways and sometimes cause malodorous scums of blue-green algae (Igbinosa and Okoh, 2009). The algae may release toxic substances (cyanotoxins) into water bodies. Eutrophication increases the treatment costs of drinking water through filter clogging in water treatment works (Murdoch *et al.*, 2000).

2.1.2. Sewage effluents and eutrophication

Before the 1980's, South Africa was universally recognised as a leading country in eutrophication research. However, this credit was lost because eutrophication management focused on implementation of inappropriately high phosphorus concentrations (1 mg/litre as P) for effluents that were discharged from sewage treatment plants to surface water systems (Oberholster and Ashton, 2008).

The policies that were made for eutrophication-related issues were also hardly implemented. In recent years, eutrophication issues receive little attention in South Africa (Oberholster and Ashton, 2008). Eutrophication was reported by DWAF in 1993 as the major water environmental problem in South Africa. Extreme eutrophication cases have been reported in South African and Zimbabwean lakes throughout 2010 (Grafton and Hussey, 2011).

Sewage effluents are among the leading contributors of nitrogen and phosphorus compounds in water bodies. Even effluents from the most sophisticated sewage treatment plants still contain significant concentrations of nitrogen and phosphorus compounds. These nutrients are quite difficult to remove completely. In agriculture, fertilisers are applied to improve crop yield. However, not all fertilisers are taken up and used by plants. Some are retained in the soil and later leached into ground water and finally into rivers and lakes (Grafton and Hussey, 2011).

Reducing the use of fertilizers and pesticides by practicing natural lawn care, planting indigenous vegetation, and limiting chemical use are some of the simple measures that when effectively practiced, can reduce pollution significantly. When every citizen undertakes the responsibility to ensure that hazardous wastes, including paints, stains, solvents, cleaning products, used motor oils, antifreezes, and pesticides are disposed-off properly, the environment would be less polluted. The use of phosphorus-free detergents and non-toxic cleaning products is also an environmental friendly practice (The Minnesota Stormwater Manual, 2005).

Eutrophication encourages algal growth in water. The decaying remains of algae use up massive quantities of oxygen in water. In the process, fish and other aquatic animals are denied adequate amounts of oxygen. Prolonged anoxic conditions have been proven fatal to some

water life (Grafton and Hussey, 2011). Study cases in which fish and a myriad of other aquatic organisms died as a result of oxygen starvation in water, are well-documented.

The use of algaecide is an effective control of algal growth but it is very expensive. To avoid suffocation of fish as a result of lack of oxygen that the decaying algae causes, it is important not to treat the whole lake or dam at the same time. Treatment should be begun along the peripheries of water bodies to allow fish to move into untreated areas. It is advisable to allow sufficient time, at least two weeks between treatments for oxygen levels to recover (Grafton and Hussey, 2011). This treatment is usually undertaken in private waters but prior consultation with the Department of Agriculture is necessary before applying this product to public waters.

Solar-Bee technology controls harmful algal blooms, reduces and eliminates odours and improves water clarity. It is a proven technology for reduction of seasonal fish kills. It improves spawning, density and diversity of zooplankton. It has been noted for improving water quality through increasing dissolved oxygen levels and reducing ammonia (Coetzee, 2010).

The introduction of detergents that do not contain phosphates is an every-day practice that in the long run, will help reduce eutrophication problems. The use of phosphate-free detergents is mandatory in Europe and the USA (Moollan, 2004). This practice has reduced phosphorus loads reaching wastewater treatment works by up to 30%. The use of phosphate-free detergents throughout South Africa would help to combat water quality and scarcity problems that are caused by eutrophic waters. At present, these detergents are being tried in Pretoria, Johannesburg and some parts of KwaZulu-Natal.

The culture of recycling and re-use of wastewater for other purposes at or close to the point where wastewater is generated should be cultivated. This principle should be incorporated into water resource management plans for land use activities. This will reduce the quantity of effluent that is discharged directly to the aquatic systems and in the long run, help to reduce eutrophication and contamination of these aquatic systems. Sewage treatment and disposal systems that are used by industries and mines ought to be upgraded where necessary. These systems must be managed appropriately and monitored consistently to ensure that they meet the set wastewater standards.

Biomanipulation is an exercise in which an ecosystem is deliberately altered by adding or removing species, especially predators. In the north-western Europe and the USA, biomanipulation has resulted in improved fishing conditions for anglers, especially when predatory fish are stocked. Biomanipulation should be considered in relation to the whole ecosystem and is only one of the options for water body restoration. Using fish for biomanipulation may require a continual, sustained removal effort and may be efficient only

when applied in collaboration with other nutrient control and reduction mechanisms (Benndorf, 1995). So South African water pollution could be addressed through bio-manipulative measures but profound expertise, manpower and financial resources would be needed.

Water pollution is a phenomenon that can be decreased or even diminished through educating members of the general public to convert their simple everyday ways into more environmental friendly practices. If people would drop some ignorant habits such as disposing waste materials carelessly and begin to properly use designated rubbish bins, the urban run-off would not be such a profound source of pollution to the receiving water body.

Uncontrolled access to water bodies encourages water pollution through various human activities. It is important to define and implement bank-line zoning along all rivers and watercourses. All land uses should be carried out at a certain specified distance from the bank of water course. At erosion-prone zones, the bank-line zoning should be even further inland.

Water quality management procedures aim to maintain the water's fitness for use. This is a difficult task to perfect because a balance has to be struck between socio-economic developments and environmental protection. Socio-economic issues focus at improving the welfare and standards of living for people. However, these economy-boosting schemes such as industrial developments are usually accomplished at the detriment of the environment. Hence environmental legislative measures have to be executed before developments are implemented. South Africa has progressed fairly well in terms of developing environmental laws and implementing them, at least in comparison to other developing nations.

The issue of eutrophication alleviation requires a well-planned and an effectively implemented long-term approach. The issue requires a collaborative approach between government, water resource managers, businesses and communities. Solving this problem requires the implementation of a suite of social, economic and technical interventions.

2.1.3. Bacterial water pollution

Pathogens are infectious agents that transmit diseases from one organism to another. The common pathogens are the protozoa (*Cryptosporidium parvum*, *Entamoeba histolytica*), parasites (Bilharzia), bacteria (*Escherichia coli*) and viruses such as hepatitis A. Pathogens may cause diseases in humans, plants and animals when they are released into water bodies. Most water-borne pathogens occur in human and animal faeces and enter water resources in various ways (Miller, 2001).

Outbreaks of water borne infections such as cholera, diarrhoea and skin diseases are some of the evidences of pathogens in water. Some of these infections can be deadly. The elderly

people, children and the immune-compromised individuals in a community are more susceptible to water-borne infections (DWAF, 1996a).

Human adenoviruses (HAd) are important human pathogens that are associated with gastrointestinal, respiratory, urinary tract and eye infections. The occurrence and concentration of HAd in sewage have little seasonal variability. The occurrence of HAd in the natural aquatic environment is likely due to the contamination with untreated or inefficiently treated human sewage. Studies have shown that HAd survive longer than faecal indicator bacteria in sewage and in the environment. Chlorination seems to be the only effective method to disinfect HAd (Jiang, 2006). Jiang (2006) undertook studies from which they discovered that HAd in finished drinking water and tap water occur in massive quantities for both South Korea and South Africa. This calls for a more comprehensive treatment of drinking water in both countries.

It is imperative that the government through its department of social welfare provides sanitation facilities and proper waste disposal services to all citizens. These are some of the basic services to which all citizens are entitled. They facilitate proper hygiene and therefore promote better health for all. Besides, in the absence of such services, there is usually an eruption of bush toilets. The latter are a tremendous threat both to the environment and health because in time, they are washed into rivers and streams. Running waters ultimately become carriers of human and animal faecal wastes.

2.1.4. Chemical pollution

Chemicals such as pesticides and herbicides may be washed off from areas of agricultural practices and end-up in water resources. These chemicals are very harmful to aquatic life and may cause both acute and chronic infections. In humans and animals, agrochemicals cause respiratory diseases. Accidental spillages, wash-off of pesticides and spray-drifts into water sources are some of the sources of agrochemicals in water bodies (Allan, 1995).

Dichlorodiphenyltrichloroethane (DDT) is a pesticide which is also an organic pollutant. It was used for control of malaria in many parts of the world, including South Africa. The methods of treating and controlling malaria include residual spraying of insecticides. DDT in particular became more popular because it was cheap, easy to use and has long-lasting effects. However, DDT is toxic and resistant to breakdown. This chemical has the potential to be transported over long distances. It bio-accumulates once consumed and it is an endocrine-disrupting chemical (Tren and Bate, 2004). However, the use of DDT was banned in South Africa.

Industrial chemicals which are usually used in detergents, cosmetics, paints and herbicides are alkyl-phenols. These chemicals bio-accumulate in human and animal fat; this occurs through

ingestion of suspended particles. Higher trophic organisms in the food chain, such as humans and fish-eating birds, are more at risk due to consuming high concentrations of intoxicated food. Catfish is an important source of protein in many African countries, especially the poor countries. It is unfortunately one of the fish species which are predominantly susceptible to chemical bioaccumulation (Barnhoon *et al.*, 2004).

2.1.5. Pharmaceutical and medical wastes

The presence of medical wastes in drinking water (usually occur in the partially metabolised form) can cause serious health implications and adverse effects on the ecosystem. Steroid hormones which are produced by humans may end up in water bodies via sewage effluents. Pharmaceutical waste products and disinfection by-products are some of the other medical and pharmaceutical wastes in water bodies.

Endocrine Disrupting Chemicals (EDC's) are environmental chemicals that are known to interrupt the normal functioning of the endocrine system. Several studies have proven that there is a direct connection to the presence of EDC's to reproductive, developmental and behavioral effects in humans and wildlife. Exposure to certain EDC's is again attributed to the increasing reports of testicular cancer and poor semen quality in men. Environmental health researchers have reported on various occasions that EDC's are present in South African natural waters (Barnhoorn *et al.*, 2004).

The possible effects on human reproductive health that are posed by estrogens are poor sperm quality and sperm count reduction in men, testicular and male breast cancers. Evidence exists that estrogens are serious health hazards to the animal kingdom (Meintjies *et al.*, 2000). Several cases have been documented in which female fish have been masculinised and reproductive incompetences have been noted in turtles. Some changes in the sexual behavior of birds and endometriosis in rhesus monkeys have been attributed to estrogen and estrogen-mimicking substances in their drinking water (Malmqvist and Rundle, 2002). However, most intersex fish have been caught in water near receiving from sewage related effluent. Exposure to estrogen or estrogen-mimicking chemicals during sexual maturation has been shown to induce sex reversal or intersexuality in catfish (Barnhoorn *et al.*, 2004).

2.1.6. Salinisation

Salinisation is the accumulation of salts in a water body to levels that pose threats to the ecological integrity of such a system (Dallas and Day, 2004). This is a condition in which the concentration of total dissolved salts of water is high. It commonly results from urban, agricultural, mining and industrial activities. The usefulness of water usually increases with decrease in its salt content; for most purposes, less saline water is preferred (DWAf, 1996a). In South Africa, the problem of salinisation is aggravated by water pre-use, as a result of limited

water supplies. Water is a very scarce natural resource; this is partly attributable to that most South African rivers flow seasonally (Davies and Day, 1998).

Salinisation is a result of both natural and anthropogenic sources. Natural waters contain sodium, chloride and sulphate ions in varying concentrations. If the water is subjected to evaporation, its salt concentrations increase. Some easily weathered rocks that contain high concentrations of soluble minerals may also increase salt concentrations in natural waters (Grafton and Hussey, 2011).

Human activities cause salinisation in a myriad of ways. Saline industrial wastes and mine effluents increase the salinity of water resources to the point where their value and quality is diminished. Sewage purification subjects water to evaporative concentration especially during dry periods. Long term spray irrigation results in the evaporative concentration of salts; leading to salinisation of soils and water. Salts that accumulate in the soil during dry seasons are released when rain flushes them out, so the receiving rivers are characterised by increasing concentrations of salts (Grafton and Hussey, 2011).

Salinity reduces the usability of water for different purposes. It diminishes the taste of drinking water; salty water does not have a desirable taste for drinking. When used for irrigation, saline water decreases the yield of crops. Equipment that gets in contact with saline water gets corroded over time. Industrial equipment and household materials that are used for processes that involve saline water are destroyed and require replenishing and replacements frequently (DWAF, 1996b).

There are remedial processes to salinisation that can be applied and have been proven successful. Reverse osmosis is an advanced and effective chemical technique which can be applied to desalinate (reduce salinity of) water. However, it is expensive and requires special expertise for operation (Aihoon *et al.*, 1997). Constructing ground water barriers can be costly but it is an effective method of protecting ground water resources from salt contamination.

2.1.7. Erosion and sedimentation

Soil erosion and sedimentation involve the processes of detachment, transport and deposition of soil particles by erosive forces of wind, the impacts of raindrops, water and wind shear, and water run-off over the soil surface. Erosion results in loss of arable land and valuable agricultural land i.e. erosion reduces the productivity of a land (Dallas and Day, 2004). Sedimentation increases the treatment costs of water. Water quality is usually diminished by soil-adsorbed pollutants that are carried by sediments. Sedimentation is one of the most widespread pollutants of surface waters ((National Research Council (U.S.), 1996).

Erosion of landscapes and stream courses are some of the natural sources of sedimentation. Urbanisation and mining are the major anthropogenic sources of erosion in South Africa. Construction of roads and buildings, clearing of land for developments are activities that emanate from a growing economy and expanding urban areas. Quarrying, sand mining and open cast mining are some of the activities that lead to landscape fragmentation and finally erosion. Agricultural practices such as overgrazing, irrigation and cultivation of land also cause erosion (Allan, 1995).

The physical effects of erosion and sediment deposition on water quality include shortened life span of reservoirs, decreased water retention capacity in dams, increased flood frequencies and decreased light penetration (National Research Council (U.S.), 1996). Sediments also have biological implications in water. Sedimentation in small streams affects the biotic communities; disrupts spawning grounds of fish and thereby reduces diversity of fish. They destroy habitats of biota and decrease the productivity of aquatic populations (National Research Council (U.S.), 1996). Sediments are transport media of pathogens, phosphates and heavy metals. Therefore, sedimentation also influences the chemical composition of water.

Porous pavements are surfaces that allow water to pass through their voids in the paving material or between pavers. This kind of paving allows storm water to filter through soil that lies below paved surface, reducing the numerous environmental issues associated with water runoff. Soil particles filter rainwater that percolates through the soil as it moves to surface waters and groundwater aquifers. This important step in the natural process of water purification is bypassed when rainwater falls on impermeable pavement surfaces or roofs, in which case water is carried directly through storm drainage systems into waterways.

Pollution carried in rainwater runoff is a serious environmental concern, especially in urban areas. Storm water that flows across urban areas such as streets, parking lots and sidewalks picks up contaminants. Air pollution particles, spilled oils, detergents, solvents, dead leaves, pesticides, fertilizer, and bacteria from various wastes are some of the usual components of urban run-off water (The Minnesota Stormwater Manual, 2005).

Sweeping sidewalks and driveways are practical and easy solutions to water pollution. The sweepings should then be disposed-off into the trash. It is a good practice to prevent yard wastes from entering storm sewer systems and water bodies by composting the wastes. An effective use of rubbish pick-up services also helps to keep rubbish from entering storm water systems (The Minnesota Stormwater Manual, 2005).

These are storm water basins which are designed to impound storm water before it is released into a receiving stream or a sewage system. Dry ponds usually empty out completely between storm water run-off events. These ponds are important in limiting downstream flooding (into the

receiving stream) through reducing peak discharge of run-off water. Dry detention ponds however do not remove sufficient storm water pollutants (Hussain *et al.*, 2006).

Wet detention ponds are probably the most common management practice for the control of storm water run-off quality. When they are properly designed, constructed, and maintained, they are effective in controlling pollution. Many processes are responsible for removal of pollutants in wet detention ponds. Physical sedimentation is the most significant removal mechanism. Biological and chemical processes also play some roles in pollution reductions. The use of aquatic plants, in a controlled manner, provides additional pollutant removal. Detention ponds are technically feasible, their implementation costs are fair, long-term maintenance requirements and costs are also bearable (Pitt, 2004).

Grass waterways are a type of conservation buffer. They are downhill grassed channels, generally broad and shallow and designed to prevent soil erosion. Grass waterways are also used as filters to remove sediment, but may sometimes lose their effectiveness when too much sediment builds up in the waterways.

2.1.8. Climate change

Climate change is a phenomenon in which global average temperatures change, the rates and patterns of precipitation also change (Miller, 2001). Climate change is encouraged by accumulation of greenhouse gases in the atmosphere. Greenhouse gases in the atmosphere have increased profoundly since the pre-historic times. These gases tend to warm the earth's surface and produce other dramatic alterations. Carbon-dioxide (CO₂) is one of the most important greenhouse gases; it has shown about 30% increase in the atmosphere since the last 250 years. Methane (CH₄) and nitrous oxide (N₂O) are also significant greenhouse gases whose concentrations have increased by 145% and 15% respectively (Arnell, 1999).

The current change in climate influences water quality through altering the inter-relationships between human activities, atmosphere, terrestrial and aquatic processes in the watershed. Global increases in air temperature are directly correlated to increases in water temperature. These changes will therefore affect surface water quality. Temperature increases lead to decrease in water volumes (Murdoch *et al.*, 2000).

The climate change predictions have shown that the mid-latitudes of the southern Hemisphere will continue to get hotter and drier. This prediction means that the present water shortages will only get worse over time. The water conservation measures that have been executed will only buy a few years of grace before the general water supplies become inadequate (Davies and Day, 1998).

South Africa is situated in the arid part of the globe where water resources are scarce. This country is located on the negative run-off zone, where annual evaporation exceeds rainfall by a factor between 1.2 and 4. On average, only about 8% of South Africa's annual rainfall becomes available as surface run-off (Oberholster and Ashton, 2008).

Some of the adverse conditions that are observed in aquatic ecosystems result from changes in climatic conditions. Increases in floods and drought, degradation of drinking water quality, loss of biodiversity, increased transmissions of water-borne diseases and the associated costly remedial measures and loss of food supplies are some of the negative impacts of climatic changes (Miller, 2001).

It is extrapolated that by 2025, about 5 billion people out of the total of 8 billion people will be living in water-stressed countries that use more than 20% of their available resources. Climate change may be an aggravating factor for such tremendous water scarcity in many countries of the world (Arnell, 1999).

The rate and extent of various chemical interactions are dependent on temperature. For instance, temperature determines the solubility of oxygen in water. At higher temperatures, the amount of dissolved oxygen is lower than it is at lower temperatures. Higher water temperatures (as a result of global warming) may have an adverse effect on biota as a result of compromised oxygen concentrations. Increased water temperature is anticipated can also result to increased anoxia of eutrophic water (Murdoch *et al.*, 2000).

The amount of precipitation in an area determines the amount of water that flows in rivers and streams. It also determines the degree of dilution of natural and anthropogenic constituents in water. The projected climate of the next century is such that the temperature will increase by an average of 3 °C, the atmospheric carbon-dioxide concentration will be double the pre-historic value of 270 ppm and the global average precipitation will increase by 3 – 15 % (Davies and Day, 1998). On the contrary, evaporation concentrates the constituents in water. In extreme conditions, salts may crystallize or precipitate as a result of intense evaporation (Murdoch *et al.*, 2000).

Global warming and changes in precipitation patterns exert a profound effect on the quality of water. There is abundant evidence for dramatic and rapid climatic warming throughout the globe. Some evidence has been gathered from lake sediments, paleo-hydrology and tree-ring records. Many areas of science have proven that climate change has coincided with large-scale land-scape fragmentation and exploitation of water resources (Miller, 2001).

Precipitation and run-off patterns, sea-level rise, land use and precipitation shifts are prospective results of global warming. Rising sea level is a result of thermal expansion of the

ocean and increased melting points of glaciers and land-ice. The global sea level increased by about 10 - 20 cm during the past century. This was caused to a large extent, by the melting of land-based ice-sheets and glaciers. IPCC results suggest an average of 15 – 95 cm increase in sea level by the year 2100 (Arnell, 1999).

Most studies have predicted that global warming will lead to reduced surface water volumes, particularly during summer months. Climate records have shown that 0.3 - 0.6 °C increases in global air temperatures have occurred over the past century. Climate prediction models have shown that the winters will be milder, there will be longer growing seasons, the evaporation and transpiration rates will also increase. Estimated rates of transpiration are predicted to exceed precipitation rates. The ultimate results will be low stream-flow, decreased rates of ground-water discharge and diminished lake levels (Murdoch *et al.*, 2000).

In oxygen deficient waters, the increased productivity would result in anoxia and subsequent decreased productivity. Increase in the rate of chemical transformations and longer periods of biological activity could result in increased bioaccumulation of toxins in aquatic ecosystems. The toxicity of metals in aquatic ecosystems is enhanced by increased water temperature through chemical interactions with dissolved organic carbon in low pH waters (Murdoch *et al.*, 2000). Previous studies have shown that changes in soil productivity and biochemical cycling can affect the quality of run-off from terrestrial ecosystems.

Higher sea level and storm episodes could negatively affect freshwater bodies especially in the coastal areas. Saline waters in river mouths and deltas would be pushed towards the inland. Coastal aquifers would also be at risk of salt water intrusion. If saltwater would intrude into the inland waters, the value of freshwater would be jeopardised. The water quality would be diminished for purpose of domestic, agricultural and recreational use. In California for example, rising sea level poses a particularly critical threat to freshwater supplies. Over the last century, sea level increase of about 17 cm happened in San Francisco Bay (Arnell, 1999).

Climate change is a natural process that may also promote the spread of alien plant species. With the increasing levels of CO₂ in the atmosphere, there are shifts in the plant species composition, populations and communities. Previous studies have proven that, the newer species compositions are usually dominated by alien plant because they adapt better to a change in climatic conditions than the native species (Henderson, 2001).

2.1.9. Thermal pollution

Heated or cold water that is discharged into a water course causes thermal pollution. It disturbs the normal functioning of organisms that live in water, and ultimately interrupts the way the entire lotic system operates. Water pollution usually emanates from the heating and cooling

systems of industries and power stations (Cunningham and Cunningham, 2007). Returning irrigation waters also have a profound disturbance to water temperatures. This form of water pollution may increase water temperatures by 10 to 20 °C (Dallas and Day, 2004).

Thermal water pollution is also caused by water that is released from deep dams into streams and rivers. This results in summer-cool and winter-warm water temperatures (Dallas and Day, 2004). Transfer of water from one basin to another also causes water temperature disruptions. The changes in vegetation cover on the banks of streams contribute to water temperature changes (Davies and Day, 1998).

Temperature is a cue to plants which alerts them when it is time for germination, for emerging and for flowering. Wrong signals are therefore transmitted to aquatic plant life upon receiving warm water (Davies and Day, 1998).

Water temperatures have serious effects on aquatic life. Cold or warm water temperatures may send wrong signals to biota for their migration times, times to lay eggs and moments to change diet (Cunningham and Cunningham, 2007). This may mess up the biota's normal regimes and seasonal cycles. Fish may die due to heat or cold shocks as a result of increased or decreased water temperatures (Davies and Day, 1998).

Furthermore, thermal pollution may disrupt aquatic food chains. As a result of a sudden increase of water temperature (due to hot water releases from industries), insects and other zooplankton may complete their life cycles quickly (pre-mature development). This becomes a disadvantage to fish and other aquatic predators because the victims (sources of food) matured quickly and perhaps even escaped from their usual habitats (Davies and Day, 1998).

The rates and intensity of many chemical reactions are temperature dependent (Horne and Goldman, 1994). When water temperatures increase, the amount of dissolved oxygen (DO) decreases, and the toxicity of many substances such as cyanide and zinc, increases. Higher temperatures also enhance the growth of sewage fungus. This reduces the water's quality and its aesthetic value (Dallas and Day, 2004).

It is imperative for engineers and other developers to construct reservoirs in a biologically sensitive manner. When designing such structures, there has to be an allowance for maintaining a natural temperature regime, so to avoid thermal pollution. Constructions of multi-level outflows (on dam walls) that mimic natural variations in water discharges have proven to prevent radical temperature changes in water bodies (Dallas and Day, 2004).

2.1.10. Radioactivity

Accumulation of radionuclides in water and sediments is a serious environmental hazard in South Africa. Traces of heavy metals such as uranium, thorium, radium and lead may end up in water bodies. The most prominent source of radioactive pollution is seepage from gold mine tailings and slime dams (Akcil and Koldas, 2006). Radioactive substances may bio-accumulate in crops that are irrigated with contaminated water. On consumption of such crops, humans become susceptible to serious health risks such as cancers. There are even worse health implications to people that use radioactive polluted water for domestic purposes such as drinking (Akcil and Koldas, 2006).

2.1.11. Urban Litter

Littered materials become malodourous rafts that float in urban water courses. The plastics, papers, rags and other colourful materials become hung along river banks and distort the beauty of such lotic systems. Litter diminishes water aesthetics and interferes with the biota therein. Since the 1970's, littering has been deemed both a behavioral and an educational problem (Marais and Armitage, 2004). When urban areas do not have or do not use landfill sites appropriately, littered materials are washed into storm water and are released into rivers and streams.

Educational campaigns are conducted to ensure public awareness about hazards of littering to water bodies and the environment as a whole. Cleaning campaigns that are usually conducted by school children are some of the educational programs that are practiced in South Africa. The morale is to teach children to be responsible enough to dispose-off rubbish appropriately (Nhamo, 2005).

Industry and commerce are direct manufactures of products that at a later stage litter the environment. It is a wise decision therefore to involve them in the reduction of waste. In developed countries, manufacturers produce packaging that is environmental friendly. Increasing the cost of products that are packaged in non-biodegradable and non-recyclable packages has been a successful strategy for waste reduction (Nhamo, 2005).

Legislation was enforced to South African grocery stores that they sell plastic carry-bags. This was a measure to encourage the public to re-use the plastics or resort to environmental friendly shopping bags. This has been a fairly viable initiative; it has reduced plastic litter significantly. But still, a lot of littering still happens at taxi stations, parks and other public areas. More educational programs still have to be devised to disseminate awareness to the general public (Nhamo, 2005).

Manufacturers should be persuaded to consider environmental impacts of their products. When litter gets to the broader environment, it becomes a nuisance and quite difficult to collect. It is important therefore that it be taken care of, at its source. Refuse removal of litter is one feasible method of litter collection. Even better, door to door refuse removal is practiced in South African suburbs and townships, and it is quite effective. Care must be taken to position and design litter bins such that they are not susceptible to vandalism. Bins must be placed carefully to prevent wind scatter and scavenging by animals (Marais and Armitage, 2004).

2.2. WATER SCARCITY PROBLEMS IN SOUTH AFRICA

2.2.1. Alien Plant Invasions

Alien plants are plant species that were introduced to a certain habitat but later became naturalised within that habitat. These plants owe their existence to direct and indirect human activities. Some plants were introduced intentionally because of their values. For instance, some alien plants are used as sources of fiber and timber in agricultural economics (Henderson, 2001). With time, alien plants grow unassisted in natural environments. However, other species of alien plants occur only temporarily and do not persist for long periods without human assistance. Alien plants are termed invasive if they displace indigenous vegetation within their habitats (van der Maarel, 2004).

Alien plant invasion is a serious environmental concern in South Africa. An area of about 10.1 million hectares in South Africa (including Lesotho), is invaded by alien plant species. The Free State province has an average of 12 993 575 hectares, of which 166 129 hectares is an area that is invaded by alien plants (Le Maitre *et al.*, 2000). It is important to execute mitigation measures against the spread of alien plants; otherwise they will invade even a large area. Alien plants are usually concentrated in habitats that experience frequent disturbances (van der Maarel, 2004).

Cullis *et al.*, (2007) calculated that a massive amount of water, averaged at $523 \times 10^6 \text{ m}^3$ of water is lost annually as a result of invasive alien plants. If remedial measures are not put into place, water loss due to alien invasion is extrapolated to increase to $1\,314 \times 10^6 \text{ m}^3$ / anum in South Africa.

Invasive alien plants have a profound impact on the structure and function of indigenous vegetation and ecosystem. When alien species grow as dense populations in the riparian zones, they reduce the volume of water that flows in rivers. In extreme cases, when such thick stands of trees have grown along the river courses and in catchment areas, a river may stop flowing (ARC, 2008). Invasive alien plants also reduce the carrying capacity of grazing lands. In South Africa, rangelands are invaded by exotic trees, shrubs, succulents and unpalatable

vegetation. This has a negative impact on livestock farming because the grazing areas get reduced in size and quality (ARC, 2008).

Floods promote alien invasion in the sense that they remove native vegetation and increase moisture, nutrients and light within riparian zones. This becomes an opportunity for alien vegetation to grow faster and stabilize within these areas while the native vegetation is wiped away in the floods. Alien plants are usually characterized by vigorous growth rates. This is also an advantage for them to outgrow native vegetation (Henderson, 2001; van der Maarel, 2004).

When changes occur in land sculpture, the native vegetation becomes disturbed. For instance, when a dam is built within the river course, the latter's hydrology changes. Native species' habitats to which they are adapted, are disturbed. This becomes an opportunity for alien plants to grow in that area and with time, colonise it (Henderson, 2001).

Some alien species such as the *Eucalyptus* species secrete chemicals which prevent germination of other plant species in that area, a phenomenon called allelopathy. Further-apart, many alien plants are fire hazards. Certain alien plant species produce fruits which are attractive to the native fauna. This promotes dispersal of alien seeds at the disadvantage of native species' seeds (Henderson, 2001).

Some dense stands of alien shrubs choke water flow regimes. During floods, these shrubs are ripped out easily and can therefore damage ground vegetation cover. In the process, bare soil is created, which may later be eroded thus creating space for more alien invasions. Some alien plants, especially in South Africa, are large trees which overshadow native vegetation. Such covered vegetation is denied sunlight and rain. Over some time, the native vegetation maybe wiped out (ARC, 2008).

The advances in GIS and the relevant computer-based technological measures provide an opportunity to model the effects of alien invasions on water yield (Le Maitre *et al.*, 1996). This is however a specialized area of expertise and requires expensive and experienced personnel to handle. Indirectly, alien plants cause the government unnecessary costs.

It is a massive challenge to remove alien plant species. One of the measures would be to introduce a large seed bank to an alien-invaded area. The idea would be for the active population to out-compete alien plants and then completely displace them. This is an extensive exercise and would have to be managed and monitored from time to time. If proper managerial mechanisms are followed, it is a fairly viable remedy to alien plant invasion (Henderson, 2001). Alien plants can also be controlled through a combination of felling and burning, chemical control and biological control measures.

Working for Water (wfw) is an extensive alien plants eradication programme. It has been highly effective in managing alien species in some areas. It is however important that the eradication management team gets equipped with basic information on the species- and site specific ecological properties. This knowledge would be relevant when prioritizing sites which could be more prone to invasions. Accurate management initiatives would also result when managers are well-informed. Knowledge about possible further distribution of invasive species in the changing environment may help to optimize eradication initiatives (Crous, 2010).

South Africa's Working for Water initiative was triggered by predictions that invasive alien plants would use significant amounts of water, if they grow unchecked. This program aims to protect water resources by clearing these plants. Invasion of an ecosystem by alien plants has serious effects on water yield from catchment areas (Görgens and Van Wilgen, 2004). The Working for Water initiative has brought a collaboration between ecologists, forest hydrologists and engineers to combine efforts in order to control the effects of invasive alien plants to hydrological characteristics of catchments.

2.2.2. Water abstractions

Water abstraction is the process of taking water from any source, either on a temporary or permanent basis. Water extraction is usually done to accumulate water for agricultural purposes especially irrigation. The accumulated water in some cases is treated and then distributed as drinking water. Environmental legislations are executed to control the methods and extents to which water may be abstracted. In extreme cases, extensive abstractions have led to rivers drying up and the level of ground water aquifers have been reduced terribly. The science of hydrogeology focuses on the monitoring, assessment and management of water abstractions.

Chemical substances enter running waters through natural means; atmospheric inputs, degradation of terrestrial organic matter and the weathering of rocks. Most of the waters that enter lotic systems have passed through terrestrial catchments which are composed of different geologies, soil types, vegetation and hence contribute to lotic water chemistry (Malmqvist and Rundle, 2002).

Water is a renewable resource and most abstractions are sustainable in that, water will in time return to the hydrological cycle. Some scientists including Foster and Charlesworth (1996) and Price (2002) argued that temporary water abstractions should not be viewed as undesirable especially when they are practiced for economic benefits. They however agree that strategies have to be put in place to maintain water levels within the recommended limits even after abstractions. The United Nations (1998) reported that 20 countries suffered water-stress i.e. have less than 1 000m³ of water per person per year.

It is difficult to ignore this warning about the potential state of water scarcity. This calls for urgent sustainable development in which the available water resources are preserved for the future, while they are also used economically and appropriately to avoid exploitation. However, assessing the environmental impacts of groundwater abstractions is a difficult task (Hiscock *et al.*, 2002).

Ground water has historically provided a cheap and local source of water for domestic and agricultural purposes in many parts of the world (Hiscock *et al.*, 2002). Over the last 20 years, many developing countries have experienced an enormous increase in the exploitation of ground water for irrigation. Provision of ground water resources have allowed the economical and fast development of reliable and better quality water supplies for rural communities in African and Asian countries (Hiscock *et al.*, 2002).

An example of ground water over-exploitation happened in the High Plains of the United States in 2002; this was a non-sustainable condition. Water from this aquifer was over-extracted and used for irrigation. The area around this aquifer was transformed into one of the most prominent agricultural regions of the world. Substantial pumping from the 1940's up to 1980 caused a water level decline of about 30m in some parts of this region. This water level decline threatened the productivity of this area. There has been a shift from irrigation-based forms of agricultural practices to dry-land farming. This shift has jeopardized economy through (dishing) revenues that were generated from agriculture (Hiscock *et al.*, 2002).

Dam construction increased rapidly during the 20th century. During the 1970's, this practice reached its peak (Malmqvist and Rundle, 2002). In the majority of South African metropolitan areas, high quality drinking water is available. On the contrary, in many rural communities, the situation is pathetic. The drinking water quality is poor (Hiscock *et al.*, 2002).

Water abstractions have a negative impact on the density and diversity of biota. Aquatic macro-invertebrates are important in the dynamics of lotic systems because they act as shredders, collectors and filters of organic matter. They are a primary connection to the fish community, providing food source for both game and forage fishes. Benthic invertebrates may change in their composition because of the reduced water flow as a result of water abstractions. Water abstractions may lead to the following changes in hydraulics: channeled bed dewatered, sedimentation for fine particulate matter, compaction of substrate sediments, development of periphyton and macrophytes and changes in water quality (Castella *et al.*, 1995).

World Commission of Dams (2000) reported that water abstractions in the form of damming increased during the 20th century. However dam construction decreased in the 1990's because most suitable sites had been exploited. The legal protection against exploitation of rivers is another reason for decreased dam construction. There are evidences that damming may

contribute to other environmental problems such as emission of greenhouse gases and mercury releases. Damming also has long time effects on biota which include disturbing the migration patterns of fish and mammals (Malmqvist and Rundle, 2002).

Water abstraction and impoundments have led to both catchment degradation and transformation of perennial rivers into seasonal rivers. Some of the most striking examples of rivers that were previously perennial (that are now seasonal) flow through the Kruger National Park. These rivers are exploited before they flow through this national park. The Luvuvhu, Great Letaba, Olifants and Crocodile were perennial. Kruger National park is one of the most premier natural environments in southern Africa. It is however threatened by over-exploitation of its rivers, which are its only water supply (Allanson *et al.*, 1999).

Changes in management practices and public awareness are viable measures that have benefited the health of lotic systems in developed countries. These strategies could improve the conservation initiatives in developing countries if they are appropriately implemented (Malmqvist and Rundle, 2002).

Water abstractions in many rivers of the world have become so intense that some rivers only flow for certain periods of the year. In some cases river flows have been reduced to fractions of their original water levels. The tributaries of the Aral Sea for example, lost most of their waters to irrigation of nearly 3 million hectares of cotton fields in their catchments. The once rich flooded plains of these rivers are being replaced by salt-tolerating vegetation or left infertile (Malmqvist and Rundle, 2002).

There are big gaps in the documentation of the trends of the association of biota with land-use changes. However, some evidence suggests that stream biodiversity has been significantly altered by past land use. Harding *et al.* (1998) suggested that the catchment land use in the 1950's predicted the present-day diversities of lotic invertebrates and fish. They further indicated that historical developments especially agriculture, caused long-term modifications and reduction in invertebrates diversity.

CHAPTER 3

DESCRIPTION OF THE STUDY AREA

3.1. LOCATION

The Free State Province (FS) of South Africa is located on flat plains in central South Africa. This province is situated between latitudes $26^{\circ} 40''$ and $30^{\circ} 41''$ South of the equator and longitudes $24^{\circ} 21''$ and $29^{\circ} 47''$ East of the Greenwich meridian (Moeletsi, 2010). Figure 3.1 shows the position of the Free State Province in South Africa and the lines of latitude and longitude within which it is situated.



Figure 3.1: The position of the Free State Province in South Africa
(http://www.nationsonline.org/oneworld/map/za_provinces_map2.htm)

The Free State province shares borders with other South African provinces namely; Northern Cape Province to the west, North-West Province to the north western side, Gauteng to the north and Mpumalanga to the north eastern side. The eastern escarpment separates the Free State from the Eastern Cape and KwaZulu-Natal provinces. Free State also shares an international boundary with Lesotho. The Free State covers the surface area of $129\,825\text{ km}^2$ and it is the third largest province in South Africa (Davis *et al.*, 2006). It covers an area about 10.6 % of South African's land area (Moeletsi, 2010). Of the total surface area, about 3.2 million hectares was indicated as cultivated land (Maphalla and Salmon, 2002).

Rivers and their associated streams within the Free State and Gauteng provinces are reportedly endangered in a critical manner. Immediate measures of intervention should be deployed. River systems in some parts of the Western Cape and the Eastern Cape are endangered while most are critically endangered. Lotic systems within the Mpumalanga Province and the KwaZulu-Natal are endangered while most are just vulnerable. The North West Province and the Northern Cape pride themselves with rivers systems that are mostly least threatened in terms of their water quality and quantities. In a country that has been declared water scarce and burdened with water pollution as South Africa, it is worth applauding the Northern Cape and the North West provinces for protecting and conserving their water bodies. Figure 3.2 indicates the river systems of South Africa and the state to which they are vulnerable, threatened or endangered.

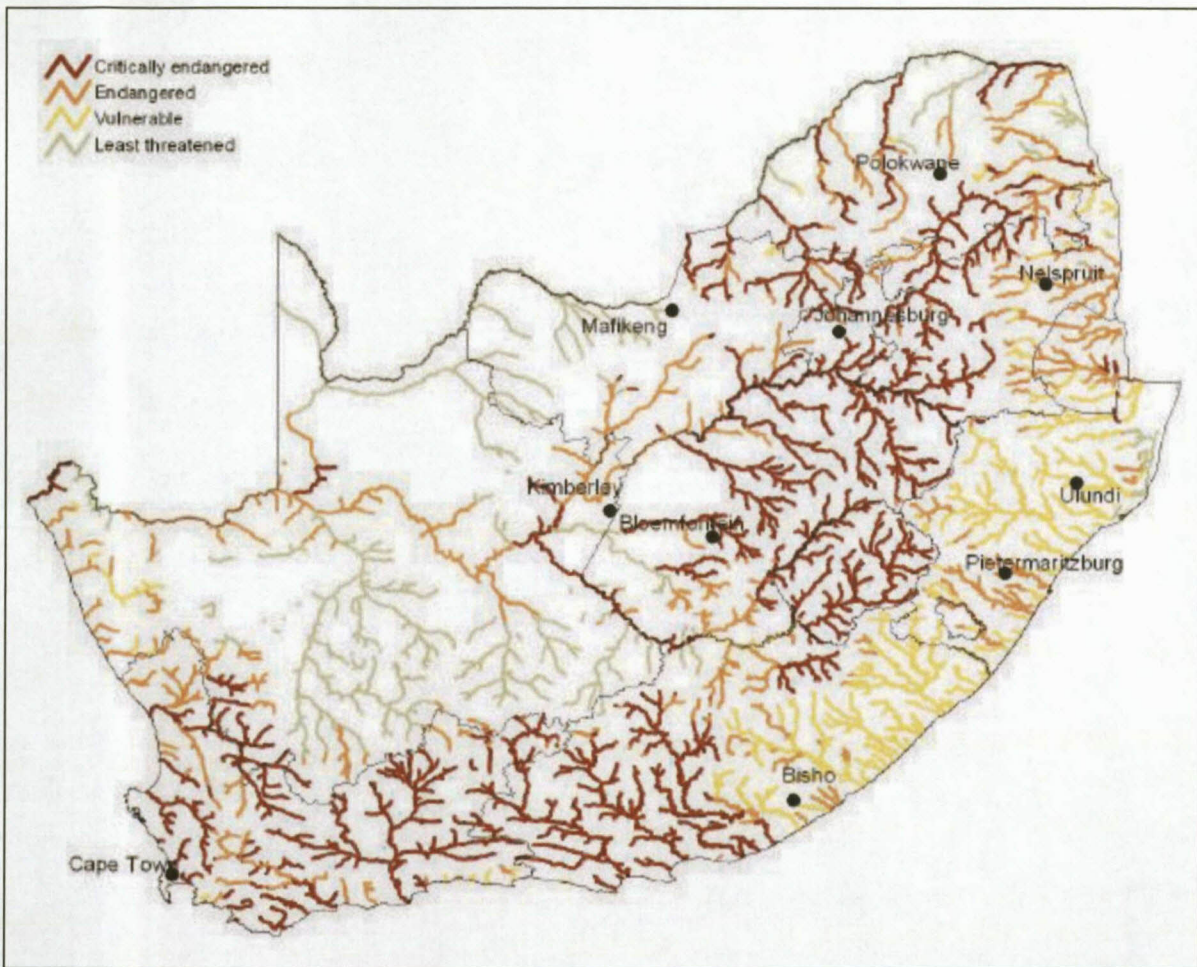


Figure 3.2: The state of South African rivers in terms of how threatened or vulnerable they are (hppt://www.googlemaps.com/water_pollution_ (Accessed: January 2012)

Thaba-Nchu, Botshabelo and Bloemfontein are the three districts of the Mangaung Metro Municipality, central South Africa. Bloemfontein is the capital city within the municipality. Both Botshabelo and Thaba-Nchu are located south-east of Bloemfontein, along N8 highway that

group, and the Late Triassic Molteno Formation of the Karoo Supergroup underlay the Free State Province (Bosch, 2001). The Free State is situated in the central eastern portion of the main Karoo basin of South Africa (Theron, 1970).

At Thaba-Nchu, it is difficult to separate the Tarkstad subgroup and Burgersdorp Formation. It is however worth noting that this difficulty is evident in the entire Free State province. The rock of Tarkstad Subgroup mostly outcrops along higher areas of Thaba-Nchu. Bosch (2001) employed X-ray diffraction (XDR) analyses to reveal the constituents of mudstone of the Tarkstad Subgroup. He discovered that it is composed of 57% quartz, 10% muscovite, 9% hematite, 8% ilmenite/smectite interstitial, 7% chlorite, 4% plagioclase and 4% smectite. The Molteno Formation also outcrops on the Thaba-Nchu Mountains (Bosch, 2001).

About 10% of the Thaba-Nchu area is covered by dolerite. Dolerite is a dark-grey to black, dense igneous rock. This hard nature of dolerite renders it resistant to weathering and erosion. The hills, ridges and higher lying ground in the area are mostly formed by dolerite. This rock is finely to coarsely crystalline (Bosch, 2001).

The lowest strata which form the base of the Thaba-Nchu Mountain are the Beaufort beds. These beds are part of the outcrop that runs from Harrismith through Thaba-Nchu to Bethulie. Above the Beaufort series lay the Stormberg series which consists of Molteno beds, the Elliot beds (Red beds) and Clarens Formation sandstones (Cave sandstones). Molteno beds are usually characterized by coarse sparkling sandstones. They also have a terraced nature of topography because of the resistant nature of the main sandstones. The result of which are cliffs and huge boulders. When Molteno sandstones undergo weathering, they form rusty spherical lumps and pits (Bosch, 2001).

Layers of the Elliot Formation (Red beds) are distinguished by the dominant red or maroon colour. Slopes of Red beds are usually unbroken inclines. The purple and red mudstones are typical of red beds; they can be recognised at a distance especially on dry slopes with sparse vegetation cover (Tekle, 2004).

Thick sandstone layers of the Clarens Formation (Cave sandstones) are fine-grained sandstones that are particularly prone to weathering. The sandstones usually form shallow caves. The sandstone layers are white or green but may appear pink in the vicinity of its junction with red beds (Bosch, 2001).

Alluvium is water transported sediment that is deposited along rivers, streams or depressions in the landscape. Small localized deposits of alluvium occur next to the streambeds of Sepanespruit (Tekle, 2004). Both dolerite and alluvium deposits have an economic value in this area. Dolerite is excavated and crushed as a stone aggregate for road building material.

Deposits of sand which are suitable for building and plastering are present in the alluvial deposits (Bosch, 2001). The Sepanespruit catchment is profoundly overlain by the mudstone and sandstone of the Adelaide and Tarkastad formation (Tsokeli, 2005). The streambed is composed of bedrock which forms random shallow pools. The pools then narrow down and then flow over the gravel, medium-sized stones and larger boulders.

3.3. TOPOGRAPHY

Topography influences water distribution patterns and soil-water regimes. Topology determines the water drainage pathways, surface and subsurface flow patterns. Erosion and deposition patterns are profoundly dependent on topology. The distribution of sediments, solutes and various organic fractions over a landscape are dictated by the area's topology. Along a topology, soils vary continuously while along similar contour lines, they do not change in composition (Fitzpatric, 1986).

Free State is characterised by a low topographic contrast. The western, northern and central Free State is generally flat and slightly undulating. The western part in particular consists of plains and pans as important hydrological features; the elevation is generally below 1200m above sea level (Moeletsi, 2010). The eastern and southern parts are defined by steep foothills, elevated peaks and prominent ridges, with height above sea level ranging between 1200 and 1600 m. The eastern Free State is mostly characterised by mountains. The Maluti range along the Lesotho border is connected to the Drakensburg on the border with KwaZulu-Natal (Bosch, 2001). This mountain range reaches a high altitude of 3000m above sea level (Moeletsi, 2010).

The thin soil depth that often occurs in steep and convex slopes is evident of rapid removal of weathered material. The removal of finer particles and soluble salts of calcium (Ca), sodium (Na) and magnesium (Mg) from upper steeper slopes may be washed into the water bodies. Areas where water accumulates or flows are often at lower slopes (Tekle, 2004). Salt deposits are present on rocks in Sepanespruit (Avenant, 2000).

Flood plains and valley-bottom wetlands are determined by geological formations on a landscape. These topographic features mostly occur as sills and dike that intruded weak sedimentary formations. Since dolerite is resistant to erosion than the surrounding sedimentary rocks, it inhibits vertical erosion of a landscape where they occur. This encourages the horizontal erosion of the landscape which over time results in the formation of wide and flat landscape features such as pans (Tooth *et al.*, 2007). Of all the Karoo sediments, the shales, sandstones and mudstones of the Ecca Group are easily eroded away therefore forming depressions that later become pans (Botha *et al.*, 2003).

3.4. CLIMATE

The Free State province occupies the interior part of South Africa and its altitude on average is 1 300m above sea level (Moeletsi, 2010). The climatic conditions within the Free State are similar to those of an interior plateau which is characterized by summer rains, cold winters and lengthy periods of sunshine.

The eastern Free State is characterized by mountains that become covered in snow during winter and valleys that flourish with dense and diverse vegetation during summer months. The eastern and north eastern parts of the province experience the humid subtropical climate that is characterized by summer rainfall and warm temperatures. The annual minimum temperatures are below 5 °C while the mean annual maximum temperatures are below 22 °C. The south eastern parts are defined by subtropical climatic conditions with summer rainfall and cool winters (Moeletsi, 2010). The southern parts are defined by hot and dry summer periods, the winters are defined by long and cold nights. The western Free State's weather conditions are not as extreme as the eastern counter parts. The minimum annual temperatures are higher than 9 °C. The annual mean maximum temperatures range between 26 °C and 28 °C (Moeletsi, 2010).

The average annual minimum temperatures within the Free State province range between 7 °C and 9 °C. The average maximum temperatures range between 22 °C and 26 °C. The average summer temperatures are around 23 °C while the average winter temperatures are about 8 °C. January is the hottest month with a temperature range of about 15 °C to 34 °C (Moeletsi, 2010).

South Africa has an average rainfall of 450 mm per/ anum, this is nearly half of the global average rainfall which is 860 mm/ anum. This makes South Africa a dry country. Our country has very limited water resources and several factors, such as climate change and water pollution worsen the present situation of water scarcity (Claassen, 2010). The western and southern areas of the Free State Province are semi-desert. Half of the total rain that falls in the Free State Province occurs in thunderstorms. More than 75 % of the rain falls between October and March (Toerien *et al.*, 1995).

Thaba-Nchu falls within the transitional climatic area because it lies between the higher rainfall mountainous region of the north-eastern Free State and the drier plains of the central part of the province (Earlè and Grobler, 1987). Figure 3.4 shows the rainfall regions of South Africa. Thaba-Nchu falls within the 400 - 600mm rainfall range.

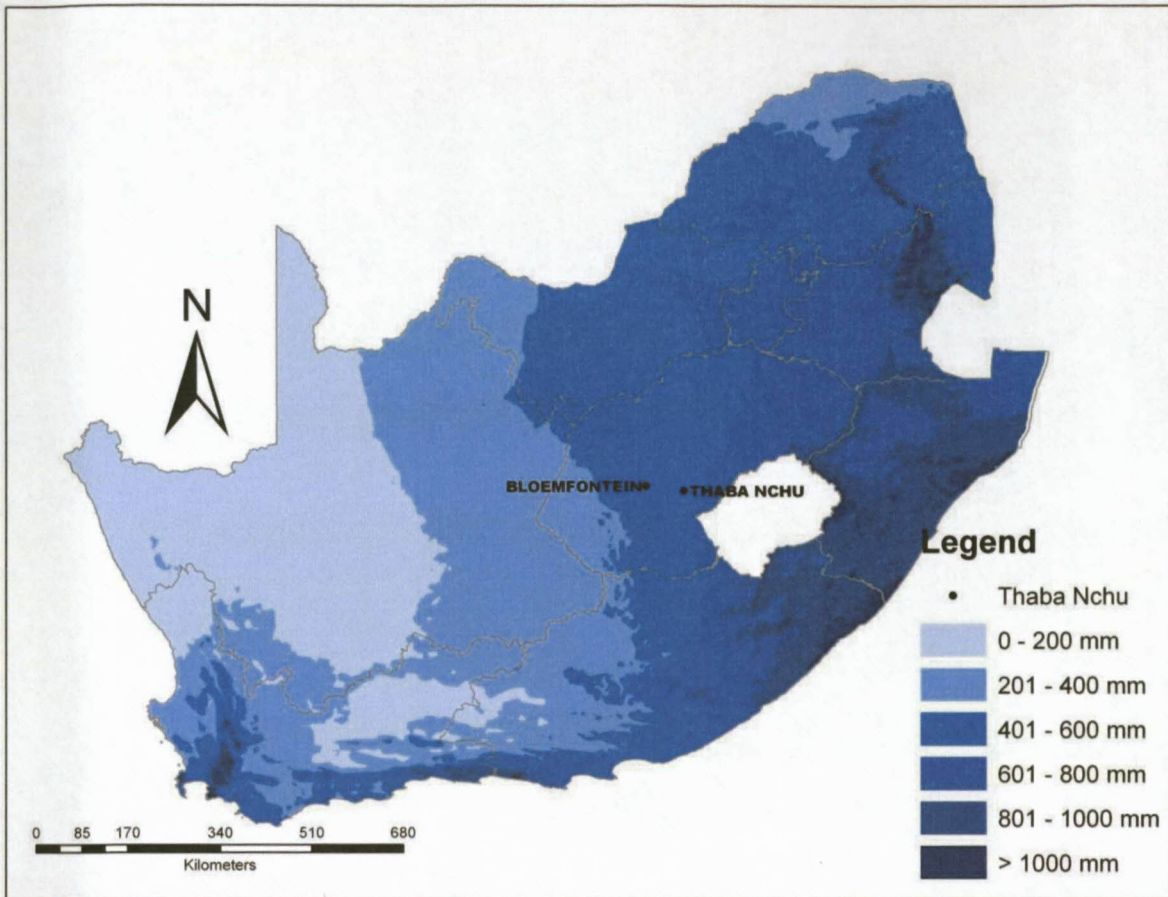


Figure 3.4: The different rainfall regions of South Africa (Maps provided by the Department of Geography, UFS)

Sources of winds in different areas differ. In South Africa, the most common sources of winds are thunderstorms and cold fronts. The study area is located in a high pressure area and is subjected to dry anti-cyclonal winds during winter months (Tyson, 1987). Central South Africa is characterised by extreme winds as a result of thunderstorms. Wind is the primary source of movement and mixing in a water body (Horne and Goldman, 1994).

3.5. BIOMES

The Free State province is covered by the Grassland, the Nama Karoo and the Savanna Biomes. The study area however is entirely situated within the Grassland Biome. This biome covers the central and high lying regions of South Africa. Figure 3.5 shows the different biomes of South Africa as was determined by Kleynhams *et al.*, (2004).

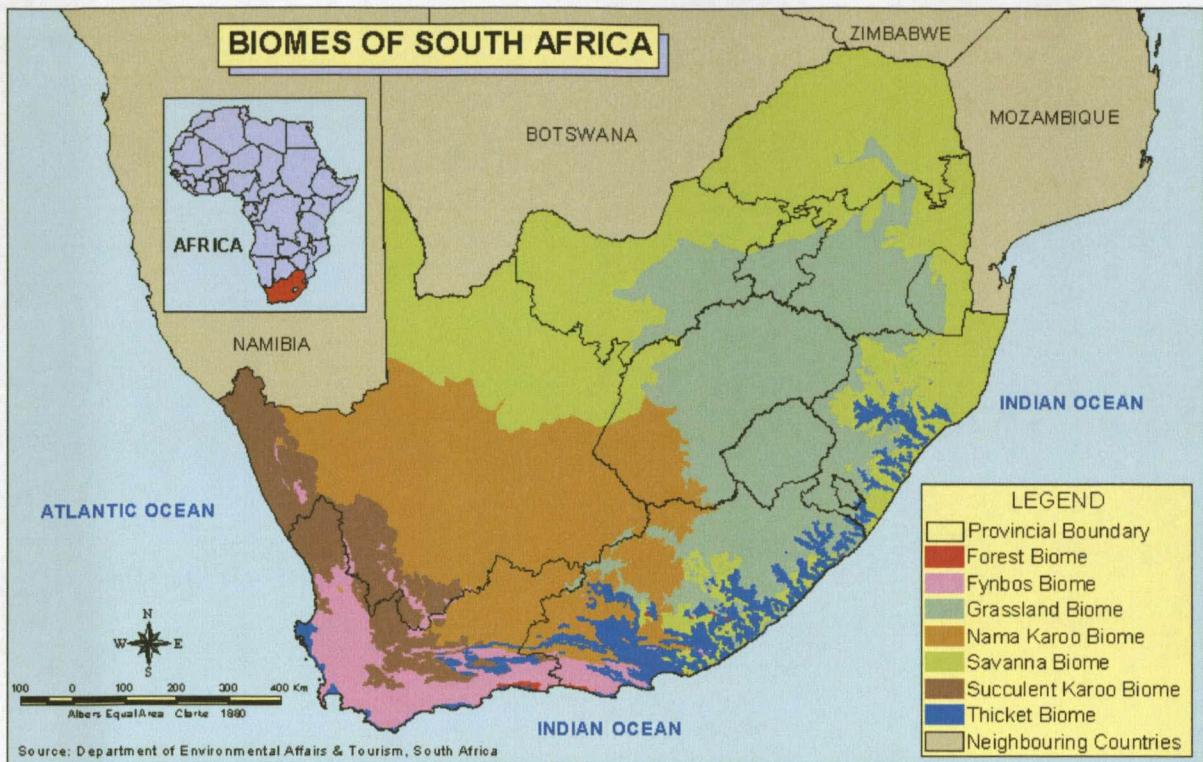


Figure 3.5: The biomes of South Africa in relation to the provincial boundaries
 (<http://www.google.co.za/url?sa...>)

The soils that underlay the grassland biome are generally derived from shales, mudstones and sandstones of the Karoo Supergroup. The soil types are also very variable; may range from humic clay soils to loose sands. The most common soil in the grassland biome which accounts for about 50% of the total area is the red-yellow-grey latosol plinthic catena. The black and red clays, solonetzic soils, freely drained latosols, and black clays also occur significantly (Rutherford and Westfall, 1986).

The vegetation units in this area are dominated by Poaceae and Hemicryptophytes. O'Connor and Bredenkamp (2007) described six floristic regions in the grassland biome of South Africa. The dry western region is reportedly defined by 'sour' grasslands while highland regions of the Drakensburg are covered by more palatable grasses. The rainfall variability within this biome is a major determinant of plant community compositions, and indirectly influences primary production, nutrient cycling and photosynthetic pathways. The grassland biome is almost entirely composed of perennials, there are some tufts especially in the semi-arid grassland as a result of drought-related withering. The vegetation along Sepanespruit is dominated by grasses and a few shrubs. The secondary vegetation is mainly sedges and reeds.

3.6. ECOREGIONS

When river systems share similar physical and chemical characteristics, they can be grouped together into ecologically similar units (Gerber, 2003). Ecoregions are areas that are defined by similar climatic conditions, geology, lithology and vegetation types. The geomorphology, chemical and physical parameters of a river system, its size and hydrology determine its impact on the ecoregions within which it flows. South Africa has a diverse range of ecosystems including rivers. The system of ecoregion classification or typing aids the grouping of rivers according to their similarities. This system of river typing is simple and makes ecological assessments for water requirements easy. The river typing system can be advantageous in cases where a data-rich river system is used to extrapolate information to data-poor rivers that fall within the same hierarchical typing context (Kleynhams *et al.*, 2004). The Modder River, to which Sepanespruit is a tributary, is located within the Highveld Ecoregion as determined by Kleynhams *et al.* (2004).

The topographic attributes of the Highveld ecoregion are low to moderate relief; there are lowlands, hills and mountains. The dominant vegetation types are the highlands grasslands which are found within the following soils: dry and sandy, moist and cool, rocky, moist sandy, wet (though limited in abundance), moist clay and very limited patches of afro-montane forest. The altitude of areas within this ecoregion ranges between 1 100 and 2 100 mm, in limited cases, an altitude of up to 2 300 mm was recorded. Highveld ecoregion is a summer rainfall area. The median runoff for the quaternary catchment has been simulated to range between 5 and 250 mm/ anum. The mean annual temperature ranges between 12 and 20 °C. Figure 3.12 shows the map of South Africa within which the Highveld Ecoregion is coloured. The map shows Level I River Ecoregional classification system for South Africa.

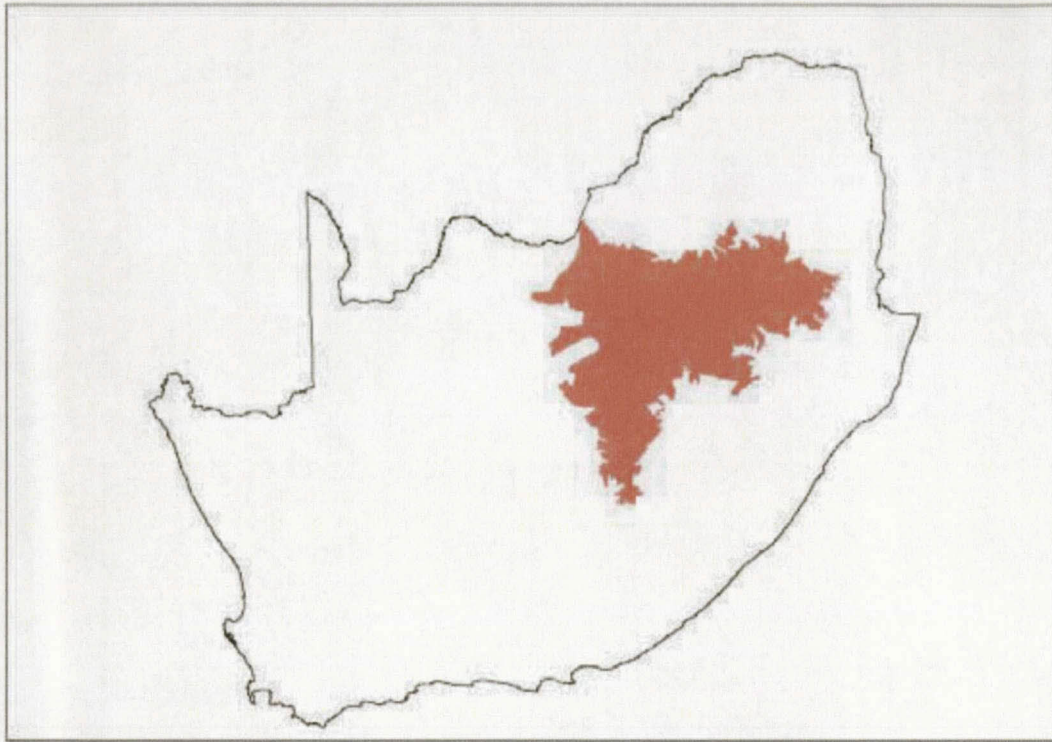


Figure 3.6: The Highveld Ecoregion of South Africa within which the Modder River runs (adapted from Kleynhans *et al.*, 2004)

3.7. WATER USE

The northern parts of the Free State are drained and irrigated by the Vaal River. Farming is practiced to a significant degree in this region. The Free State province is responsible for 32%, 33% and 51% of the country's wheat, maize and sorghum production respectively. It is also the second largest producer of sunflower, groundnut and dry beans (Department of Agriculture, 2003). This is therefore why the Free State is sometimes called the 'bread basket of South Africa'. The moderate-to-low rainfall condition renders the Free State province not optimal for crop production. The most pressing attribute that limits agricultural production in South Africa is water scarcity (ARC, 2008).

The Thaba-Nchu area is dominated by small scale farmers that primarily practice farming for subsistence purposes, however there are a few commercial farmers. Commercial farmers grow and sell lawn grasses, vegetables such as cabbage and potatoes. There are also farmers that grow poultry, keep sheep and cattle. The commercial farmers drain water from Sepanespruit to sustain their pivotal irrigation systems and for animal watering.

Sepanespruit runs just outside the Thaba-Nchu city centre. It also flows within the residential areas. This part of the stream is highly polluted by domestic waste and receives high quantities

of urban run-off. The stream water is used for irrigation, mostly by subsistence farmers. An average and typical household in this area owns cattle and or sheep. The stream water is thus useful for livestock watering as well. Occasional canoeing excises were noted. The dam water was also noted to be used for cultural and traditional cleansing ceremonial activities. Religious activities such as Christian baptisms were also noted at the Seroale Dam. Water is an important element in African beliefs, religions, cultures and traditions. For generations, a vital value has been assigned to water as a spiritual medium through which Africans believe they receive cleansing and revival for their souls (Zenani and Mistri, 2005).

There are old factory buildings that are located between the Thaba-Nchu industrial area and the Thaba-Nchu sewage treatment plant. These buildings have been vandalised; the windows are broken, the doors and frames have reportedly been stolen, the interior equipment such as toilet sets, geysers and water sinks have been pulled out. For about eight months within the duration of this project, potable water supply had not been cut to these buildings. Clean water was therefore dripping continuously from these buildings. The grassland area that constantly received water that flowed from these buildings was turned into a temporary wetland. However, around March 2012, the local municipality solved the problem by cutting water supply to this area.

CHAPTER 4

MATERIALS AND METHODS

4.1 STUDY DESIGN

Physical, chemical, microbial and vegetation data were collected at five sites along Sepanespruit. The selected sampling sites were representative of the catchment and easily accessible. The study was conducted for a period of twelve months to ensure that all seasons of the year were represented; it ran from August 2011 to July 2012. Water samples were collected once every month.

4.2. SITES ALONG SEPANESPRUIT

One sampling point was about 500m upstream of Seroale Dam and the second sampling point was at Seroale Dam. This dam is upstream of the Thaba-Nchu sewage treatment plant. The release point of sewage effluent within the sewage treatment plant marked the third sampling point. The fourth sampling point was about 300m downstream of the sewage works. The fifth sampling point was in the canal that flowed just outside the perimeters of the sewage treatment works. This canal carried storm water and untreated sewage that overflowed from an open manhole. Water overflow from the dam also flowed into this canal. The canal fed water into the wetland that finally flowed into Sepanespruit.

Sepanespruit flows in a north-westerly direction just outside the Thaba-Nchu central business centre. About 100m from the city centre lays a graveyard which is encompassed by Sepanespruit on the northern side. The stream then flows through an informal settlement area and a low income household location. Beyond this area, the watershed of this stream is defined by old school buildings and undeveloped primary and high schools. Figure 4.1 is a google map that shows the relative positions of all the sampling points along Sepanespruit.

Sampling point 1 was upstream of all other sampling points. It was located about 800m downstream of Thaba-Nchu city center. This sampling point was situated just below the culvert on the road that leads to Selosesha Unit 1 from Selosesha 10.

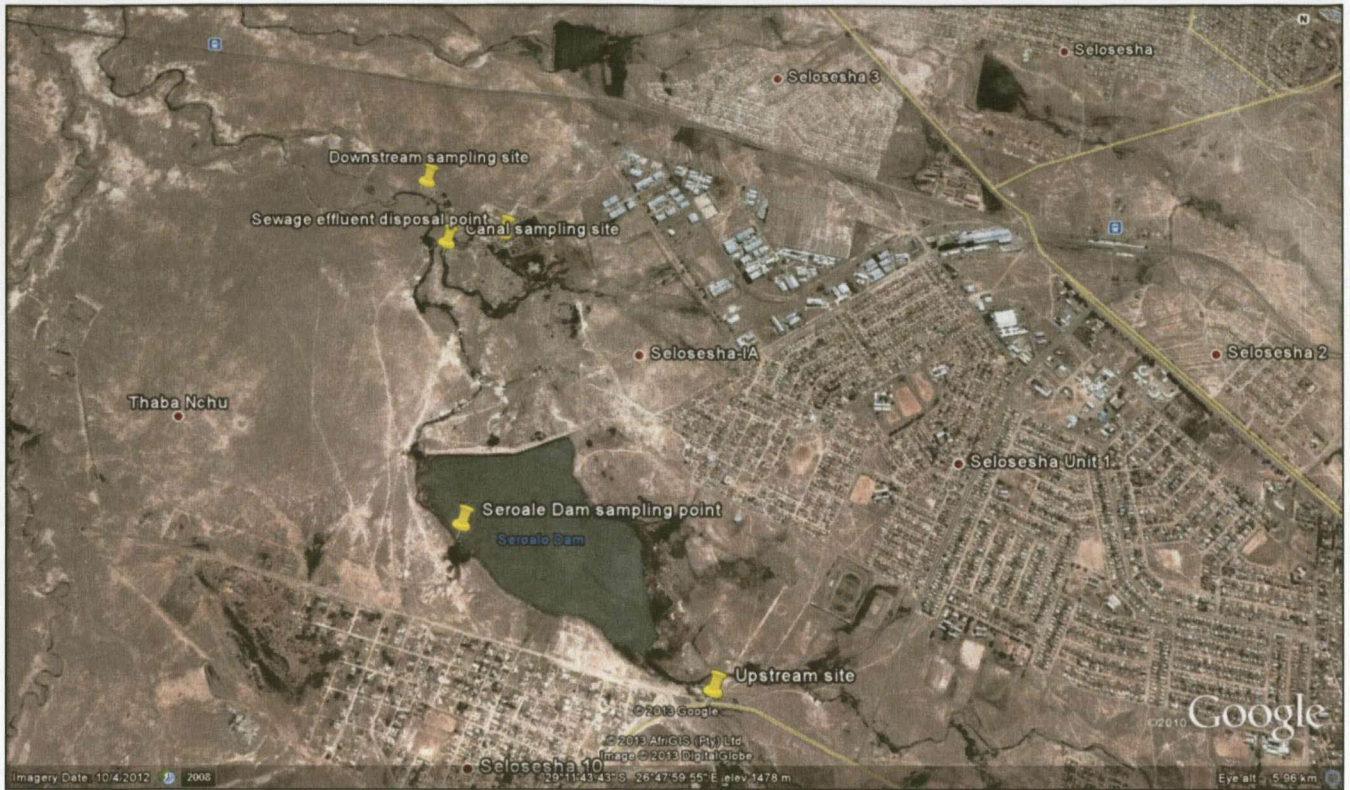


Figure 4.1: The sampling points along Sepanespruit (Google maps – accessed June 2013)

The dominant vegetation types were sparse shrubs and riparian grasses and sedges as shown in Figure 4.2. The biotypes present in this area were gravel, stones-in-current, sandy-clay banks and marginal vegetation. The stream at this area was between 2 – 6m in width. Water moved sluggishly most of the time and looked almost stagnant sometimes.



Figure 4.2: The sampling site upstream with marginal vegetation on sandy-clay banks (Picture taken: September 2012)

Since this upstream site was close to the city centre and settlement areas, a lot of solid rubbish was observed flowing in water. There were papers, rags and plastics hung on the banks of the stream. The culvert spot was also used by local people as an illegal dumping site for their domestic wastes as depicted by Figure 4.3.



Figure 4.3: The upstream site showing heaps of domestic waste in water (Picture taken: January 2012)

The stream water at this point was stinking, looked turbid, was unclear and stagnant foam formations were also noted. Midges and beetles were observed at this part of the stream. Excessive vegetation growth and thick algal stands were also noted. This site had a diminished visual aesthetic value as shown by Figure 4.4.



Figure 4.4: The upstream site with turbid, foamy water and burdened with domestic wastes (Picture taken: January 2012)

About a meter away from the sampling spot within the upstream sampling site, was an open manhole (as shown by the arrow on Figure 4.5) that fed raw sewage into the stream. Floating algae, both submerged macrophytes and floating macrophytes were observed at this site.



Figure 4.5: The upstream site in which a leaking manhole added sewage to stream water (Picture taken; January 2012)

Minimal disturbances such as footpaths and livestock trampling were also observed on the sides of the stream banks. From this point, the stream flowed through a thick reed bed of

Phragmites australis and *Typha capensis* into Seroale Dam (Figure 4.6), the second sampling point.

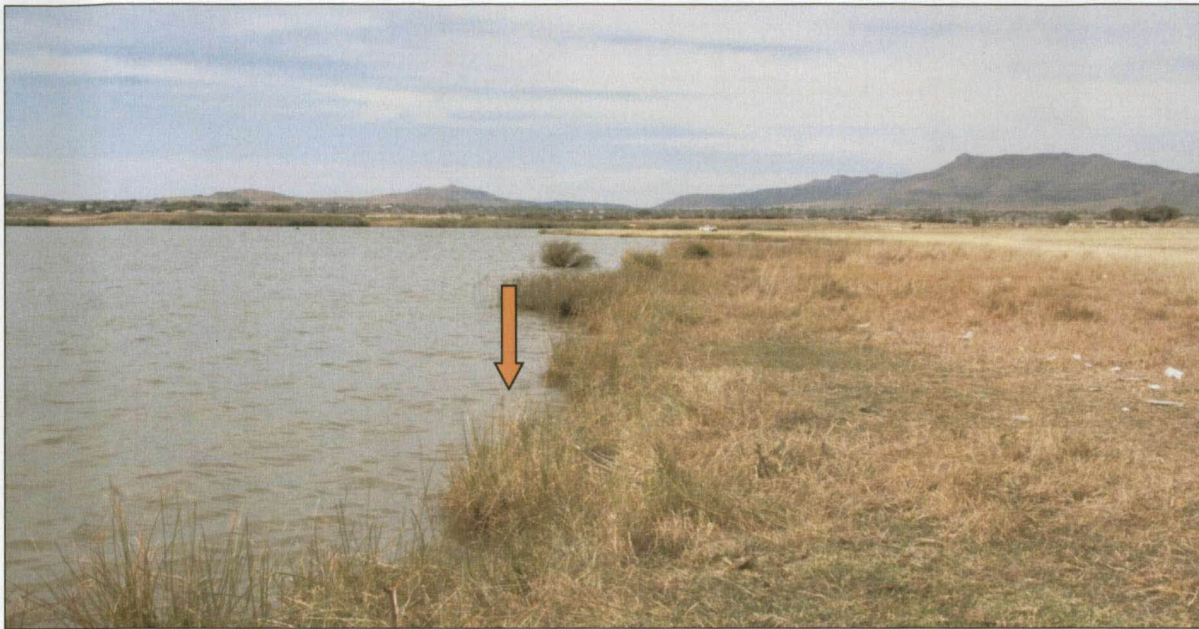


Figure 4.6: The sampling point at Seroale Dam (Picture taken: May 2012)

The Selosesha 10 residential area also known by the locals as Kopi is situated about 300m above Seroale Dam. This residential area is composed of Reconstruction and Development Program (RDP) houses (mostly four-roomed) and some squatter-shelters. The area did not have running water facilities and sewage systems until around April 2012 when the local municipality began to develop the area. Some developmental work which involved excavations to prepare for installation of potable water pipe networks was noted. This project was aimed at supplying residents with running potable water and the later phase of the project would be to install sewage infrastructure, this is according to a personal communication with one local manager of the project.

It was only on one incidence throughout the study period that canooers in this dam were noted. Seroale Dam had comfortable and easily accessible spots for local fishermen. There were several fishing spots along the circumference of the dam. Fishing at this area was practiced both for subsistence and commercial purposes. The fishermen constructed stone-mud walls to create pools in which they held fish that they had caught as shown in Figure 4.7. The walls disturb the natural flow of water within the dam. If this practice perpetuates, the ecology of this dam will be disturbed as a long-term impact.



Figure 4.7: Seroale Dam and the catchment residential area - Selosesha 10 (Picture taken: May 2012)

Water that overflowed from the dam during rainy seasons drained into a canal that fed water into Sepanespruit. Water that flowed in that canal did not only come from the dam overflow, it also came from the sewage overflow. The Selosesha 10 residential area, did not have sewage infrastructures so the municipal tanker-trucks would pump out and collect sewage from households. Figure 4.8 shows the manhole in which tankers disposed-off domestic sewage. The surrounding area was strewn with raw sewage and turned into a pathogen-breeding haven in which dirt-loving insects peacefully dwelled. This was a careless disposal of crude sewage and it stole the aesthetic value of this area. An immediate area around the manhole whose radius was about 100m was affected by this sewage mismanagement.



Figure 4.8: The manhole that received domestic sewage through municipal truck-tankers
(Picture taken: October 2011)

Sewage overflow from this area was channeled into a canal that directed untreated sewage into a wetland and then finally flowed into Sepanespruit. The sewage was diluted by overflow from the dam (during rainy seasons) before it flowed into the stream. This manhole is situated on the eastern side of the sewage treatment plant, just about 100m away from the sewage plant's fence. The canal flowed outside the campus of the sewage treatment plant until it joined the wetland.

The canal was the Sampling Point 3. The canal was only about a meter in width. Domestic animals especially cattle trampled in the canal as they drank water from it. The trampling caused the canal banks to be unstable and the water therein was muddy. The canal water looked brownish in colour most of the times. There were visible floating matter in the canal water and the water looked turbid. Figure 4.9 shows the canal with the excessive vegetation that grew in it during January 2012 (summer).



Figure 4.9: The brownish, turbid canal water (Picture taken: January 2012)

During November 2011, the canal was dry as shown in Figure 4.10. This was the the only time throughout the length of the sampling period that the canal was empty and dry.



Figure 4.10: The canal was dry during November 2011

Thaba-Nchu sewage treatment plant is located within the Selosesha area, Thaba-Nchu district of the Mangaung Metropolitan Municipality. The plant is situated a bit outside the industrial-residential area (about 600m away) and adjacent to old factory buildings. This plant received mostly domestic and industrial sewage as determined during the study period. This plant has a hydraulic capacity of 6 Ml/day (DWA, 2007). Figure 4.11 shows exit point of the sewage effluent was Sampling Point 4.



Figure 4.11: The sampling point at the exit of the sewage effluent (Picture taken: August 2011)

Beyond the sewage treatment plant, the sewage effluent flowed into a valley-bottom wetland which leads to Sepanespruit. This wetland is located along Sepanespruit just outside the campus of Thaba-Nchu sewage treatment plant. The wetland receives sewage effluent, raw sewage water through the canal and overflow from the dam during rainy seasons. The wetland area was a common grazing spot for domestic animals especially cattle; they were noted within the wetland throughout the year. Figure 4.12 shows cattle grazing within the wetland.



Figure 4.12: Cattle grazing on the wetland area (Picture taken: September 2011)

The Sampling Point 5 was situated about 300m downstream of the sewage effluent release point. At this sampling site, the immediate marginal vegetation was scarce because of the rocky geomorphology. The following biotypes characterize this area: parent rock, out-of-current stones, in-current stones, gravel and sandy soils. Algae were observed on rocks and in water. The stream consisted of rapid runs and pools and the flow was variable: mostly medium-to-low. The water was clear-to-cloudy in clarity. The effects of the colour of the sewage effluent were noted at this point; during the times when the red-colored sewage effluent was released, even water at this point would be reddish. The width of the stream at this point was about 5m. Relative to the upstream and canal sampling sites, the greatest volume of flow was observed at this site. Figure 4.13 shows the downstream sampling site. The arrow indicates a spot on which sampling was done.



Figure 4.13: The sampling point downstream (Picture taken: August 2011)

Sludge is the end-product of sewage treatment process. The sludge that was produced from the Thaba-Nchu treatment plant was disposed-off just outside the campus of the treatment works. The plastics, rags, papers and other rubbish materials that were stuck within fresh sludge became sources of pollution to the environment once sludge dried out. Figure 4.14 shows heaps of sludge that were discarded outside the gates of the Thaba-Nchu sewage treatment works.



Figure 4.14: Heaps of dry sludge posing a potential danger of environmental pollution (Picture taken: August 2011)

Before 2010, the sludge produced from the Thaba-Nchu sewage treatment plant was dried up and taken by farmers to nourish their crop fields. However in the latter years up to present,

farmers do not take sludge anymore. At this time, the sludge produced has become an environmental nuisance. Alternative disposal areas have to be identified in which sludge can be disposed-off without compromising the aesthetic value of the surrounding areas.

4.3. WATER ANALYSES

The subsurface water temperatures ($^{\circ}\text{C}$) and pH were measured *in situ* using Eutech Instrument pH-Cond-TDS-DO Cyberscan Standard Portable Series. Percentage Dissolved Oxygen (%DO), salinity in (mg/l) and Electrical Conductivity (EC) in mS/m were also measured *in situ* using YSI 85 Oxygen-Cond-Salinity & Temp device.

Sub-surface water samples of 1 liter volume were drawn from each of the sampling sites for chemical analysis. For bacteriology, 250 ml glass bottles were used to collect samples. The collected samples were kept under ice from the field to the laboratory. The chemical and some bacteriological analyses were done by the Institute for Groundwater Studies (IGS) at the University of the Free State (UFS). The water analyses were done according to the protocols which are outlined in the laboratory book; 'The standard methods for examination of water and waste water, the 21st edition'. The authors are included in the reference list. These standards methods are also available online at www.standardmethord.org. The following physico-chemical parameters were determined and quantified: Electrical conductivity (EC), Chemical Oxygen Demand (COD), Suspended Solids (SS), Orthophosphates (PO_4^{3-}), NH_3 and $\text{NO}_3^-/\text{NO}_2^-$. The following bacteriological analyses were also undertaken at IGS: Total Coliforms, Faecal coliforms and *E. coli*. Chlorophyll *a* concentrations and algal divisions were identified and quantified from the water samples by the Centre of Environmental management according to the protocol as denoted by Sartory and Grobbelaar (1984). The full reference details are included in the reference list.

During January 2011, treated sewage effluent samples were drawn and taken for analysis at the LiquiTech Advanced Biomolecular Research Cluster. Full screening of organic contaminants such as pharmaceutical chemicals, pesticides and herbicides was done. A 2MRM screening for AZO dyes was also performed.

During August 2012, water samples were drawn from the sampling points for microbial evaluation. An additional investigation was done in which freshly produced sludge was pressed and the resultant liquid was collected and investigated for microbial diversity and concentrations. The analysis and counts were done by the Department of Microbiology, Biochemical and Food Biotechnology in UFS. The bacteria investigation protocol which in outlined in the standard methods for examination of water and waste water (21st edition) was used.

4.4. SELECTION OF WATER QUALITY PARAMETERS

4.4.1. Dissolved oxygen (DO) in (%)

The sources of oxygen include rainfall, air ingress in flowing water (such as at hydraulic structures such as weirs), and photosynthesis by algae and aquatic plants. Dissolved oxygen is essential to support the lives of fish, zooplankton and invertebrates. Water polluted with organic matter, e.g. partially treated sewage effluent can be deficient with oxygen. Oxygen is also depleted when algae die and decompose in water. Fatoki *et al.*, (2003) calculated that a minimum level of 5 mg/l DO is required in order to prevent adverse effects on aquatic life. For unpolluted water in an aquatic environment, typical oxygen saturation ranges between 9 – 13 mg/L (DWAF, 2001).

4.4.2. Temperature (°C)

The principal source of thermal energy on earth is the sun. Aquatic ecosystems are dependent on the intensity of solar radiation for their temperatures. Other factors that have a profound influence on surface water temperatures are: latitude, altitude, time of the day, air circulation, cloud cover, flow rates and depth of the water body (Chapman and Kimstach, 1996).

The different reaches and habitats of a stream may have different water temperatures but an average variation of 3 °C is normal. Stream temperature determines the degree to which gases and ions dissolve in water. Flow dynamics and metabolic rates of organisms are also temperature-dependent. Temperature variations that emanate from water pollution may trigger some responses in organisms; certain insects may emerge and fish may spawn (Dallas and Day, 1993). Thermal pollution may signal misinformed environmental cues.

It is crucial to measure the temperature of water bodies *in situ* because during transportation, water samples would otherwise shift towards the temperature of the surrounding air (Chapman and Kimstach, 1996).

4.4.3. pH

This is an index of the concentration of Hydrogen ions (H^+) present in water. It is the measure of an acid balance within a solution. It is influenced by the geological formation of an area and atmospheric contributions (Hughes, 2002). This parameter (pH) is also controlled by dissolved chemical compounds and biochemical processes in solution. This is an important variable in water quality studies because it influences biological and chemical processes within an aquatic ecosystem (Bartman and Ballace, 1996). When continuously measured, pH variations may indicate the onset of pollution problems in water. The target water quality range for South African rivers and streams is pH 6.5 - 9 (DWAF, 1996d).

Macro-invertebrates are particularly sensitive to drastic pH changes. Variations of more than 10% in pH over a short period of time negatively affect osmosis, growth and respiration of aquatic biota. Semi-aquatic and aquatic warm blooded mammals' skins and mucosal membranes are easily irritated by drastic pH changes (Hughes, 2002).

4.4.4. Electrical Conductivity (EC) in (mS/m)

This is a measure of the ability of water to conduct electric current (Bartman and Ballace, 1996). Electrical conductivity is determined by the amount of dissolved solids that dissociate into ions. The amount of electrical charge on each ion and the temperature of a solution determine the concentration of EC within the water body (Bartman and Ballace, 1996).

In instances whereby monoculture is practiced, run-off may be reduced and this causes water salinity (as a result of high salts concentrations). High salinity indicates an increased content of ions and therefore high EC. The Government Gazette No 9225 of May 1984 stipulates that wastewater or effluent in aquatic ecosystems should not exceed 250 mS/m (determined at 25°C).

4.4.5. Salinity in (mg/l)

This denotes the salt content of water. High salinity may interfere with the natural growth of aquatic and riparian vegetation. Salt may decrease the osmotic pressure, encouraging plants to lose water in order to stabilise plant-salt concentrations. Plants may also absorb less water; this may result in stunted growth and poor plant yield. High salt concentrations may cause leaf tips and margins' burn, bleaching and defoliation (Dallas and Day, 2004). It is imperative to monitor salinity in aquatic bodies as a method of protecting the vegetation. Changes in water salinity may come as warning signals for possible water pollution problems (Allan, 1995).

4.4.6. Chemical oxygen demand (COD) in (mg/l)

Some agricultural practices worsen the ecological state of surface water bodies. Pesticides and fertilizers get washed into rivers or leach into ground waters. Fresh water pollutants in terms of Chemical Oxygen demand (COD) was estimated at 4.7 tonne/km³ in 2003 in South African rivers. These values indicate that South African freshwaters are moderately to diffusely eutrophic (Oberholster and Ashton, 2008). The water quality standard for COD in water bodies as stipulated by DWAF (1996b) should not exceed 30mg/l.

4.4.7. Nitrates (NO₃⁻) and Nitrites (NO₂⁻) in (mg/l)

Nitrates and nitrites are abundant in soils, water and plants. However, nitrites occur in low concentrations (Hughes, 2002). Nitrates are the highly oxidized form of nitrogen compounds. They are common in surface and groundwater because they are an end-point of aerobic break-

down of organic nitrogen compounds. In unpolluted natural waters, nitrates are found in trace amounts. High nitrate levels in treated final effluent could be a source of eutrophication for receiving waters (Igbinosa and Okoh, 2009).

In water quality studies, nitrogen (N) and phosphorus (P) compounds are recognised as pollutants. Nitrogen is identified in the form of ammonia (NH_3) and nitrates (NO_3^-). However, these compounds are essential to plant life. In excessive amounts, these nutrients encourage plant growth (Igbinosa and Okoh, 2009).

4.4.8. Ammonia (NH_3) in (mg/l)

It is an important component of freshwater chemistry. It is highly soluble in water; it reacts readily with water to form ammonium ions (Horne and Goldman, 1994). DWAF (1996a) reported the ammonium ion (NH_4^+) has little or no toxicity but the un-ionised form (NH_3) is highly toxic. After ammonia has dissolved in water, it increases the pH of water. High levels of ammonia in water bodies may indicate an input from agricultural run-off, sewage and industrial wastewater. At high pH values and temperature, ammonia becomes toxic to biota and it also reduces the DO concentration of water.

4.4.9. Orthophosphate (PO_4^{3-}) in (mg/l)

Soluble Reactive Phosphate (SRP) or Orthophosphate is the phosphorus which is immediately available to aquatic biota. The composition of phosphorus in water is continuously changing between organically bound forms and oxidized forms because of processes of decomposition (Hughes, 2002). The DWAF (2001) standards indicate that a river is oligotrophic with moderate species diversity and low productivity if its phosphorus concentration is less than 0.005mg/l. The system is eutrophic with high species diversity and productivity when phosphorus concentration ranges between 0.05 - 0.25 mg/l. For South African Rivers, the average phosphorus concentration as orthophosphate was estimated at 0.73 mg/l in 2003. This serves as an indication that our water sources are diffusely eutrophic.

The concentration of phosphates in water needs to be kept in check to assess the health of a water body. When there are high levels of phosphates in water, cyanobacterial populations are most likely to be high, diminishing the quality of water. High phosphates in water also indicate pollution, usually of agricultural or industrial origin (Bartman and Ballace, 1996).

4.4.10. Suspended solids (SS)

Natural processes such as hurricanes and torrential rainfall lead to excessive erosion and landslides which increase the content of suspended material in streams and rivers (Bartman and Ballace, 1996). Suspended solids in a water body may result from unstable river banks and channel beds. Exposed soils that are subject to erosion, landslides, litter fall, anthropogenic

activities are some of the catchment processes that add suspended solids to water bodies (Davies and Day, 2004). The determination of suspended solids' concentrations is an important tool that can indicate the onset of soil erosion and input of soil materials in water.

The concentrations of suspended solids and turbidity in water are related (DWAF, 1996c) but Dallas and Day (2004) argued that the two parameters are not strongly correlated and are not linearly proportional. High concentrations of suspended solids and turbidity in water decrease the degree to which sunlight penetrates into the water column. This leads to a decrease in the rate of photosynthesis and the concentrations of phytoplankton in water. This entire phenomenon may affect the prey-predator interactions and therefore impact on the entire food chain. The suspensoids may suffocate the fauna and repress the flora. This may alter benthic organisms' community compositions, populations and structures.

4.4.11. Chlorophyll a

The chlorophyll a concentration indicates the presence and quantity of algae in water. The use of chlorophyll a to indicate the trophic status of a water body is based on the notion that chlorophyll a is the most abundant and important pigment in phytoplankton cells. Its concentration indicates algal biomass.

4.4.12. Total coliforms, Faecal coliforms and *E. coli*

Total coliforms are bacterial species of faecal origin, and other bacterial groups. Total coliforms indicate the general hygiene of water. Faecal coliforms and more specifically, *E. coli* are indicators of faecal pollution.

4.5. SEWAGE TREATMENT

4.5.1. Introduction

Sewage treatment provides an essential community service that is fundamental to public health and conservation of aquatic environments. Without supply of descent potable water and effective wastewater treatment services, members of a community become susceptible to contracting water-borne diseases. It could be through using water for domestic purposes or recreation. When sewage flows into a river system untreated or ineffectively treated, it poses a threat to aquatic biota and diminishes the quality of water therein (DWAF, 1996c)

The release of inadequately treated sewage effluents into river systems has severe economic implications. In those cases whereby water is reused, it becomes expensive to treat heavily polluted water for potable use; this creates a serious financial burden on the water authority concerned.

Wastewater treatment industry in South Africa faces serious challenges such as; rapid urban population growth, meeting discharge regulations (as designated by DWA) and demand for water conservation through wastewater reuse. The challenge is worsened by the fact that most of the existing waste water treatment plants (WWTPs) function beyond their capacity as a result of an ever-increasing human population, expanding mine activities and rising industrial developments. In some cases, WWTPs do not work optimally because of lack of mechanical and analytical expertise. As a result of these downfalls, sewage effluents that are released from most WWTP in South Africa do not comply with the recommended standards. Water treatment for purposes of reuse is a viable solution to water scarcity problems but much water pollution eradication measures still need to be deployed (Oberholster and Ashton, 2008).

Domestic sewage contains lots of organic waste matter and nutrients such as nitrogen in the form of ammonia; waste products from human and animal metabolic processes. Nitrogen in wastewater is also present in the form of nitrites and nitrates; chemical remains of pesticides, fertilisers and insecticides from agricultural activities. Phosphate salts are released from washing powders and soaps. Industrial wastes are dynamic and therefore contain a diversity of pollutants. In the case of this study project, dyes and pharmaceutical wastes form a bulk of industrial wastes were also identified. Removing the organic matter and nutrients, then disinfecting the water to kill pathogens before it is released back into the natural environment forms the basis of sewage treatment (Allan, 1995)

The relevance of managing freshwater ecosystems has become more evident in recent years because pollution problems have escalated. The management strategies and policies should be environmentally sound and economically feasible (Wetzel and Likens, 1979). This calls for an informed selection of limnological parameters that need to be monitored to protect and restore good water quality in water resources. These parameters differ from case to case. The choice of such parameters is usually dependent on the sources of both point and non-point pollution.

4.5.2. History of sewage treatment

Wastewater treatment is an old technique that dates as far back as the early 19th century. The first septic tank was installed in the United States (US) in 1876. The trickling filter, which is nowadays employed as the secondary treatment, was first installed in the US for municipal sewage treatment. The first municipal activated sludge plant was built in 1916 (Randtke and Horsley, 2009).

In South Africa, early sewage purification systems were based on septic tanks. The effluent was treated in contact beds and then irrigated. This method of sewage purification and effluent treatment was established by British authorities in the 1900's. The first operational sewage works in South Africa were built in Bloemfontein in 1904 (Osborn, 1988).

The effluent from the single, open septic tank was treated on five primary filters, followed by five secondary filters of the same size. This was South Africa's first double filtration system. Before then, crude sewage was irrigated over arable lands and it was considered a viable means of waste disposal. The introduction of legislation that prohibited such practices only started operating in 1956. Irrigation of land by wastewater was then viewed as a form of environmental pollution. Environmental authorities also advised South African citizens against discharging wastewater effluents into rivers (Osborn, 1988).

Southern Africa has a poor record for sewage treatment and in some areas sewage effluents still gets released into the environment not properly treated. However South Africa's sewage treatment is advanced and the country has been a world leader in nutrient removal for many years. In contradiction though, there are some areas of South Africa such as many rural areas and informal settlements that still do not have sewage treatment facilities (Oberholster and Ashton, 2008).

In modern South Africa, sewage effluents are usually disposed-off in the nearby stream, river or lake. The operational and maintenance costs of running wastewater treatment plants are high; perhaps that is one reason why effluents are released in a partially-treated state back into the environment. However, treatment of such polluted river water for domestic purposes becomes even more expensive. According to law, before an effluent is discharged into a water body, it should be properly treated (DWA, 1996b).

4.5.3. Sewage treatment's capacity

Wastewater management is a rather developed and yet under-performing industry in South Africa. It comprises of more than 831 municipal treatment plants and extensive pipeline networks. An average of 5 258 MI/day of wastewater is treated in South Africa. The collective hydraulic capacity of wastewater treatment plants is 6614 MI/day. However, the municipal wastewater services in South Africa are considered to be below the recommended national and international standards (DWA, 2011).

According to the DWA (2011), there are 95 wastewater treatment plants in the Free State province, with the total hydraulic capacity of 482 MI/day. In the Green Drop report (2009/2010), Thaba-Nchu WWTP was noted to be good in the monitoring efficiency and wastewater quality compliance. The management of this facility is applauded for its loyalty for submission of wastewater quality results and reports to the Department of Water Affairs (DWA). The inflow capacity of this WWTP was also noted to be within its hydraulic capacity. This facility was given a 66% Green Drop Score.

4.5.4. The science of sewage treatment

Aerobic Activated Sludge (AAS) is by far the most frequently used wastewater treatment process in South Africa. It therefore comes as no surprise that Thaba-Nchu sewage treatment plant uses activated sludge type of sewage treatment. AAS consists of primary treatment, secondary treatment, optional tertiary treatment, disinfection, and then sludge processing (Boyd and Mbelu, 2008).

Screening is an important preliminary part of the pollution reduction process. It removes the bulk of non-biodegradable matter such as plastics, papers, woven materials, pieces of wood and metallic items from the sewage stream. Screening removes solid materials that would otherwise cause jamming in the influent stream. The collected waste is then buried at a dedicated site (van Haandel and van der Lubbe, 2007).

At Thaba-Nchu treatment works, the collected screenings were kept in the rubbish bins (200L volume) as shown in Figure 4.15 below.



Figure 4.15: Screening process at Thaba-Nchu WWTP (Picture taken: August 2011)

For the manually cleaned screens, frequent raking is necessary to prevent clogging. Cleaning frequency depends on the characteristics of the wastewater entering a plant (US EPA, 2003). At

the study area, raking is done as need arose, there was not a set schedule for the raking frequency. But it was generally done once every two days.

An average of four full bins is collected every day. However, during the rainy seasons, up to nine bins were filled up with screenings each day. This was a result of storm water (which contained lots of solid pollutants) that entered manholes along the sewerage infrastructure. The collected screenings were then transported and buried at a dedicated landfill site, which was located on the western side of the Thaba-Nchu central business centre.

During the mornings, the collecting bins would be filled up to brim with screenings. That indicated that the overnight screen collection was more than a 200L bin would accommodate. At times the screenings would overflow and fill up the screening area. A striking incidence in which screenings were left uncollected occurred during the municipal strike in February 2012. Figure 4.16 below shows the screening area during February 2012 when the screenings were not cleared-up because the workers on a wage-increase strike.



Figure 4.16: The screenings filling up the area during a municipal workers strike (Picture taken: August 2011)

Wastewater (mostly domestic and industrial) contains solid particles that are classified as grit (van Haandel and van der Lubbe, 2007). Thaba-Nchu sewage treatment plant receives predominantly domestic and industrial wastes. Grit is composed of non-putrescible organic

matter such as eggshells, bone chips and food substances. Sand and gravel are also components of grit (US EPA, 2003).

The main aim of grit removal is to separate (by sedimentation) materials that may be detrimental to the treatment process. Grit is then cleaned of putrescible matter in a washer. The putrescible matter is returned to the treatment process. The washed grit is then collected and disposed-off at a landfill area. The grit removal process lengthens the life span of pumps and equipment along the path of the influent because grit's hardness is abrasive to metals (van Haandel and van der Lubbe, 2007).

A wastewater treatment plant is designed with a specific hydraulic capacity which should not be exceeded if the treatment processes have to be optimised. The flow meter is a device that is installed to measure and keep track of the daily influent and effluent. At the Thaba-Nchu treatment works, both the influent and effluent meters were non-functional through-out the entire study period. The effluent meter is shown in Figure 4.17 below. The reading on the meter was incorrect and it stayed the same for the whole period.



Figure 4.17: The effluent flow meter displaying an incorrect figure of 43 153 l/s (Picture taken: September 2011)

After screening and grit removal, the sewage stream then goes through aeration and or bio-filtration process before entering the sedimentation tanks. Aeration is the process of bringing water and air into close contact in order to remove some dissolved impurities such as metals and gases. Aeration is used in water treatment process for oxidising substances such as iron and manganese. Gases such as carbon-dioxide and hydrogen sulphide (which imparts the rotten egg smell) are removed from water. Since air is a powerful oxidizer; it quickly converts ferrous iron to filterable ferric iron, and it reduces hydrogen sulphide to elemental sulphur, which is easily removed from water by a filter. The effectiveness of aeration depends on the amount of contact between the water drop and the air bubble (Boyd and Mbelu, 2008). At the Thaba-Nchu WWTP, there were three aerators of which only one was fully functional at all times. The functional aerator is shown in Figure 4.18.

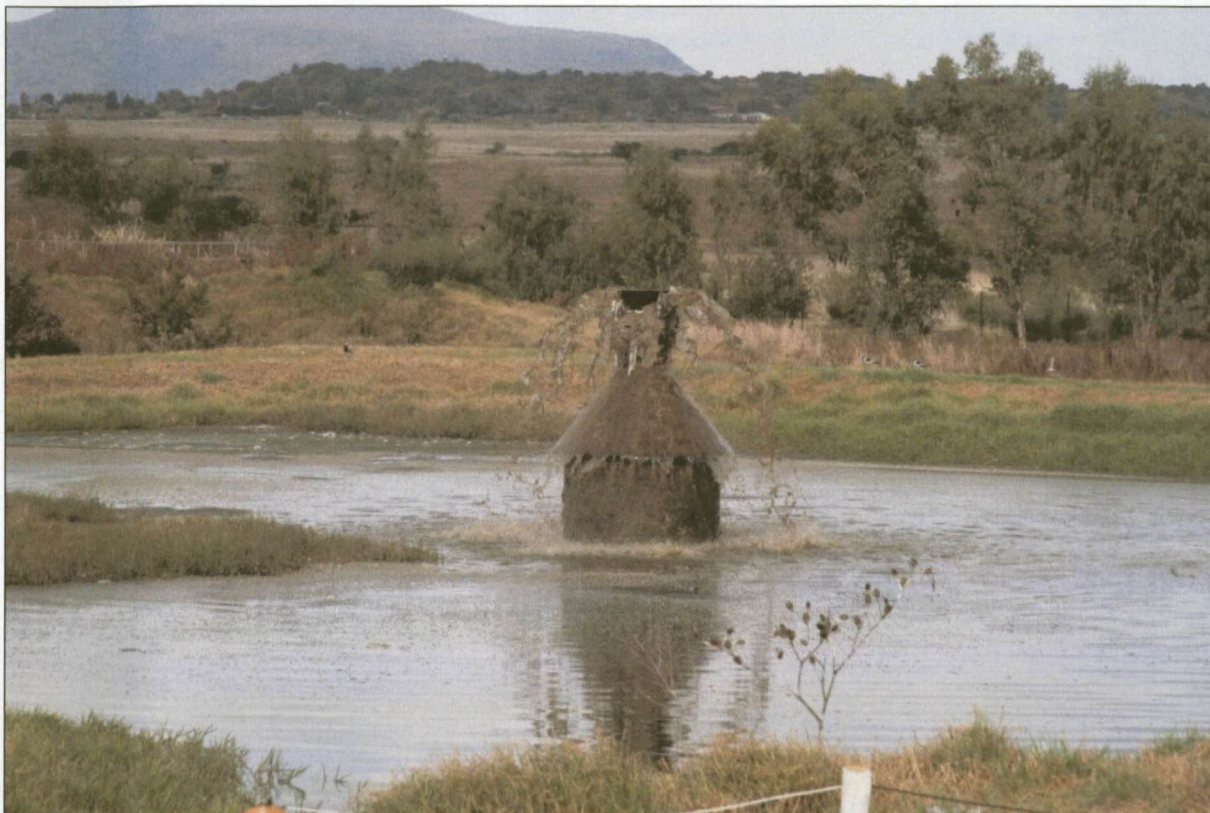


Figure 4.18: The functional aerator at the Thaba-Nchu WWTP (Picture taken: April 2012)

A well-designed and fairly-operated primary treatment has the capacity to remove up to 70% of the suspended solids and up to 40% of the BOD. If not removed, such materials also cause mechanical problems such as pipe blockages (M/J Industrial Solutions, 2003).

On average, detention time within primary sedimentation tanks is 1.5 to 2.5 hours. Chemical flocculants or polymers are added to primary sedimentation tanks to improve solids removal. The solid wastes that are removed during primary treatment are dewatered and disposed-off as part of the sludge treatment process (M/J Industrial Solutions, 2003).

The secondary sedimentation process separates mixed liquid suspended solids or humus sludge from the purified effluent stream. The sewage stream then flows into a large tank where the solid wastes are allowed to settle. These sedimentation tanks are partitioned into four parts to allow for increased effectiveness of waste settling.

Secondary sewage treatment process is defined by a biological process called aerobic, suspended growth, activated sludge treatment. This treatment consumes about 30 to 60% of total plant energy. Effluent that is received from the primary treatment is then processed in large reactors or basins. At the Thaba-Nchu sewage treatment plant, the reactors are partitioned into four rectangular tanks as is indicated by Figure 4.19 below. The sewage effluent is mixed for several hours with bacteria-rich sludge.



Figure 4.19: Mixer tanks at Thaba-Nchu WWTP (Picture taken: August 2011)

The secondary treatment process can include some anoxic processes which remove nitrogen from the sewage. The anoxic zone is a section where there is no air and this is where nitrification-denitrification occurs. Nitrification is a process in which ammonia is converted to nitrates and nitrites. Denitrification is the biological conversion of nitrates to nitrogen gas. The so-produced nitrogen gas rises through the wastewater and is released into the atmosphere. The objective of the nitrification-denitrification process is to reduce the amount of nitrates in the sewage stream. In addition to nutrient removal, tertiary treatment also removes suspended

solids by filtration. Inorganic solids are removed by using ion exchange or membrane processing (M/J Industrial Solutions, 2003).

In the mixer tanks, the solids are set out to be removed by mechanically driven scrapers for further displacement. In the case of the circular tanks the scraper blades scrape the settled sludge to a central sludge removal hopper and in rectangular tanks to an end hopper. Scraper mechanisms are fitted with surface scum removal equipment to remove floating matter, scum and grease (van Haandel and van der Lubbe, 2007). The scum formed at the Thaba-Nchu WWTP during mixing is shown in Figure 4.20 below.



Figure 4.20: Scum formed after mixing in tanks (Picture taken: September 2011)

Clarifiers separate solids from the liquid stream. The clarifier has sludge scrapers attached to a rotating arm that scrapes sludge towards a central hopper. Circular settling tanks and clarifiers are generally a preferred choice for secondary sewage treatment because they require less maintenance, remove sludge faster and have higher removal efficiencies. The suspended organic solids settle as sludge. There are still lots of pathogens and the water is still not safe to discharge into the environment (Cunningham and Cunningham, 2008). The sewage effluent is then transferred into final settling tanks. Figure 4.21 below shows water in the clarifier at the Thaba-Nchu WWTP. Water in the final setting tanks is less viscous and clearer than at any of the earlier stages of the treatment process.



Figure 4.21: A final settling tank at Thaba-Nchu WWTP (Picture taken: August 2011)

The sewage effluent is then disinfected with chlorine before being discharged into receiving waters, such as a nearby stream or river. Chlorine gas is pumped into the water to kill pathogenic bacteria, and to reduce odor. When it is done properly, chlorination kills more than 99% harmful bacteria in a sewage effluent (M/J Industrial Solutions, 2003).

The white house shown in Figure 4.22 below is the storehouse in which the chlorine chemical is being administered to the final effluent. The network of pipes and tubes that are used to pump chlorine into the sewage effluent are all stored in the chlorine house.



Figure 4.22: The white house is the chlorine house in which chlorine addition to the effluent happened (Picture taken; August 2011)

After disinfection, the sewage effluent is released into the nearby stream. In the case of the Thaba-Nchu sewage treatment plant, the receiving stream is Sepanespruit. Figure 4.23 below shows the disinfected sewage effluent that was leaving the sewage treatment works.



Figure 4.23: Chlorinated final effluent leaving the sewage treatment plant (Picture taken: August 2011)

In developed countries, the process of wastewater treatment has gradually shifted from chlorine-based disinfection to UV disinfection. This change aims to eliminate the risk of storage and handling of toxic chemicals (in this case – Chlorine). Although UV disinfection is energy intensive, it does not add any chemical residue to the effluent. UV disinfection is advantageous especially when the effluent is discharged into sensitive aquatic environments or when water will be re-used. In general terms, low pressure UV systems are more efficient than medium pressure systems (M/J Industrial solutions, 2003).

Sludge is a thick concentrate of waste matter. It is an inevitable end-product of sewage treatment (NRC, 1996). Sludge is rich in organic matter and nutrients, it is usually used to nourish soil that is used for agricultural purposes. This is a common practice in many arid countries such as South Africa. The sewage treatment process is not complete without the process of sludge-processing.

Figure 4.24 below shows one of the two sludge dams at the Thaba-Nchu WWTP. The dams were quite shallow and looked rather abandoned. The chemical wastes that were not allowed to flow through the sewage treatment process were disposed-off to dry-up in the sludge dam. A factory waste truck on featured in figure 4.24 was observed disposing-off a thick red-coloured liquid.



Figure 4.24: The sludge dam and an non-functional aerator (Picture taken: July 2012)

For centuries in Asia, sludge has been spread on land as an inexpensive method of disposal and consequently, the soil was conditioned (WHO, 1979). First class countries such as Canada and the United States also use sludge to improve the quality of agricultural soil (NRC, 1996).

4.6. VEGETATION SAMPLING AND ANALYSES

4.6.1 Introduction

Kent and Coker (1992) described a plant community as a group of species' populations that are growing together in a specific area. Van der Maarel (2005) defined a plant community or a phytocoenose as a piece of vegetation in a homogenous environment with a relatively uniform floristic composition and structure that stands out from the surrounding vegetation. Kent and Coker (1992) further emphasized vegetation as an indispensable parameter in ecological studies for three essential reasons:

- In most cases, vegetation is the most easily recognizable physical representation of the ecosystem;
- Vegetation is an important part of the food web because it is the producer;
- Vegetation is a habitat to some organisms such as insects, birds and reptiles.

Vegetation ecology is a facet of ecology that identifies and describes plant communities. It also describes the relationships that exist between plant communities and associated environmental factors (Lawrence, 2005). Vegetation can also be recognised as a system of largely spontaneous growing plants (van der Maarel, 2005).

The relevance of riparian vegetation to water quality studies and conservation measures cannot be ignored. The riparian vegetation along Sepanespruit and at the wetland was studied. The Braun-Blanquet technique was deployed to assess, describe and classify wetland and riparian plant communities. This method is also useful for interpretation of the study area in ecological terms; it provides a framework within which vegetation can be classified (van der Maarel, 2005).

This method is widely accepted and has been successfully used by plant scientists in different biomes that occur around the world. Dingaan *et al.* (2001), Siebert and Siebert (2005), van Aardt (2010) and van Rensburg (2011) are some of the scientists that successfully used the Braun-Blanquet method and applauded its effectiveness. The environmental and floristic data were captured using TURBOVEG database (Hennekens, 1996) and then exported to JUICE program (Tichy and Holt, 2006).

4.6.2. The Braun-Blanquet method

The Braun-Blanquet method is a straight-forward method which provides a method for selecting, simplifying and modifying vegetation data for analysis. This method has been commended to function well in areas with high species numbers (Kent and Coker, 1992).

Werger (1974) emphasized that the Braun-Blanquet method is a reliable and a significant tool that is essential for environmental studies. This method meets three essential requirements:

- It is methodically sound; efficient and effective;
- The necessity of classification is fulfilled at an appropriate level;
- Its effectiveness, resourcefulness and reliability far exceed that of comparable approaches.

Westhoff and Van der Maarel (1978) and Botha *et al.* (2003) summarized the gist of the Braun-Blanquet method as being able to recognize plant communities by their floristic composition and organize them into vegetation types. Within the floristic composition of a community's species, different species differ in their abilities to express relationships. This approach deploys species

which are the most diagnostic species based on the notion of their ecological relationships. Diagnostic species are fundamental in organizing communities into a hierarchical classification; the association is the basic unit. The hierarchy becomes an indispensable and valuable tool for understanding community relationships.

4.6.3. Vegetation assessment

Cover is the physical piece of land which is occupied by above-ground parts of each species when reviewed from above (Kent and Coker, 1992). Werger (1974) described cover as the shoot-area projection per species in the plot. Abundance is the number of individuals per species. All plant species were identified at the field. The field work was undertaken during summer 2012. Applicable spatial environmental factors that were taken into account include land types, aspect, terrain units, slope, exposure to the sun, topography, soil-water characteristics. The altitudes (height above sea level) at all sampling plots were measured using a hand-held Garmin V GPS.

The dominant land uses in the immediate catchment of the stream and wetland were noted. These data is crucial because it helps to assign a category to the vegetation of interest; it may be natural, bare, afforested or fallow. A measure of grazing intensity was estimated on the basis of the observed livestock numbers, frequency of grazing at riparian zones and at the wetland and the noted effects of grazing. Grazing pressure can also be determined on the basis of the ecological response of individual species towards grazing (van Rooyen, 2010).

Soils were categorized as being temporarily, seasonal or permanently wet. Kotze *et al.* (1996) proposed criteria and soil-wetness indicators that can be applied to determine soil wetness on a piece of land and across a gradient of variable soil-water conditions.

4.6.4. Vegetation analysis

A sample plot is equivalent to a quadrant in vegetation terms (van der Maarel, 2005). The positions of plots were carefully selected so that the areas were representative of all the vegetation types present. Placement of sample plots within each homogeneous and uniform vegetation-*cum*-habitat unit was done randomly within the sampling area. There were a total of 12 sample plots that were selected at the sampling points and at the wetland. Each sample plot size was fixed at 5 × 5 m to give a total surface area of 25 m² which was large enough to encompass all the representative vegetation units. Within each sample plot all plant species encountered were identified, recorded and a cover abundance value was assigned to each species as guided by Braun-Blanquet scale presented in Table 4.1.

Table 4.1: The Braun-Blanquet cover abundance values employed in this study (Kent and Coker, 1992).

COVER VALUES	DESCRIPTION
R	One, or few individuals, rare occurrence
+	Cover less than 1% of total plot area
1	Cover less than 5% of total plot area
2a	Cover between 5-12.5% of total plot area
2b	Cover between 12.5-25% of total plot area
3	Cover between 25-50% of total plot area
4	Cover between 50-75% of total plot area
5	Cover between 75-100% of total plot area

4.6.4. Data analysis and classification

The environmental aspects and the associated floristic data were captured using a floristic database program TURBOVEG (Hennekens, 1996). An approximation was done with the TWINSpan (two-way indicator-species analysis) algorithm of Hill (1979).

TWINSpan is a numerical classification of data. This method is based on the continual refining of a single axis ordination from the corresponding analysis. TWINSpan performs the simultaneous classification of the quadrants and of species. This algorithm is a detailed and complex method; it produces a two-way table which indicates the species present and the relevè number. The relevès are sorted in columns while the species are arranged into rows (Kent and Coker, 1992). Brown and Bezuidenhout (2005) commended that TWINSpan is a successful tool that is effective for classification of phytosociological analysis. The arrangement of relevès and species in their physiognomic table forms plant communities, sub-communities and variants (Hill, 1970).

Whittaker (1978) reported that the classification of certain species into communities is affected by certain factors such as life forms, life-cycles and strata. These factors can contribute to production of different combinations within a community. The phytosociological table was generated using the JUICE program. The JUICE program was designed for editing, classification and analysing large phytosociological data. It is advisable that JUICE should be

compounded with TURBOVEG in order to attain optimum results. JUICE also allows an option to employ TWINSPAN (Hill, 1970).

CHAPTER 5

RESULTS AND DISCUSSIONS

The canal sampling site was dry during November 2011, so there are no results and discussions for that period.

5.1 PHYSICO-CHEMICAL PARAMETERS

5.1.1 Temperature

Pronounced variations in water temperature were observed during this study. These changes in water temperature were used to mark and define different seasons of the year. High water temperatures were observed from October 2011 until March 2012 at all sampling sites. This indicated a period of about six months for the summer season. High water temperatures were recorded during November, December 2011 and January 2012. These months marked the climax of the summer season 2011/2012. The highest water temperature (25.6 °C) was recorded during January 2012 at the upstream sampling site. A high temperature of 25.5 °C was also recorded for the canal water during December 2011. During February 2012, a drop in water temperature was noted at all sampling sites; presented as the dent on the graph in Figure 5.1. September 2011 represented the spring season during this study. The following months: May, June, July and August represented the winter season. The spring season was represented by April 2012 only. Figure 5.1 illustrates changes in water temperature during different months of the year from August 2011 to July 2012 in all sampling sites.

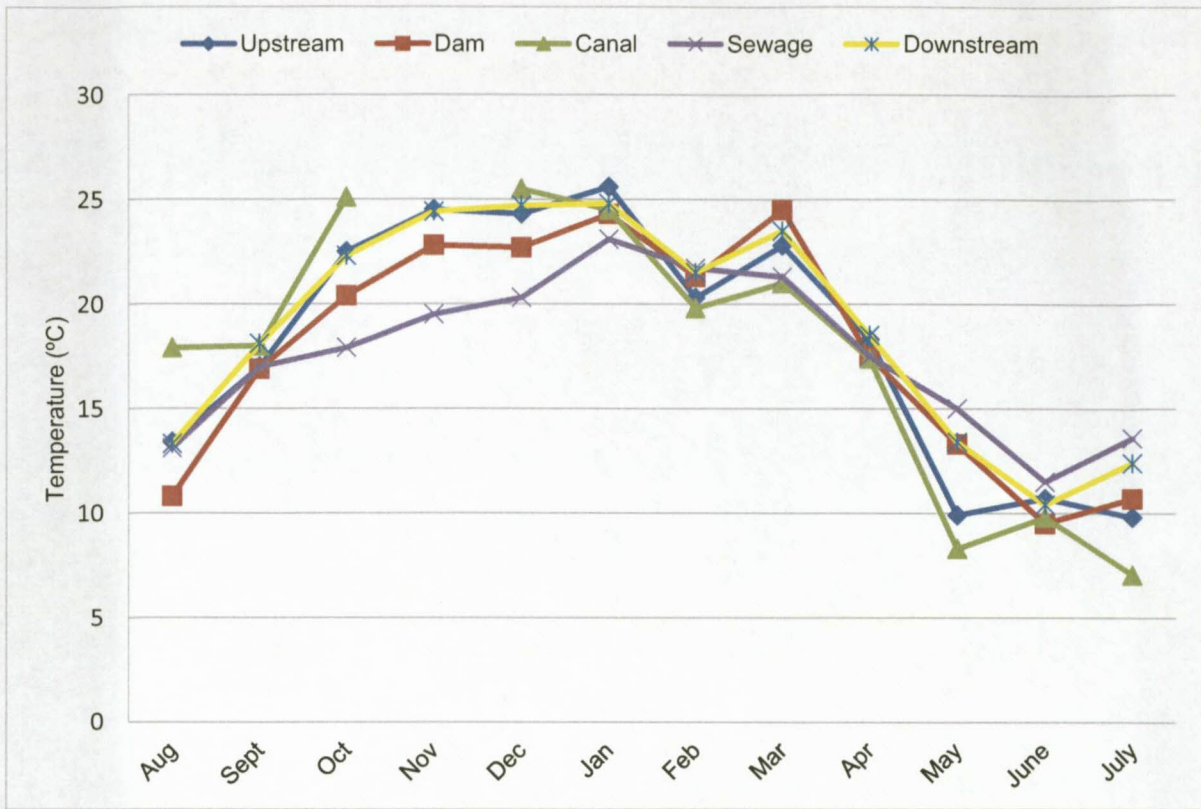


Figure 5.1: The temperature changes in stream water throughout the study period

As the sun rays heat the water surface, they form a layer of less dense warm water that overlays layers of dense, cool water. The underneath water may be characterised by profiles of varying temperatures (Horne and Goldman, 1994). This phenomenon becomes more distinct in lentic systems such as lakes, impoundments and dams. It would have been significant to determine the temperature profiles of Seroale Dam as part of this study. The findings could be used to define the limnological aspects of this dam which would function as baseline information for future studies. During this study, water samples were drawn from the subsurface which means the monitoring process was undertaken on relatively warmer water layers. The depth from which samples were drawn was not noted; this could have introduced some bias to the results. However, the dam water temperatures were lower than in the other sampling sites (excluding the sewage effluent), this phenomenon could be accounted for by the fact that water samples were drawn from the margins of the dam where shade from the sedges and tall grasses may have cooled down the water by obstructing sun rays to fully warm the water.

Water temperature in rivers and streams vary more rapidly than in lakes. Surface water temperature is positively correlated with ambient air temperatures. However, factors such as substrate composition, turbidity, vegetation cover, rainwater and groundwater do influence lotic water temperatures (Allan, 1995). The banks of Sepanespruit were covered by riparian vegetation, mostly grasses. This means water temperatures especially close to the banks were

not entirely exposed to the sun; experienced shade effect. Horne and Goldman (1994) reported that trees grow at stream banks reduce solar heating to the water by their shade.

On removing riparian vegetation that provides shade to the stream, its water becomes exposed to increased direct solar radiation. Higher temperatures may be expected during hot seasons (Dallas and Day, 2004). The water temperatures along Sepanespruit were also influenced by riparian vegetation cover. During periods in which rich arable lands that were used for livestock grazing were exhausted, specifically during winter and spring seasons, dense flocks of cattle, sheep and goats were observed grazing on the verges of this stream and on the wetland. The grazing and trampling impacts of animals reduced the riparian vegetation and thus exposing water to more environmental influences. This phenomenon could have influenced the observed variations in water temperatures; very low winter temperatures and high summer temperatures.

Gray and Edington (1969) monitored water temperature variations in a stream in England before and after the catchment was deforested; the summer temperatures went higher than normal during summer months and dropped to lower than normal during winter. Graynorth (1979) also undertook a study to indicate that riparian vegetation cover influences stream water temperatures. He confirmed the findings of Gray and Edington (1969).

Temperature influences the rates of chemical reactions and also affects the metabolic rates of organisms. Temperature is one of the most imperative parameters that are indispensable in water quality studies. This parameter also affects the distribution of aquatic organisms (Horne and Goldman, 1994). Changes in water temperature act as cues for behavioural changes in biota. The onset of sexual activities, hatching of eggs and the rates of maturity for juveniles, and other life stage developmental processes are influenced by water temperature changes (Allan, 1995). Water temperature variations also dictate the movement patterns of aquatic biota (Dallas and Day, 2004).

The temperature of the sewage effluent was higher than water in all other sampling sites during winter. The recorded effluent temperatures ranged from 11.5 to 15 °C. These high winter temperatures can be associated with warm domestic and industrial waste water which was used for bathing, cooking and heating. The average winter temperature for the sewage effluent was 13.3 °C as shown in Table 5.1. High water temperatures were also observed in the downstream site; which could be an influence of the sewage effluent. The winter temperature range for the downstream site was between 10.4 and 13.4 °C. The average downstream winter temperature was 12.4 °C which was higher than the average winter temperatures at other sites which ranged between 10.8 and 11.0 °C. However, during summer, autumn and spring, the sewage effluent temperatures were an average of 2.2 °C lower than the downstream water.

This could mean that during those seasons, the sewage effluent was adding cooler effluent to the receiving stream.

The toxicity of many chemical substances increases with an increase in temperature. Cyanide and zinc are examples of such chemicals (Dallas and Day, 2004). High water temperatures may render inorganic substances such as metals very toxic to biota. Further-apart, higher temperatures also favour the growth of algae which sometimes become nuisances to water bodies.

The upstream and canal water temperatures were generally higher than in other sampling sites during summer, autumn and spring. During winter, water temperatures were low at these sites. The winter average temperatures were 10.8 °C and 11.0 °C for the canal and upstream sites respectively. Table 5.1 shows the average water temperatures in each sampling site during different seasons. The observed temperature variations can be attributed to the shallow nature of the stream at those sites. Shallow water gets heated up by solar radiation more effectively because the UV rays have only a thin layer of water to heat (Allan, 1995). Similarly, cool air breezes effectively influenced the observed cool winter temperatures.

Table 5.1: The average seasonal temperatures at all the sampling sites

Temperature (°C)				
Sampling site	Autumn average	Winter average	Spring average	Summer average
Upstream	18.3	11.0	17.0	23.3
Dam	17.5	11.0	16.9	22.7
Canal	17.4	10.8	18.0	23.2
Sewage	17.5	13.3	17.0	20.6
Downstream	18.5	12.4	18.1	23.5

However, water at the canal and upstream sites was turbid because it was burdened by sewage particulate matter and solid particles that compose the urban run-off. Paaijmans *et al.* (2008) reported that turbidity increases water temperatures because the particulate matter absorbs solar radiation and imparts the heat to water. According to Table 5.1, the summer water temperatures at the upstream and canal sampling sites were 23.3 and 23.2 °C respectively. However, the highest summer average temperature (23.5 °C) was observed at the downstream site. Water at this side was usually clear (less turbid) but high water temperatures were observed. This can be attributed to the shallow and wide structure of the stream at this site. The water was also slow-flowing which allowed sufficient absorption of solar radiation. Some parts

of this sampling site were underlain by flat rock and gravel boulders which further imparted heat (during summer) to the water (Figure 5.2).



Figure 5.2: The flat rock over which water flows in the downstream site (Picture taken: August 2012)

The influence of lowered water temperatures from the sewage effluent were not expressed in the downstream site during summer. The average summer temperature of the sewage effluent was 20.6 °C while the downstream water average was 23.5 °C during summer (Table 5.1). The influence of cool sewage effluent into the downstream water was not observed; perhaps it was over-powered by factors that contributed to water temperature increase.

The observed high water temperatures during summer and autumn can be explained by high intensity of solar radiation during those seasons (Wetzel and Likens, 1991). Water within all the sampling points along Sepanespruit displayed a general seasonal trend in which summer temperatures ranged between 17.9 and 25.6 °C (Table 5.2). During summer, a general decrease in water temperature was observed during February (indicated as a dent on Figure 5.1). The day of sampling during that month was relatively cool. The ambient air temperatures were low and it was cloudy so there was not enough solar radiation to warm the water.

maximum winter temperature (17.9 °C). April 2012 which represented the spring season in this study showed relatively high water temperature. This phenomenon can be attributed to the heat that water had retained from the summer season.

Table 5.2: The minimum, maximum and average temperatures of Sepanespruit water in all sampling points throughout the study period.

Temperature (°C)			
Seasons	minimum	maximum	average
Summer	17.9	26.5	22.7
Autumn	17.4	18.5	17.8
Winter	7.1	17.9	11.7
Spring	16.9	18.1	17.4

The average winter temperature was 11.7 °C and the minimum temperature was recorded in the water canal during July 2012 was 7.1 °C. The spring maximum temperature was 18.1 °C with the average of 17.4 °C. The lowest spring temperature (16.9 °C) was recorded at the dam. The low water temperature values were recorded during winter and then during spring. However, Osode and Okoh (2009) reported a different pattern in which low water temperatures were observed during winter and autumn months.

Water temperatures during March (the last month of the summer season) at all sampling sites ranged between 21.0 and 24.5 °C. A significant drop in water temperatures was observed during April (range 17.4 to 18.5 °C (Table 5.2)) which suggested a change of season from summer to autumn. However, autumn was represented by April 2012 only. The winter season was represented by the following months; May, June, July and August. The spring season like autumn, was represented by only one month; September. Spring was characterised by low water temperatures with a range of 16.9 – 18.1 °C. The spring minimum and maximum temperatures were lower but comparable to autumn temperatures (Table 5.2).

5.1.2. Dissolved oxygen (DO)

The sewage effluent and canal contained low concentrations of DO during winter. The dam average DO concentrations were generally higher than in other sampling sites except during April (which represented autumn) in which an exceptionally high DO concentration (16.24 mg/l) was recorded at the sewage effluent. During December at the upstream site, a low DO concentration (1.17 mg/l) was recorded. Low DO concentrations (1.0 mg/l) were also recorded during August for the canal site and the sewage effluent. The concentrations of DO at the dam did not show distinct seasonal changes. Figure 5.3 shows the variations in DO concentrations of water at different sampling sites during a 12-months period.

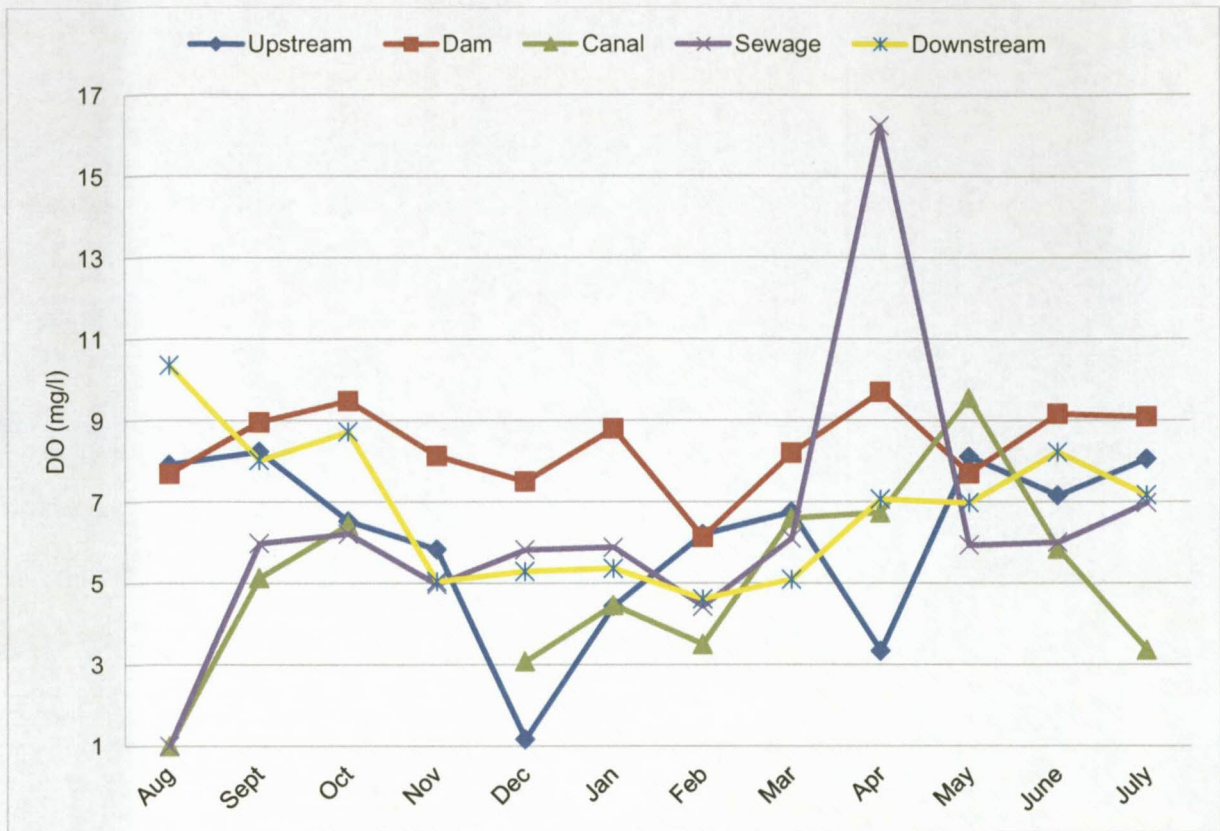


Figure 5.3: DO variations within Sepanespruit for 12-months period

The atmospheric gaseous oxygen (O_2) dissolves in water and is also generated during photosynthesis by aquatic plants and phytoplankton (DWAF, 1996d). Oxygen is moderately soluble in water. Dissolved oxygen is usually not a limiting factor in running waters except in extreme conditions in which oxygen depletion is caused by excessive biological activity (Allan, 1995). Long and short term monitoring of dissolved oxygen in a water body is imperative as a measure of its trophic status (Wetzel, 1983). In unpolluted surface water, dissolved oxygen concentrations are usually close to saturation. Typical oxygen saturation concentrations at sea level during summer (at an average of 20 °C) are around 9.09 mg/L (DWAF, 1996d). The government gazette of 18th May 1984 stipulated the minimum allowable DO as 75 % for sewage effluents.

Re-aeration from the atmosphere, low temperature and low salinity in a water body increase the concentrations of dissolved oxygen. Aerobic wastes and aerobic decomposition of organic material by micro-organisms and chemical break-down of pollutants consume enormous quantities of oxygen in water (Dallas and Day, 2004).

In unpolluted surface water bodies, DO concentrations are near-saturation (DWAF, 1996b). DO was higher at the dam than in other sampling sites. This could be attributed to the standing dam water, there was less turbulence (except on windy days) and therefore algae could grow, develop and photosynthesise thus increasing DO concentrations. The range of DO

concentration at the dam was 6.13 – 9.48 mg/l for the whole study period. Moreover, the dam water was cooler than in other sampling sites along Sepanespruit (excluding the sewage effluent) which also increased the solubility of oxygen in water.

Some parts of Sepanespruit such as the canal and upstream sites were shallow, periodically turbulent water systems. The relatively high oxygen concentrations in those sites can be attributed to the rapid, oxygen-replenishing characteristic of those parts of the stream (Allan, 1995). The summer average DO concentrations in the canal and upstream water were low (4.81 and 5.15 mg/l respectively (Table 5.3)); this can be attributed to the recorded high water temperatures at those sites. The concept that Horne and Goldman (1994) and Allan (1995) reiterated was also confirmed during this study; the higher the water temperature, the lower the concentrations of dissolved oxygen.

Table 5.3: The seasonal average DO concentrations of water at different sampling sites

The average Dissolved Oxygen (DO) in mg/l				
Sampling site	Summer average	Spring average	Winter average	Autumn average
Upstream	5.15	8.23	7.80	3.33
Dam	8.04	8.96	8.40	9.70
Canal	4.81	5.13	4.94	6.73
Sewage	5.57	5.98	4.98	16.24
Downstream	5.69	8.02	8.18	7.06

During December at the upstream side, a low DO concentration of 1.17 mg/l was observed. This could be the result of raw sewage that leaked from a manhole that was overlain by the stream. The microbial processing of organic matter in sewage consumes significant quantities of oxygen (Allan, 1995). Also during this festive time, heaps of domestic wastes were disposed at this site of the stream. This waste also added organic matter to the water which further reduced the amount of dissolved oxygen in water.

There was a general seasonal trend in dissolved oxygen (DO) concentration of water. There were high water DO concentrations during September, October and November 2011 and also during the winter months; May, June and July 2012. Summer average water DO concentration was exceptionally high at the dam (8.04 mg/l) which can be accounted by increased production of oxygen by phytoplankton. Algal scum, floating algae and algae that were suspended in the water column were all observed at the dam. During summer, increased solar energy led to increased photosynthetic activities which then produced more oxygen in water.

The minimum DO concentrations during summer and winter were 1.17 mg/l and 1.00 mg/l respectively. These were the lowest seasonal values. The minimum spring DO concentration (5.13 mg/l) was the highest of the minimum seasonal values. During autumn, a minimum DO concentration of 3.33 mg/l was recorded. The autumn average DO water concentration was the highest of all sampling points (8.61 mg/l). Summer DO average concentration was the lowest. Table 5.4 shows different minimum, maximum and average DO concentrations that were recorded in the different seasons.

Table 5.4: The minimum, maximum and average DO concentrations during the different seasons of the year

Dissolved Oxygen (DO) in mg/l			
Seasons	minimum	maximum	average
Summer	1.17	9.48	5.88
Spring	5.13	8.96	7.20
Winter	1.00	7.91	6.86
Autumn	3.33	16.24	8.61

The autumn average DO water concentration was the highest of all sampling points (8.61 mg/l). Summer DO average value was the lowest. During August, the sewage and canal water contained low concentrations of DO. During December, at the upstream site, low concentration of DO was also observed. At the dam, DO concentrations did not vary much through the different seasons of the year; the concentrations ranged between 7.42 and 9.48 mg/l.

Seasonal variations were explicitly expressed in water DO concentrations. Water DO concentrations were relatively higher during winter and autumn than during summer. This observation is attributed to the fact that oxygen dissolves more in cool water (Horne and Goldman, 1994). High water temperatures reduce the amount of dissolved oxygen concentrations in water and therefore reduce its availability to aquatic organisms (Davies and Day, 1998).

The highest DO concentration for the study period was 16.24 mg/l; it was recorded at the sewage effluent during April 2012. This rather random occurrence can be attributed to the coincidental flow of cold wastewater perhaps from the refrigeration systems of the meat-processing industry during the day of sampling. The recorded water temperature during April was 17.5 °C; this was a significant decline in water temperature relative to the March water temperature of 21.3 °C. The observed low water temperature could also be due to seasonal shift but it was speculated that an external addition of cold sewage influent may have occurred.

There were two aerators at the Thaba-Nchu sewage treatment plant but most of the time, they were both not functioning. On personal communication with the operational staff, the aerators were not functioning because they were too old and required to be replenished. However, the plant technicians would reportedly fix and nurse them to function, only a few days later they would stop functioning again. Sampling time during April coincided with the period when one of the aerators was functioning as shown in Figure 5.4. The increased DO concentration during April can also be attributed to the increased re-aeration of wastewater. The figure shows a fully functional aerator but at a close look, the aerator's head was tattered which confirmed the account that was given by the staff. This dilapidated aerator head compromised the efficiency of wastewater aeration because the degree of exposure to the atmosphere was reduced.



Figure 5.4: The working aerator at the sewage treatment plant (Picture taken: April 2012)

Venter (2000) also observed a random increase of dissolved oxygen in the Orange River during summer. She ascribed the results to the cold water that flowed relatively fast over the stones in the stream, and therefore added oxygen to the water column. The same explanation can be extrapolated to the observed high DO value of 10.35 mg/l that was recorded during August 2011 at the downstream sampling site. The downstream site was characterised by water that flowed over pebbles and boulders that may have improved water aeration. The stream was wide and the water velocity was low which allow sufficient time for water aeration.

The DO in Sepanespruit throughout the study period ranged between 1 and 16.24 mg/l. The average DO value for the entire study period was 6.45 mg/L. This was a wide range of DO

variations which resulted from interruptions such as the receipt of cold influent waste-water at the sewage, flow of raw sewage canal into the stream and the effects of livestock trampling and grazing on the banks of the stream. Most values of dissolved oxygen during this study fell between 4 and 8 mg/l. There were few outlying values such as the low 1 mg/l values that were recorded at the sewage and canal during August 2011. These low DO values resulted from aerobic decomposition of organic matter that was in the sewage matter (Dallas and Day, 2004).

The DO range that Venter (2000) recorded in the Orange River was 4.7 – 11.6 mg/l, which was also wide as a result of flow disruptions such as the effects of river damming. However, narrow DO ranges were recorded in the Modder River; 4 and 8 mg/L and the Klein Modder River; 6 and 8 mg/L (Koning, 1998).

There is a natural phenomenon in which DO cycle varies depending on the time of the day; diel variation (DWAF, 1996b). Dissolved oxygen declines through the night because photosynthetic activities cease to produce oxygen while biota uses some of the dissolved oxygen for respiratory functions. Dissolved oxygen concentrations rise to a maximum by mid-afternoon (Dallas and Day, 1993). A drawback on this study was the inconsistency of the times of the day on which water samples were drawn. The diel variations were not considered and this may have affected the overall reliability of these results.

Coefficient of determination (R^2) is a statistical analysis of determination which describes how well a regression line fits a set of data (Dufour, 2011). The closer the value of R^2 is to 1, the more the parameters correlate. Figures 5.6(a – e) indicate correlation between dissolved oxygen and water temperature during all seasons of the year at the different sampling sites. It is important to note that in all sampling sites, temperature was not the only determinant of dissolved oxygen in water. For the upstream site, a correlation (R^2) of 0.4059 (Figure 5.6(a)) was calculated which indicated a fair relationship between the upstream DO concentration and water temperature. The DO concentration at this site was a resultant of the interplay between water temperature, water turbidity, nutrients from sewage, urban run-off and domestic wastes.

The dam water, canal and sewage effluent showed a correlation of less than 10 % between water temperature and dissolved oxygen. For the canal, the concentration of DO was dependent on the amount and temperature of raw sewage that was carried in water, rather than seasonal variations hence the low R^2 value (0.0644) (Figure 5.6(c)). The dam water was stagnant (less aeration occurred) and the sampling was done on the subsurface (the warmer layers of water). Hence the correlation between water temperature and dissolved oxygen that has (R^2) at the dam was low (0.0469) (Figure 5.6(b)). The correlation between dissolved oxygen and temperature was low ($R^2 = 0.0036$) (Figure 5.6(d)) because the effluent temperature is dependent on the temperature of the influent. The dissolved oxygen in sewage effluent was low

because of non-functional aerators and the large quantities of sewage (more than its hydraulic capacity) that the conventional treatment process could not effectively degrade.

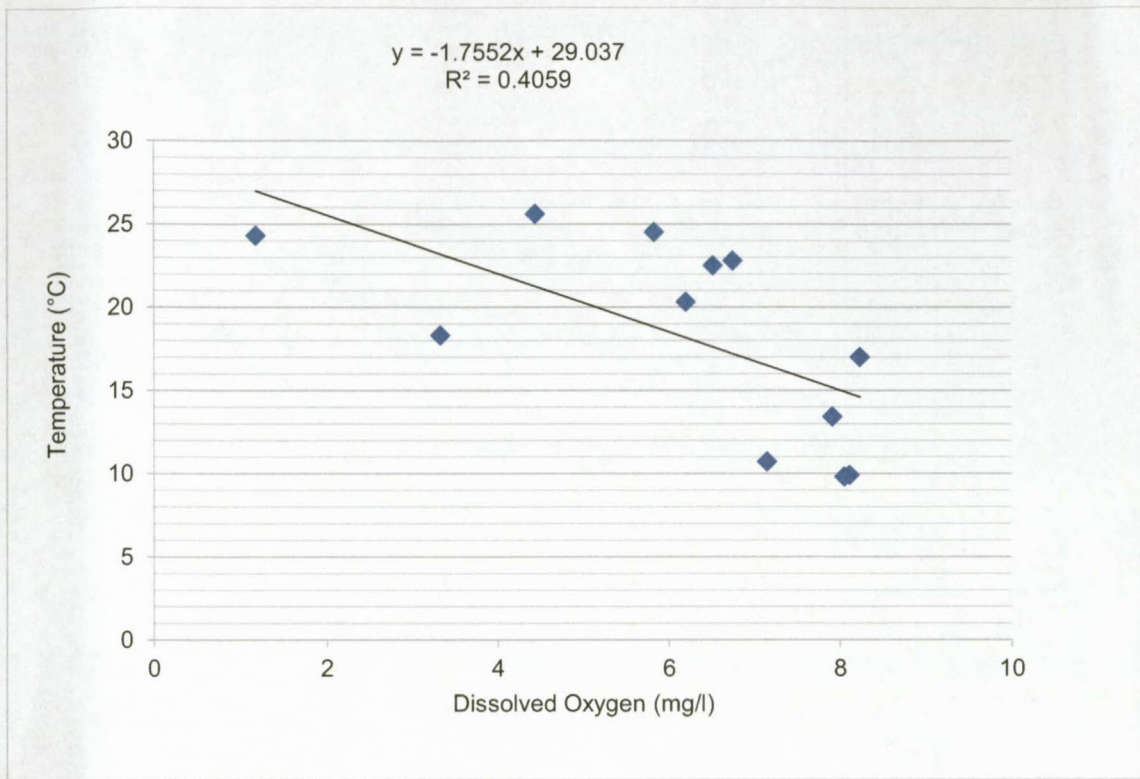


Figure 5.5(a): The graph depicts the relationship between dissolved oxygen and water temperature at the upstream site

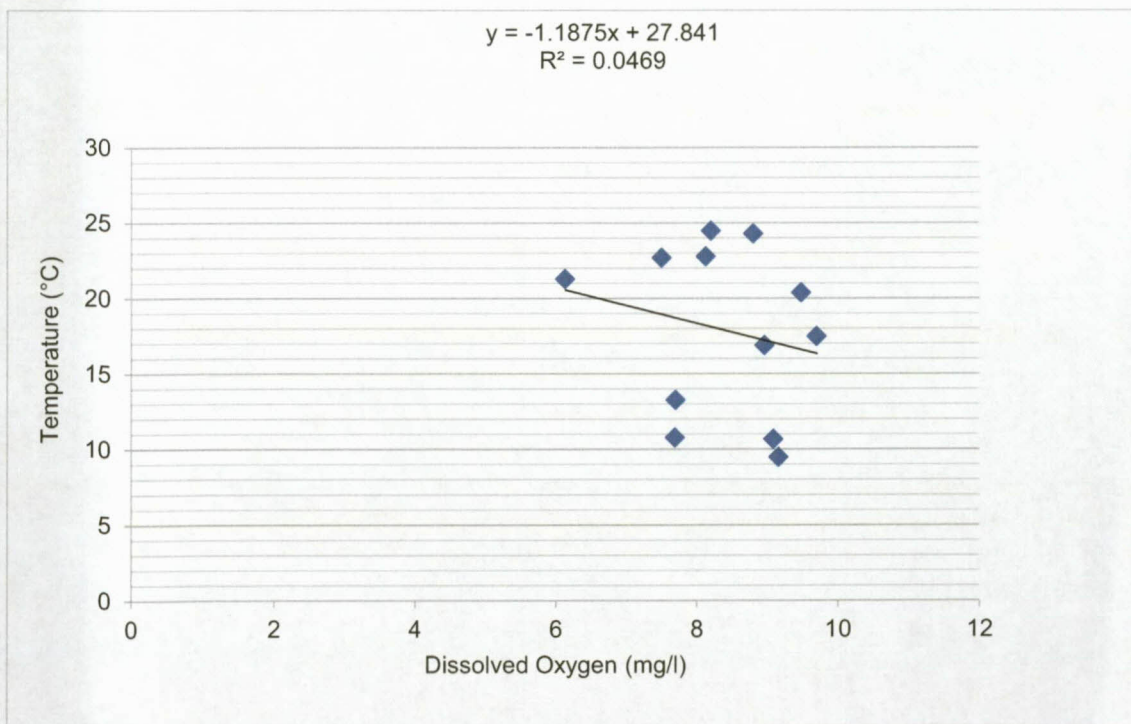


Figure 5.5(b): The graph depicts the relationship between dissolved oxygen and water temperature at the dam

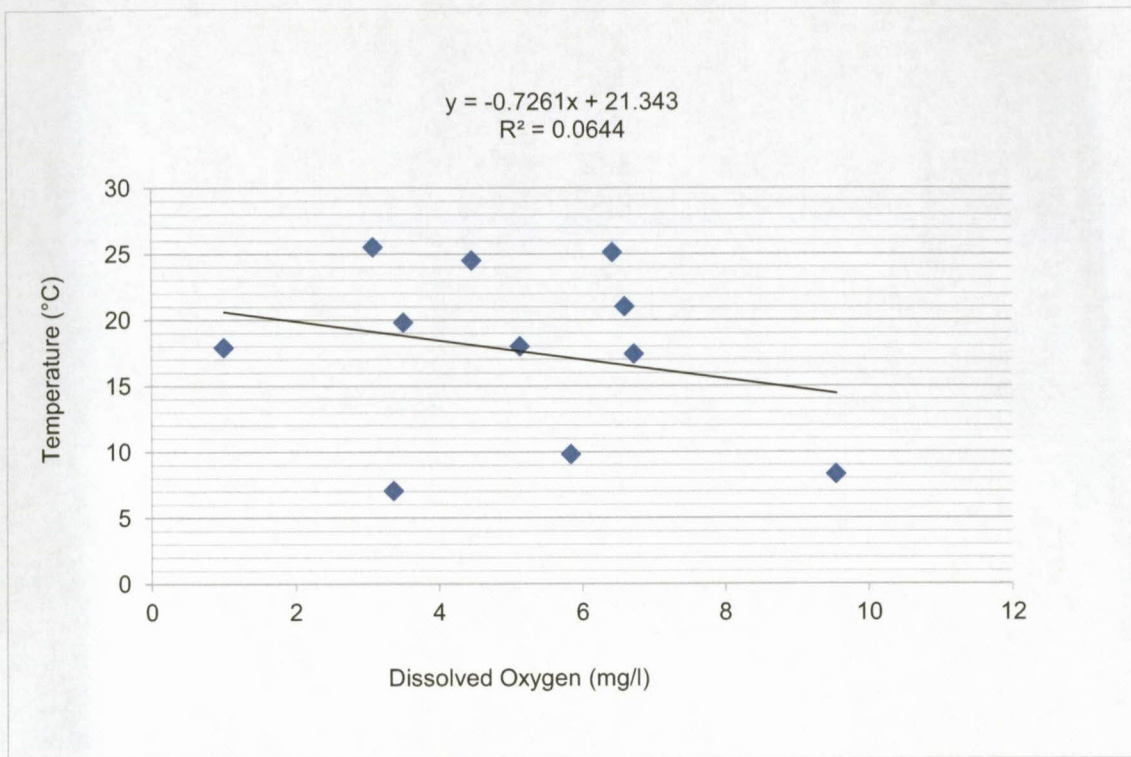


Figure 5.5(c): The graph depicts the relationship between dissolved oxygen and water temperature at the canal

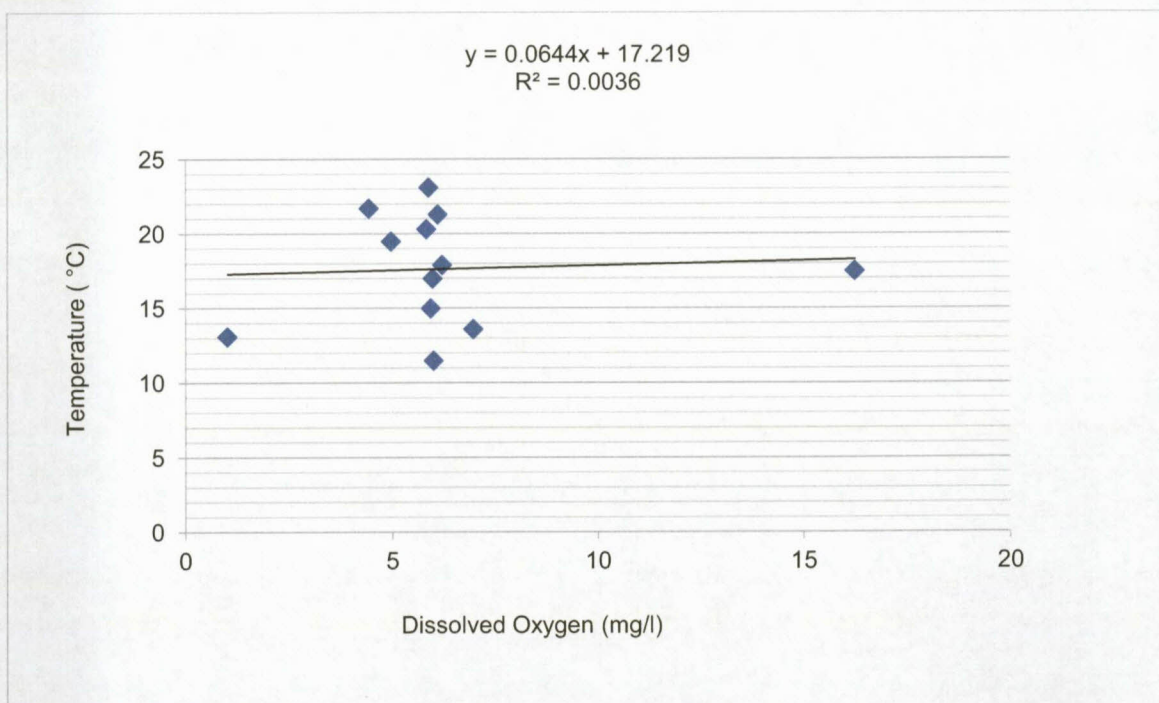


Figure 5.5(d): The graph depicts the relationship between dissolved oxygen and water temperature of the sewage effluent

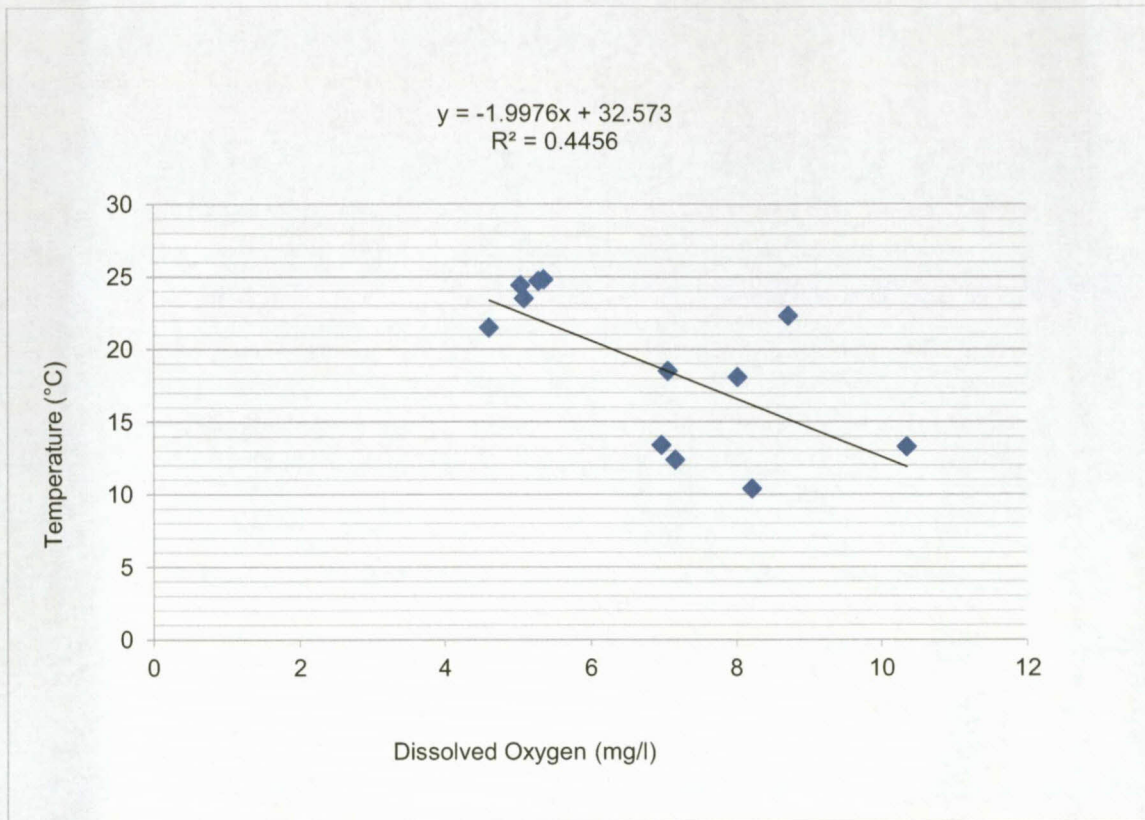


Figure 5.5(e): The graph depicts the relationship between dissolved oxygen and water temperature at the downstream site

Figures 5.5(a), (b), (c) and (e) show a negative correlation between water temperature and dissolved oxygen. Figure 5.5(d) also shows negative correlation but if the two outlying points were excluded from the graph, a positive correlation between the sewage effluent temperature and dissolved oxygen concentrations would be expressed.

High DO occurs in areas of high chlorophyll *a* concentrations (Dallas and Day, 1993). During September at the upstream site, chlorophyll *a* concentration of 187 µg/L was recorded and a corresponding DO concentration of 8.23 mg/l. During November when DO concentration at the dam was 8.13 mg/l, chlorophyll *a* concentration of 93 µg/l was recorded. During April 2012 at the sewage, the DO was 16.24 mg/l and the corresponding chlorophyll *a* of 107 mg/l was observed. Similar trends were observed by Roos and Pieterse (1995) in the Vaal River, South Africa. Koning (1998) also recorded similar correlations between DO and chlorophyll *a* concentrations in the Modder River; where DO concentration was high (around 15 mg/l) and the corresponding chlorophyll *a* was 80µg/l. The recorded oxygen concentrations that corresponded with high chlorophyll *a* concentrations displayed oxygen super-saturation in Sepanespruit.

A similar pattern of oxygen super-saturation in areas of high chlorophyll *a* occurrence was recorded by Venter (2000) during spring; she recorded oxygen super-saturation values of 9 and

15 mg/l. Venter (2000) calculated a 68% variation of water pH in the Orange River as a result of dissolved oxygen variation. She further reported a 69% pH variation because of dissolved oxygen variations in the Vaal River.

The concentration of DO in water is also affected by the amount of suspended solids (DWAf, 1996b). Suspended solids may reduce the concentrations of DO in water through reducing the physical volume of water and chemically depleting the oxygen in water. A low concentration of dissolved oxygen and under-saturation that was observed at the sewage effluent especially during August and November 2011, also during February 2012 was due to increased biochemical oxygen demand which required oxygen to break-down organic matter that was in the sewage stream (Horne and Goldman, 1994). The suspended solids also absorbed UV radiation and imparted heat to water thereby further reducing the concentrations of dissolved oxygen.

5.1.3. Chemical oxygen demand (COD)

Water at the dam contained the lowest chemical oxygen demand (COD) concentrations; however the seasonal variations could still be observed. The COD levels during August, September and October 2011 were relatively high. A general down trend was observed from November 2011 to July 2012. The low COD concentration of 1 mg/l was observed at the sewage effluent during June 2012. Water in the canal contained the highest concentrations of COD relative to other sampling points. The sewage effluent however contained the highest COD (536 mg/l) during September 2011. The concentrations of COD in different sampling sites displayed a seasonal pattern as shown by Figure 5.6.

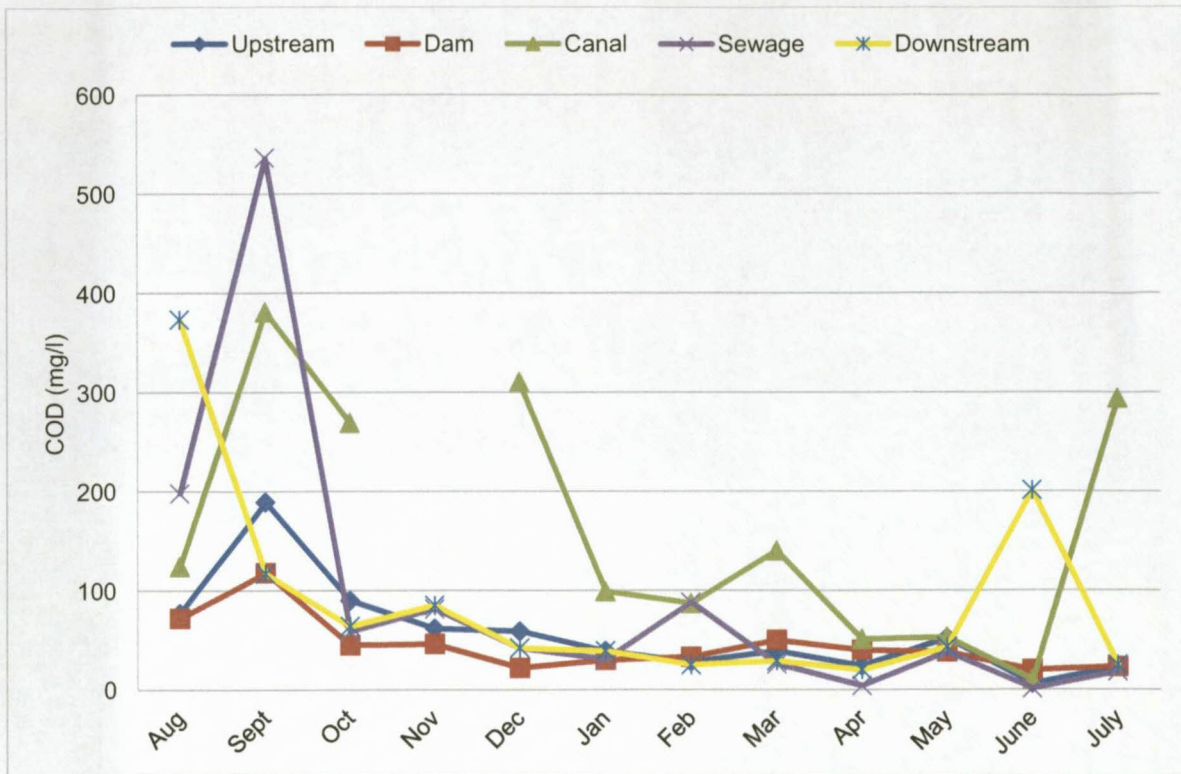


Figure 5.6: The changes in COD of water at different points within Sepanespruit for a 12-months period

The water COD concentrations at all sampling points during spring were commendably higher than during all other seasons. The observed results could be biased because spring was represented by September only, in which case there could have been a once-off occurrence of a factor which led to the observed high COD concentrations. The trampling and faeces of livestock that were noted to graze along the stream banks and within the wetland could have led to increased organic matter in water. Increased organic matter in water is associated with high COD concentrations (Allan, 1995). However, this account was insufficient to explain the high COD concentration (536 mg/l) that was recorded for the sewage effluent during September.

It is however important to note that the observed high COD concentrations during September were comparable to August results. During August, high COD levels were observed at the sewage effluent. This was the month in which there was electricity cut-off to the plant, in which case the sewage was treated fairly poorly before it was released. High concentrations of NH_3 (27.49 mg/l) and high COD concentration (198 mg/l) were recorded, in which case very low DO (1 mg/l) was also observed. The recorded COD concentration (124 mg/l) at the canal was the potential amount of oxygen that could be used to oxidise the organic matter that was contained in the free-flowing raw sewage. Both the effects of the canal and the sewage effluent were noted at the downstream water in the form of high COD concentrations (373 mg/l). Livestock

trampling at the wetland and downstream site could have increased the observed high COD in the downstream water. It was interesting to note that during August the upstream and dam site contained low COD concentrations; which reinforced that the August COD concentration were a result of sewage effluents and sewage in the canal.

During April and June 2012, low COD concentrations were noted in the sewage effluent probably because during the day of sampling, one of the aerators was functioning in both cases. This could have added sufficient quantities of oxygen to the water such that aerobic bacteria would not potentially cause a significant decrease in dissolved oxygen.

According to Table 5.5, the highest average COD concentration (268.2 mg/l) was observed during spring while the lowest average COD concentration (27.8 mg/l) was recorded for autumn. The spring and autumn were represented by one month each; this conferred the observed results during those seasons biased (it was one reading for each sampling site). The observed results could have been a result of a chance occurrence.

Table 5.5: The minimum, maximum and average COD concentrations of water at all sampling sites

Chemical Oxygen Demand (mg/l)			
Season	minimum	maximum	average
Summer	22.0	310.0	71.0
Spring	117.0	536.0	268.2
winter	1.0	373.0	84.5
Autumn	4.0	51.0	27.8

High COD concentrations were observed at the canal sampling site throughout the study period. Table 5.6 shows that the average seasonal COD concentrations at the canal were higher than in all other sampling sites. This observation could be expected since the canal carried variable amounts of raw sewage at all times. However, episodes of exceptionally high COD concentrations were noted during September (381 mg/l), October (269 mg/l), December (310 mg/l) and July (294 mg/l). These episodes can be associated with the high quantities of disposed sewage at the manhole; resulting in highly concentrated sewage water flowing in the canal at the time of sampling. The times of sampling were speculated to have occurred after sufficiently short period after disposal at the manhole; when there was still much sewage flowing in the water. The average COD concentration at all sampling sites throughout the study period was 88.6 mg/l.

Table 5.6: The seasonal average values of COD at different sampling sites

Chemical Oxygen Demand (mg/l)				
Sampling points	Summer average	Spring average	Winter average	Autumn average
Upstream	52.8	189.0	67.4	24.0
Dam	37.7	118.0	38.3	40.0
Canal	181.0	381.0	120.3	51.0
Sewage	54.6	536.0	63.8	4.0
Downstream	47.4	117.0	160.5	20.0

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are common parameters that are used to indicate the potential for organic wastes to consume oxygen. COD is usually included among parameters that are measured for routine monitoring of the quality of sewage effluents (DWAf, 1996d). Allan (1995) defined COD as an indication of the potential amount of oxygen that aerobic bacteria require to process and degrade organic matter. The graphs in Figures 5.7(a) – (e) indicate the correlation between dissolved oxygen and chemical oxygen demand. It was only at the downstream sampling site that a 54 % correlation was observed (Figure 5.7(e)).

For the upstream water, sewage effluent and canal water, the value of R^2 was lower than 10%. At these sites, it was expected that there would be a high correlation between DO and COD concentrations since the water was contaminated by organic matter (mostly from sewage) but it was not so. It seems there are other factors that influence the relationship between COD and DO which would need further studies to thoroughly understand. At the dam, a low R^2 value (0.0075) (Figure 5.7(b)) was calculated which indicated that the potential consumption of oxygen by aerobic bacteria to break down organic matter was small hence the recorded high DO concentrations at the dam.

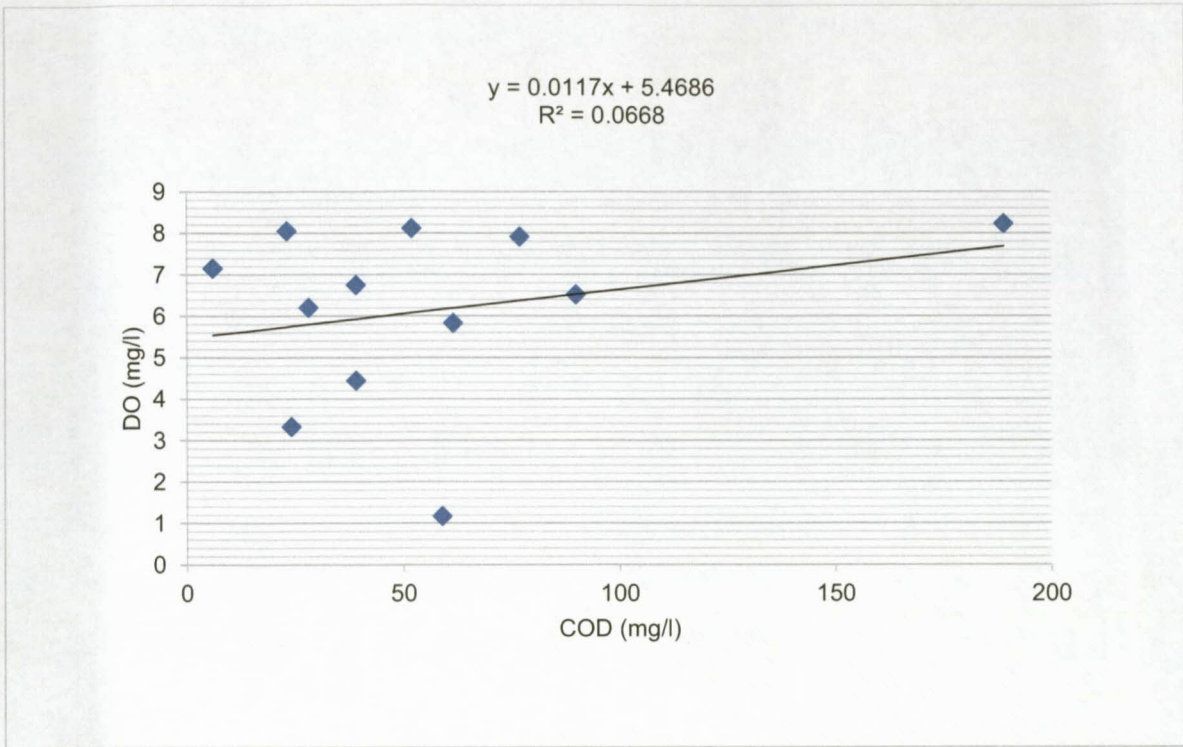


Figure 5.7(a): The graph depicts the correlation between COD and DO at the upstream site

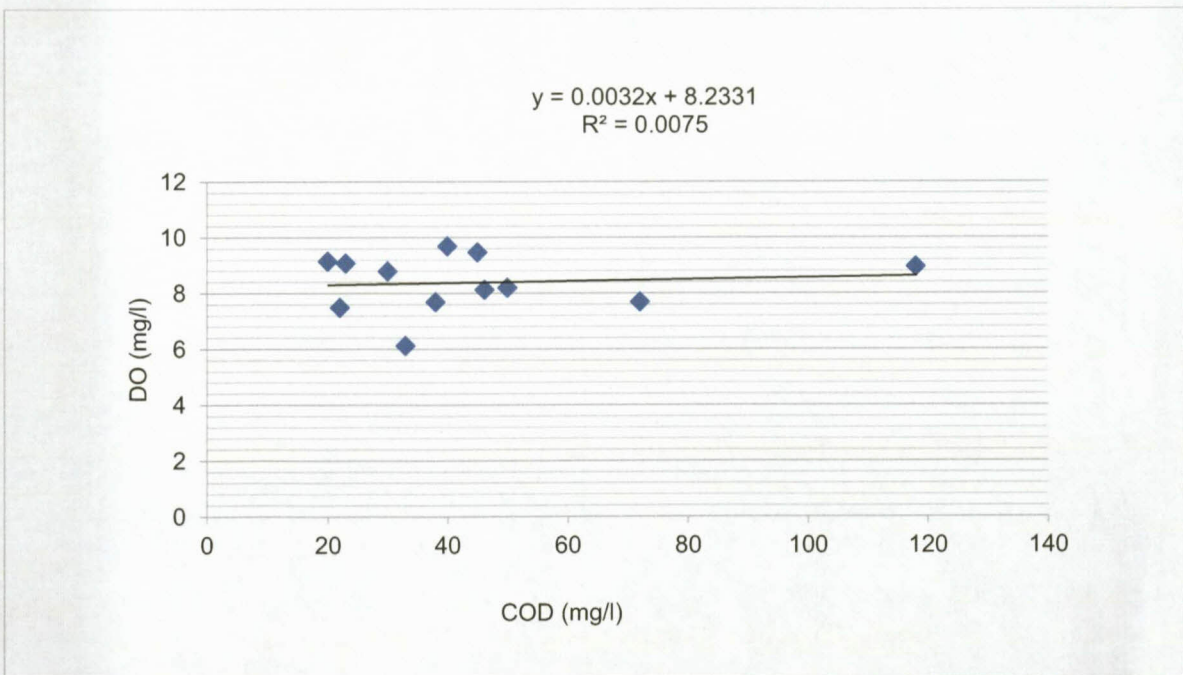


Figure 5.7(b): The graph shows correlation between COD and DO at the dam

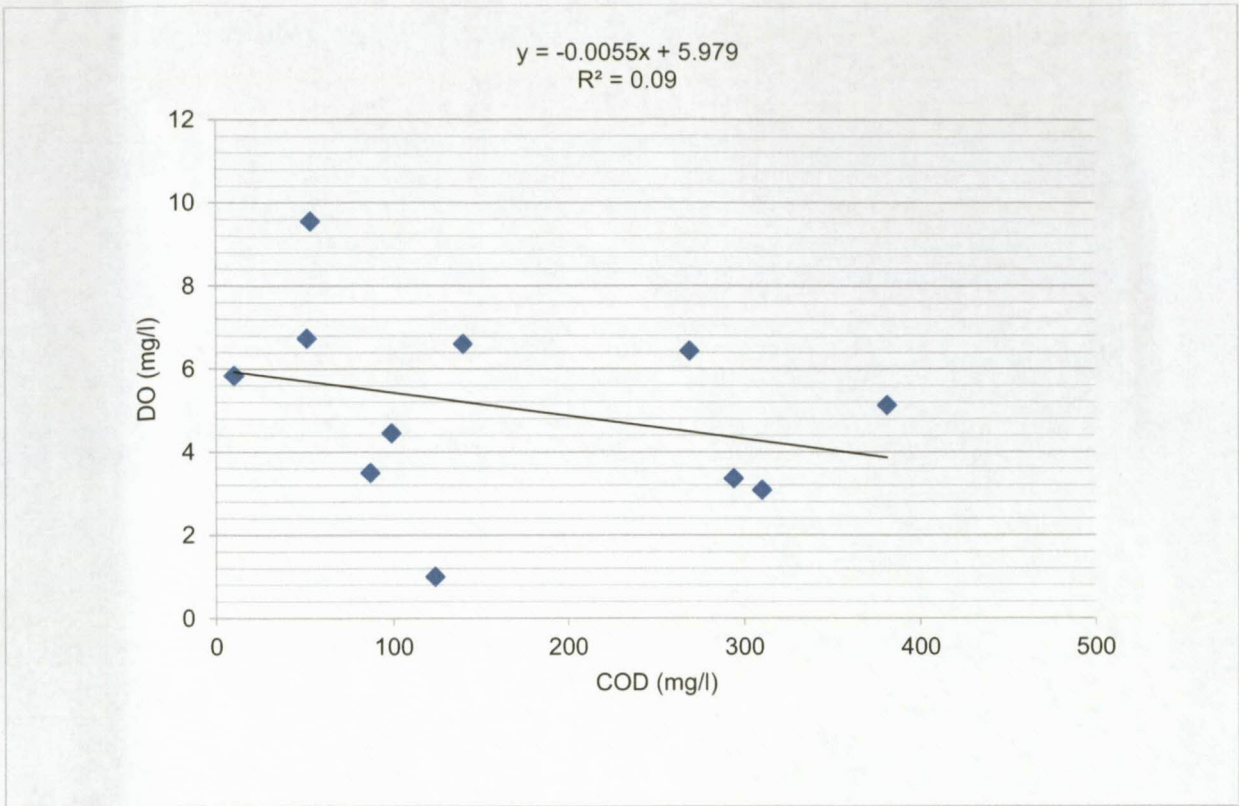


Figure 5.7(c): The graph illustrates correlation between COD and DO at the canal

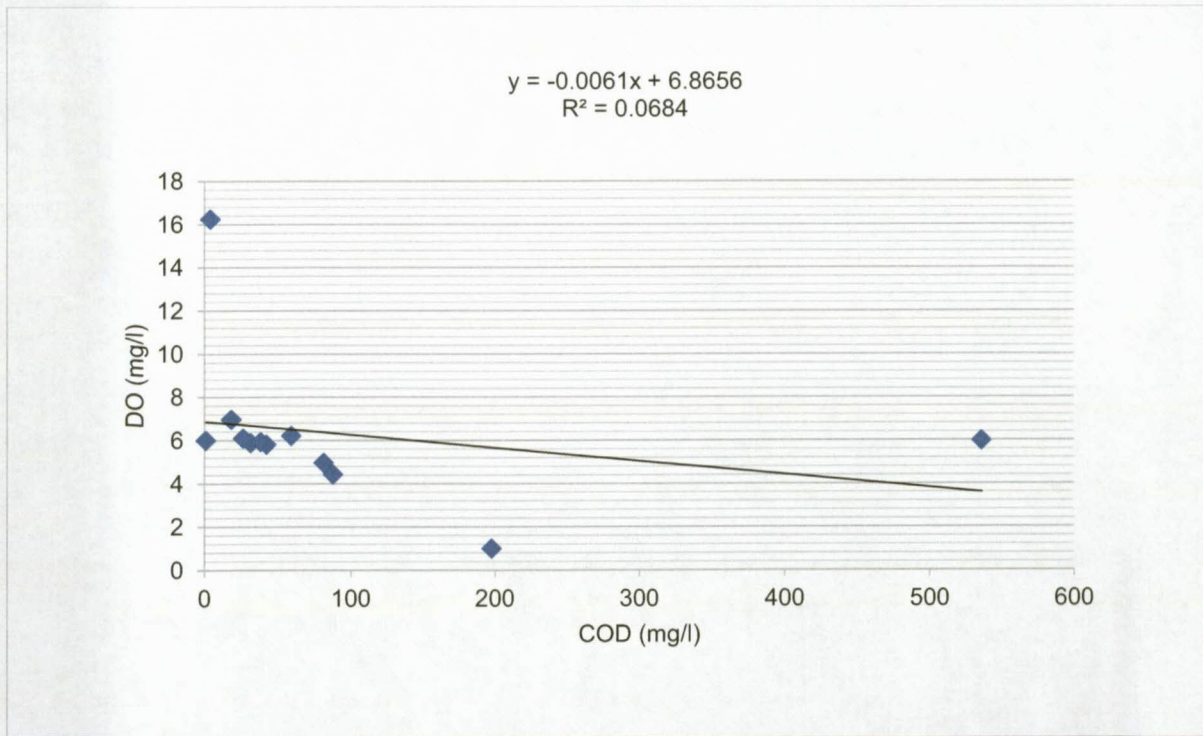


Figure 5.7(d): The graph illustrates the correlation between COD and DO of the sewage effluent

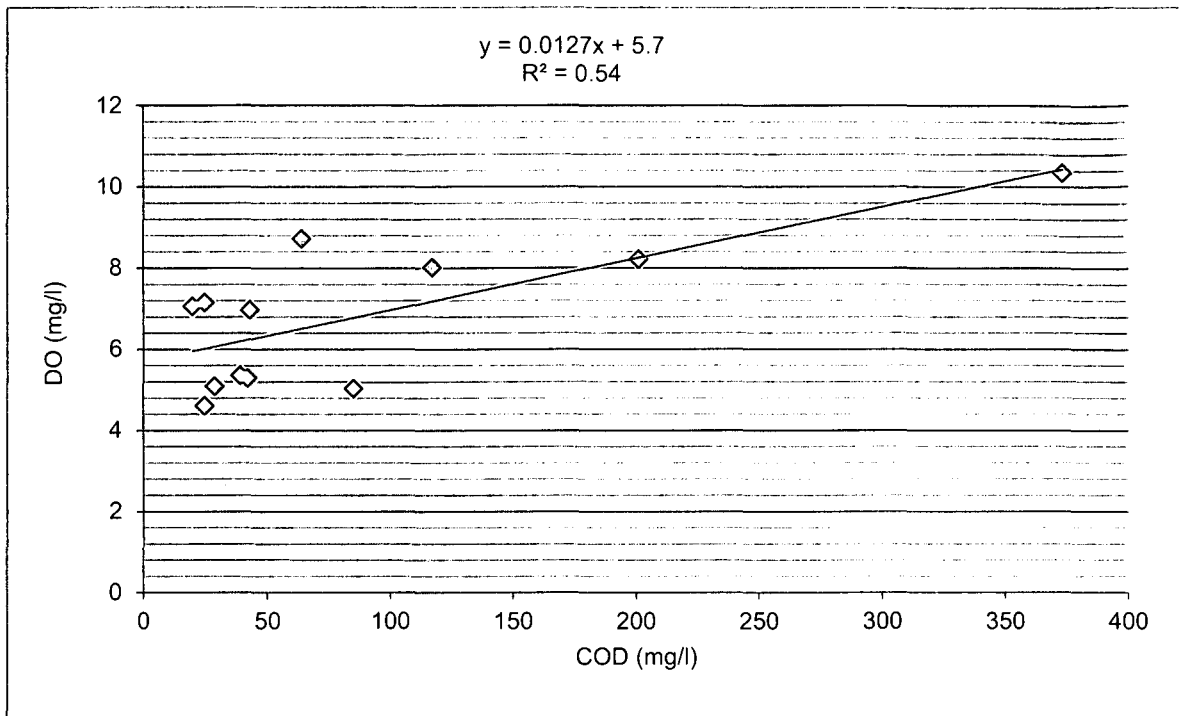


Figure 5.7(e): The graph depicts the correlation between COD and DO at the downstream site

Figures 5.7(a), (b) and (d) show a negative correlation between dissolved oxygen and chemical oxygen demand. On the contrary, Figures 5.7(c) and (e) indicate a positive correlation. Individual readings of this study, on a general note illustrate a negative correlation between COD and DO concentrations.

High levels of NH_3 consume DO which results in high COD levels (Davies and Day, 1998). A pattern that confirms this fact was observed by Iginosa and Okoh in 2009. Mgxwati (2010) also recognised a similar pattern as she undertook a study in which she investigated the impact of Somerset wastewater treatment works on the Little Fish River.

Only a part of the results in this study conform to the findings of Davies and Day (1998). The canal water during September, October and July displayed a pattern that was in line with the findings of Davies and Day (1998). The water contained extremely high concentrations of NH_3 in the order of 38.35 mg/L, 25.85 mg/L and 31.25 mg/L respectively. The COD levels were also notably high while the corresponding DO concentrations were low.

On the contrary though, a different pattern was observed during August 2011 and June 2012; the downstream water contained exceptionally high COD concentrations of 373 mg/l and 201 mg/l respectively. During the same time, the NH_3 content was notably high; 18.813 mg/l and 7.472 mg/l respectively. However, the corresponding DO concentrations were also high; 10.35 mg/l and 8.22 mg/l respectively. The relationship between COD, DO and NH_3 were not season

dependent but rather influenced by the amount of NH_3 in water. The amount of DO is imperative because it determines how quickly the process of nitrification happens (Allan, 1995).

5.1.4. pH

The water pH values at the sites upstream, downstream and the canal throughout the study period did not vary much during different seasons of the year. The recorded pH values ranged from 6.51 (sewage effluent in June 2011) and 9.33 (at the dam in January 2012). The average pH throughout the study period was 7.38. The pH at the dam was higher than at all other sampling points; the recorded pH range was 7.77 – 9.33. On the contrary, the sewage effluent had the lowest pH values; 6.51 – 7.51. The sampling point that was downstream of the sewage works contained water with low pH values. The downstream pH values were just higher than the sewage effluent pH values. The downstream pH range was 6.96 – 7.81. Figure 5.8 shows the pH variations within different sampling points for the length of the study period.

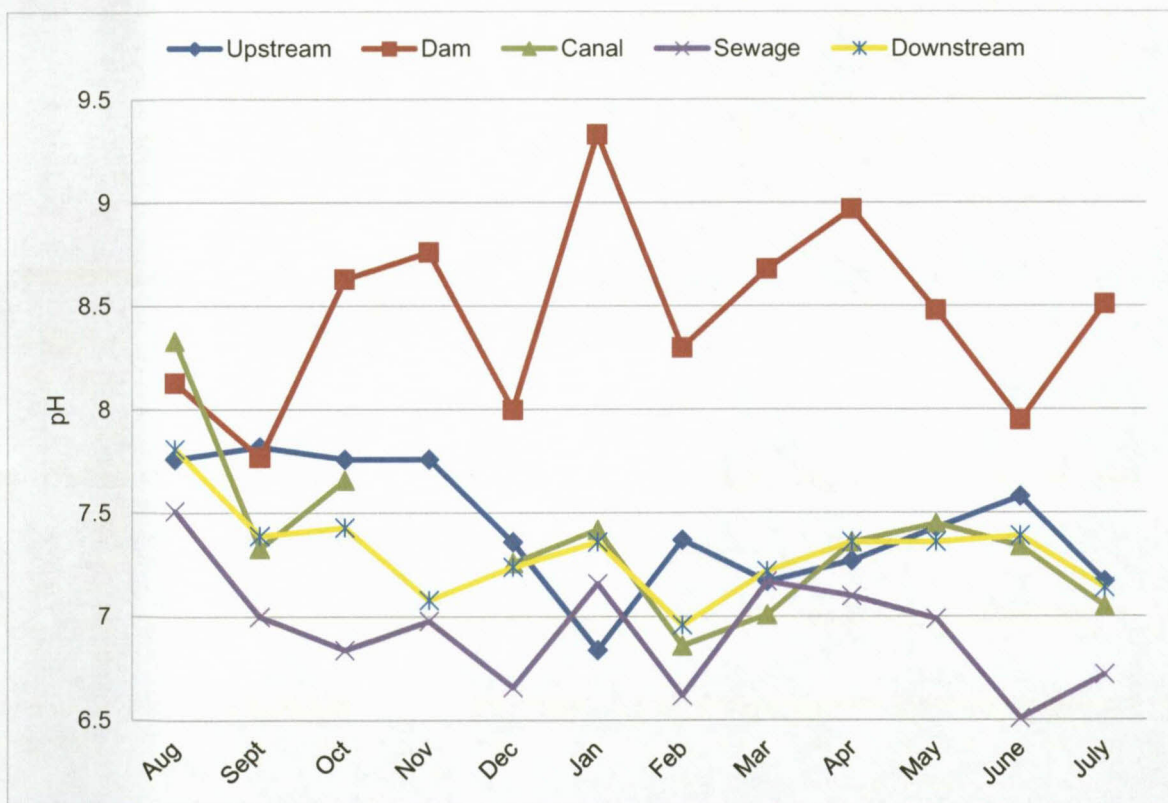


Figure 5.8: The variation in pH along Sepanespruit from August 2011 to July 2012

The pH of a water body may vary widely depending on biological activities that may increase or decrease the relative concentrations of hydrogen ions or hydroxide ions in water (Wetzel, 1983). The pH values may fluctuate widely from below six to above ten over a 24-hour period as a result of the changing rates of photosynthesis and respiration (DWAf, 1996b).

At areas where algal blooms occur, an increase in pH may be anticipated (Davies and Day, 1998). This finding was parallel with the pH results that were recorded at the dam; the pH range

was 7.77 – 9.33. The high recorded pH values may be attributed to intense algal growth that was observed at the dam. During January 2012, the highest pH value of 9.33 coincided with a high chlorophyll *a* concentration of 52 µg/L.

High concentrations of dissolved oxygen may decrease the effect of high pH values on fish, especially when alkaline conditions are the result of intense photosynthetic activities of aquatic plants. High photosynthetic activity is normally accompanied by high levels of dissolved oxygen (DWAF, 1996b).

pH is defined as the measure of hydrogen ion activity and an indicator of the hydrogen ion concentration that is present in a sample of water (Dallas and Day, 2004). Horne and Goldman (1994) gave a technical definition in which they suggested pH is the negative log of the hydrogen-ion concentration. Most natural waters contain bicarbonate and carbonate compounds which dissociate from underlying sedimentary rocks. The calcium bicarbonate content of freshwater determines the pH or acid/alkaline balance of water (Allan, 1995). Wetzel (1983) added that the levels of pH in water are determined by bicarbonate/carbonate concentrations and free carbon-dioxide.

Carbon-dioxide dissolves in water to form soluble carbon-dioxide which further forms undissociated carbonic acid (H_2CO_3). The carbonic acid then dissociates and goes into equilibrium forming bicarbonate (HCO_3^-). Further dissociation of bicarbonate produces and equilibrates as carbonate (CO_3^{2-}) and protons (H^+). The pH of a substance is the negative log of its hydrogen-ion concentrations (Horne and Goldman, 1994).

It is important to note that small variations in water pH often cause large changes in the concentration of available metallic complexes. This can enormously increase the availability and toxicity of most metals in water (DWAF, 1996b). The water pH influences the availability of important nutrients such as phosphates, ammonia, iron and trace metals for plant uptake (Horne and Goldman, 1994). The measurement, monitoring and assessment of water pH are indispensable management tools in water quality studies.

Water pH also influences the abundance and species richness of aquatic fauna and flora (Allan, 1995). Hynes (1970) undertook a study in which he related species with their varying degrees of sensitivity to water pH. Different species of algae, mosses and macrophytes all have different pH range preferences. His study concluded that the pH preference of one species may not necessarily be extrapolated to the next species, sometimes even of the same genus. Fish metabolisms are heavily rely on the stability of pH; the growth rates and upper size limit of some fish such as trout are dependent on water pH (Allan, 1995).

Prolonged periods of low water pH are detrimental to water life because metal solubility generally increases with decreasing pH. When the water pH falls to values below 5.5, aluminium can exist in solution. Dissolved aluminium and the associated free protons disrupt the abilities of benthic micro-organisms and fish to absorb oxygen (Sparling and Rowe, 1996). The lowest pH recorded in this study was 6.51 which is higher than 5.5; therefore it was insinuated that aluminium interference did not occur within Sepanespruit in areas that were covered.

Water quality guidelines should be set such that the Target Water Quality Range is stated in terms of the background site-specific pH regime. Local background conditions which include diel and seasonal pH variability need to be ascertained before a water quality objective is set. Ideally, temporal and spatial pH variations need to be determined on a case and site-specific basis. Since this task is difficult to perfect, South African DWA (DWAF, 1996b) guidelines presently recommend a pH range of 6.5 – 9 in aquatic ecosystems. Special pH standards have the following range 5.5 - 7.5. DWAF (1996b) pointed out that the average natural range in surface water is 4 – 11.

The changes in water pH did not show distinct seasonal patterns. The average seasonal pH values ranged between 7.46 – 7.61. The maximum seasonal average pH was recorded during summer (9.33). Table 5.7 shows the seasonal minimum, maximum and average pH values at all sampling points.

Table 5.7: The minimum, maximum and average pH values of water in Sepanespruit in different seasons

Seasons	pH		
	minimum	maximum	average
Summer	6.62	9.33	7.48
Spring	7.00	7.76	7.46
Winter	6.51	8.51	7.53
Autumn	7.10	8.97	7.61

The winter pH average value at the dam (8.97) was the highest average pH value during the study period at all sampling points but the highest value was recorded during January 2012 (summer season). Table 5.7 shows average seasonal pH values of water at all sampling points from August 2011 to July 2012.

The changes in water pH did not show distinct seasonal patterns. A similar pattern was recorded by Venter (2000) in the Upper Orange River during her MSc. study period. Roos and Pieterse (1995) also reported no seasonal pH variations in the Vaal River.

The highest pH of 7.51 was recorded during August 2011 at the sewage effluent. This high pH value was a result of high concentration of alkaline substances such as detergents that flowed with the sewage influent. This was the time when the sewage stream passed through the treatment processes almost raw as a result of a power-cut that occurred at the sewage treatment plant.

The mean pH of water in this study was 7.38 which rendered Sepanespruit water almost neutral. Most pH values at all sampling sites throughout the study period were above 7 which indicated neutral to alkaline water (Table 5.8). The mean pH of the Modder River as calculated by Koning (1998) was 8.1; alkaline water. Average pH values have a vague significance to water quality studies because pH variations that occur within different niches along the stream are masked.

The average pH value of the Upper Orange River was reported by Venter (2000) as 8.1; indicative of alkaline water. The Vaal River also contained alkaline water with an average of 8.2 and a range of 6.3 – 9.2, as reported by Roos and Pieterse (1995). The measured pH range in Sepanespruit was almost similar to that of the Vaal River; it was 6.51 – 9.33. The target water quality range for water that is used for irrigation purposes is 6.5 – 8.4 as recommended by DWA (DWA, 1996c). The part of Sepanespruit that was not fit for irrigation was the Seroale Dam because its pH range was 7.77 – 9.33. There were no incidences that were observed in which the dam water was used for irrigation. The water in the downstream site was used for irrigation mostly by subsistence farmers and small scale commercial farmers. The recorded range for downstream water was 6.96 – 7.81; which was a fair range that fell within the recommended water quality standards. Mgxwati (2010) reported that the pH range of water in the Little Fish River was 7.0 – 8.0. These pH values defined the Little Fish River as fit for irrigation use.

The pH at the downstream site was almost neutral during all seasons of the year that were covered in this study. This was evidenced by the recorded pH range which was 6.96 – 7.81. This almost neutral pH of water at the downstream site may be attributed to the bio-filtration processes that occurred within the wetland through which water passed before it flowed into the downstream site (DWA, 2010). The nutrient-rich sewage effluents and the sewage-contaminated canal water were bio-filtered in a wetland before it flowed into the downstream site. The wetland reduced some contaminants and improved water quality before the water passed to the downstream site. This debatable conclusion was drawn from the fact that the downstream water was more neutral as compared to the canal water and sewage effluent.

The upstream pH range was 6.84 – 7.82 for the entire study period; this also indicated near-neutral water. The water flow at this site was low most of the time and the stream was shallow with a width of about two meters; allowed sufficient water aeration thus maintaining a fairly neutral environment. There were also thick stands of riparian vegetation at the banks of the stream which might have helped uptake carbon-dioxide and produce some pH balance.

The sewage effluent had a pH range of 6.62 – 7.51; this pattern was similar to the pH ranges of the upstream and downstream water. The process of disinfection using chlorine kept the sewage effluent within the recommended special effluent quality standards of 5.5 – 7.5. The values were stipulated in the government gazette 18 May 1984 (No. 9225). The canal water was nearly neutral to alkaline as indicated by the recorded pH range of 6.86 – 8.33. Every day household substances that flow in domestic sewage such as detergents may account for alkalinity of the canal water.

Table 5.8: The average pH values of water at all the sampling sites in different seasons of the year

pH				
Sampling points	Summer average	Spring average	Winter average	Autumn average
Upstream	7.38	7.82	7.27	7.49
Dam	8.61	7.77	8.97	8.27
Canal	7.24	7.33	7.36	7.54
Sewage	6.90	7.00	7.10	6.90
Downstream	7.21	7.39	7.36	7.40

5.1.5. Electrical Conductivity (EC)

The EC concentrations that were recorded during this study varied over a wide range. The minimum EC concentration was recorded at the canal site during March 2011 (35.0 mS/m) while the highest EC concentration was recorded at the downstream site during June 2012 (174 mS/m). The EC concentrations in the dam water did not vary much; they ranged between 37.7 and 60.7 mS/m. The canal water generally contained higher EC concentrations than other sites, however dynamics of low EC concentrations during February, April and June 2012 and high EC concentrations during October and December 2011 were observed.

The general seasonal trend was such that high average EC concentrations were recorded during spring and winter. The autumn EC concentrations were the lowest relative to other

sampling points. Figure 5.9 shows changes in EC concentrations of water in Sepanespruit during a period from August 2011 to July 2012.

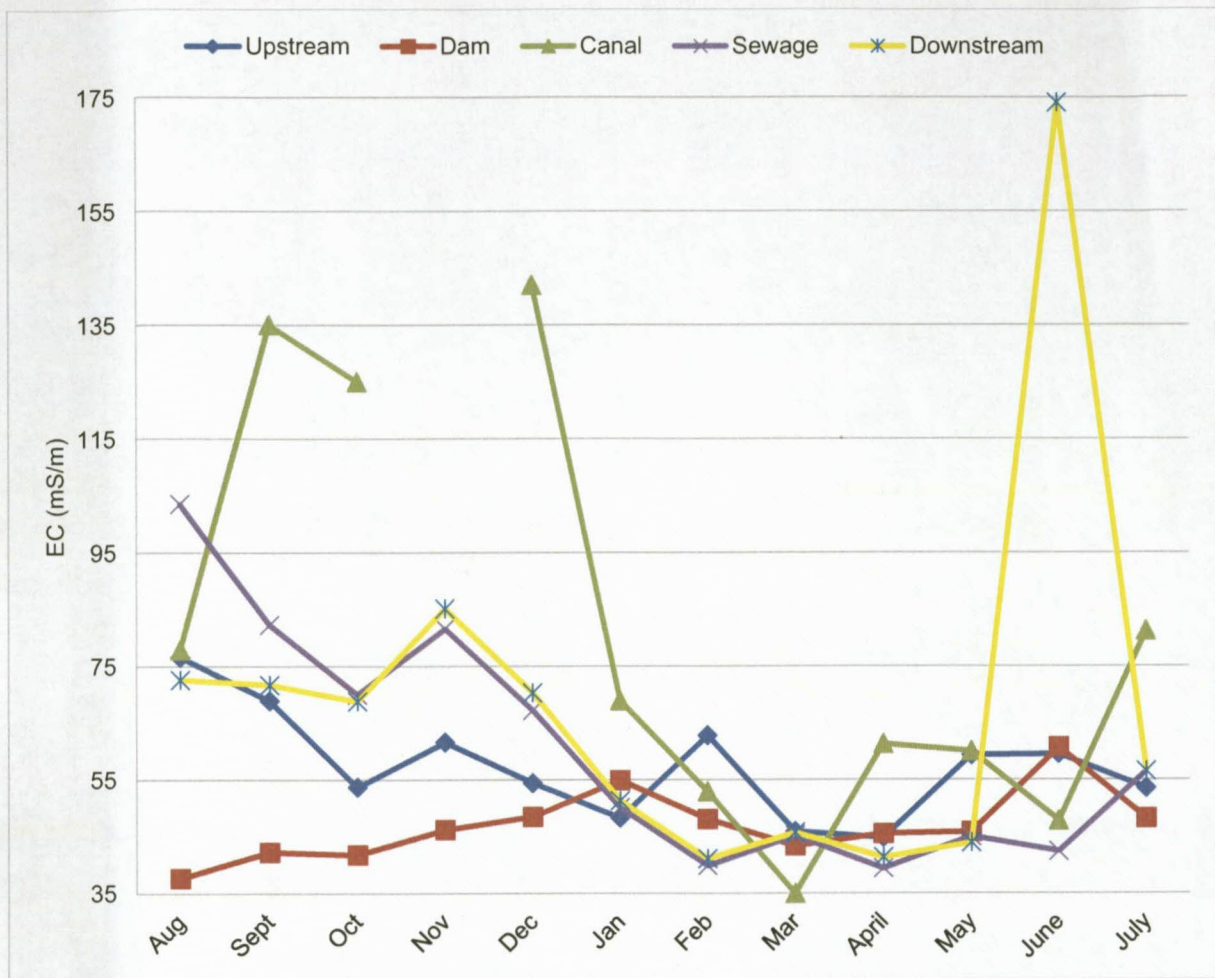


Figure 5.9: The variation in EC over a 12-months period along Sepanespruit

Electrical conductivity is the measurement of a sample of water to conduct electrical conductivity (Palmer *et al.*, 2003). The ability of water to conduct current is dependent on the presence of ions such as calcium, chloride, potassium, sodium and magnesium. The concentration of salts in water is influenced by the geological formation of the parent rock. Anthropogenic processes such as addition of sewage effluents to natural water bodies also contribute enormous amounts of salts to water (Dallas and Day, 2004). Allan (1995) also suggested that electrical conductivity is an indication of the concentrations of ions in solution. The ionic composition and water temperature influence also EC concentrations.

The average EC concentration of water in Sepanespruit was calculated as 62.4 mS/m during this study period. Koning (1998) reported that the average EC concentration in the Modder River was 36 mS/m and 52 mS/m in the Klein Modder Rivers. The salts that were carried in the partially treated sewage effluent that was released from the Thaba-Nchu sewage treatment plant increased the EC in Sepanespruit. It would be a viable water quality monitoring procedure

in the Modder River to ensure compliance within this sewage treatment plant. Roos and Pieterse (1995) reported that the average EC concentration of the Vaal River was 76 mS/m. On the contrary, the average range of EC of the Orange River from 1977 to 1997 was reported by DWAF (1997) as 18 - 30 mS/m. The average EC concentration within Sepanespruit was close to the maximum limit as set by DWA of 70 mS/m for drinking water standards. It is important to take hint from these results and implement monitoring measures before damage occurs. The average electrical conductivity of an unpolluted river system should be around 35 mS/m (Webb and Walling, 1992).

The observed general trend was such that the highest EC concentrations were recorded during spring (80.0 mS/m) and winter (57.4 mS/m) seasons as show in Table 5.9. This pattern conformed to the findings of Awachie (1981) who reported that African rivers have higher electrical conductivities during dry seasons. Evaporative water losses during dry and hot months of the year concentrate salts in water. The products of such conditions are measured as high electrical conductivity (Davies and Day, 1998). During rainy seasons, the water becomes diluted and hence the consequent low electrical conductivity values (Horne and Goldman, 1994).

Table 5.9: The minimum, maximum and average electrical conductivity concentrations of Sepanespruit water in different seasons

Electrical conductivity (mS/m)			
Season	minimum	maximum	average
Summer	35.0	142.0	60.3
Spring	42.3	135.0	80.0
Winter	37.7	174.0	57.4
Autumn	39.4	61.3	46.5

The average EC value fell within the DWA's recommended limit of EC concentration in aquatic ecosystems of 0 - 70 mS/m. There were instances however, in which values higher than 70 mS/m were recorded in some sampling sites. The sewage effluent during August 2011 contained high concentrations of EC (103.5 mS/m) as a result of power cut at the sewage treatment plant. The salts that flowed in the influent stream were not processed and removed by sewage treatment processes; this was evidenced by high concentration of EC in the sewage effluent.

The EC concentration at the canal was higher than the rest of the other sampling sites, more so during summer months. But during June, a high EC value was recorded at the site downstream (174 mS/m) which also was the maximum recorded value for this study. This observation could

not directly be attributed to the impact of the sewage effluent because it was low in EC concentration (42.4 mS/m) during that time. It could not be directly correlated to the canal water as it was low in EC concentration (47.8 mS/m). However, this high downstream EC concentration could not completely be divorced from the impacts of the sewage effluent and the canal water; it could be that a few days before the day of sampling there were high concentrations of salts in the sewage effluent or canal or both whose impact was then observed downstream. Possibly still, this high EC concentration at the downstream site could be a result of a once-off external source of salts which however was not identified. During June, water at the downstream site was enriched with nutrients; there were high concentrations of PO_4^{3-} and $\text{NH}_3\text{-N}$ which could have led to the observed high concentrations of EC. The sampling period at the canal during June was speculated to have coincided with the time of sewage disposal at the source manhole. The water flow in the canal had increased and a distinctive foul smell accompanied it. The nutrients in the canal water in particular could account for the high EC concentrations in the downstream site.

The EC at the canal also changed minimally reaching its peak during August and then kept on decreasing. Seasonal changes in EC concentrations were observed in water at the dam, the sewage effluent and the upstream site. Table 5.10 shows the seasonal average EC concentration in all the sampling points.

Table 5.10: The average seasonal changes in water EC in different seasons

Electrical Conductivity (mS/m)				
Sampling point	Summer average	Spring average	Winter average	Autumn average
Upstream	54.5	68.9	62.2	44.8
Dam	47.2	47.3	48.1	45.5
Canal	84.8	135.0	66.7	61.3
Sewage	59.0	82.3	61.8	39.4
Downstream	60.4	71.7	86.7	41.3

Sewage effluents may contain high concentrations of EC particularly because of the urine chlorides (from domestic sewage) that pass through the sewage treatment process un-altered (Hewitt, 1991). Additional chlorides may be added to the sewage at the disinfection stage of sewage processing. Low EC concentrations were recorded for the sewage effluent during February (39.9 mS/m), April (39.4 mS/m) and June (42.4 mS/m). These sampling days coincided with periods in which the sewage effluent was not disinfected prior disposal. This finding further confirmed that addition of chlorine (which dissociated to form chloride ions (Cl^-)) in the sewage effluent increased the concentration of EC. During October and December 2011,

sampling was done just a few hours after disinfection in which case, high EC concentrations were recorded for the sewage effluent. The canal water contained high EC concentration that exceeded the recommended water quality standards for aquatic ecosystems. However this was anticipated because this channel contained raw over-flowing sewage.

It was expected that the upstream site would contain high concentrations of EC since it received significant quantities of urban run-off. The observed range was 44.8 – 76.6 mS/m. This observation may be accounted for by that the composition of wastes that flowed in the stream did not add high concentrations of salts to water. The wastes were largely composed of grease, plastics, rags and organic matter. It was only during August 2011 that the upstream site contained high EC concentration of 76.6 mS/m, perhaps there was sewage leakage from a manhole over which water flowed at that sampling site. The dam water contained EC in the concentrations that were below the limit of 70 mS/m throughout the study period. The bio-filtration process that was undertaken by a thick reed bed before water flowed into the dam from the upstream site reduced the concentrations of salts and hence the observed lower EC concentration in the dam water.

5.1.6. Suspended solids (SS)

The SS concentration in the canal was the highest of all other sampling points. The maximum recorded SS was in the canal during December 2011 (161 mg/l). The lowest calculated SS was 0.33 mg/l (at the sewage) during March 2012. It was important to note that during March, SS concentration in all sampling sites was low. During summer, especially from October 2011 up to January 2012, high SS concentrations were recorded in the canal water. The sewage effluent generally contained low SS concentrations but a high concentration of 55 mg/L was recorded during February. Figure 5.10 shows the changes in water SS concentrations at different sampling sites along Sepanespruit for a period of 12- months (August 2011 to July 2012).

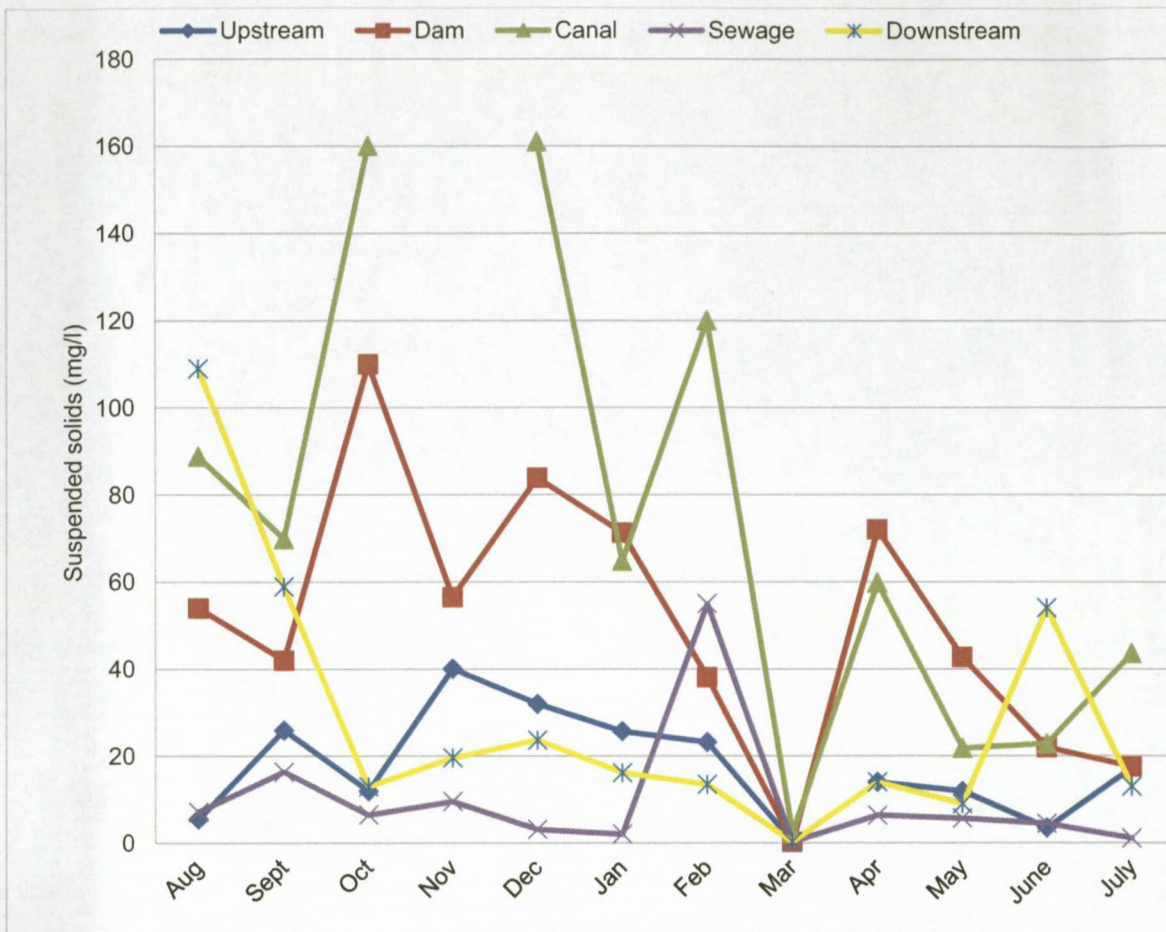


Figure 5.10: SS in the water throughout a 12-months period within Sepanespruit

Suspended solids are composed of clay particles, silt, fine organic and inorganic matter, plankton and other water organisms. Suspended solids can be organic; pollen, micro-organisms and seeds. Inorganic suspended solids include products of weathering such as quartz and mica. These solids differ in colour, sizes, shape, fluorescence and refractive index (Dallas and Day, 2004).

Suspended solids give an indication of the amount of substances that float or are immersed within the water column. When sediments are washed into a river system during rainy seasons, the concentration of suspended solids and turbidity also increase. Suspended solids also increase as a result of suspension of deposited material. When the flow decreases, the concentration of suspended solids also decrease at a rate that is determined by the particle size and the hydrodynamics of the water body (DWAF, 1996b).

Linder (1973) suggested that suspended solids are good indicators of the effectiveness of the sewage treatment processes to remove solid materials that float and/or are suspended in the sewage stream. The conventional treatment processes have the ability to remove suspended solids to a significant degree. The concentration of suspended solids also affects the predator-

prey interactions of aquatic organisms. High suspended solids disrupt the feeding mechanisms of organisms. The hunting predators are sabotaged because they become visually impaired.

Chutter (1969) reported that all South Africa Rivers (with an exception of some in the Natal foothills of the Drakensburg and in the south Western Cape) become turbid and burdened with suspended solids during the rainy season. The Orange River for example, carries large quantities of eroded sediments during rainy seasons. The sediments in the Orange River have eroded from the mountains of Lesotho, the farmlands of the eastern Free State, the Northern Cape and the Kalahari dune-field.

The highest SS concentration (161 mg/l) was recorded during December at the canal sampling site. This could have been a once-off occurrence in which the sewage disposal at the source manhole coincided with the time of sampling. The summer and spring average SS concentrations were higher than during other seasons as shown in Table 5.11. The observed results could be accounted by that the run-off during those seasons (though small) increased the immersed and suspended materials in the stream.

Table 5.11: The minimum, maximum and average of Suspended Solids (SS) in water during different seasons of the year

Suspended Solids (SS) (mg/l)			
Seasons	minimum	maximum	average
Summer	0.3	161.0	40.2
Spring	16.4	69.9	42.6
Winter	1.1	109.0	27.8
Autumn	6.4	72.0	33.2

High concentrations of suspended solids were observed at the dam during certain months of the summer season. From October 2011 until January 2012, high SS concentrations at the dam were recorded in the range 56.5 – 110 mg/l. This could have been the result of sand, clay and silt particles that flowed in the dust that came from the excavation-developments on the road and settlement area. There were installations of potable water infrastructure and running water pipes in the Kopi residential area of Seloshesha, Thaba-Nchu. The road was about 100 m from the dam.

During March 2012, it was dry as there was little rain during that summer period and the recorded temperature was high (21.3 °C), the concentrations of suspended solids in all sampling points were low. The SS concentration during this period was 0.3 mg/l at all sampling

sites but the canal water contained relatively higher concentration of 2.37 mg/l. March was the month in which significantly low SS concentrations (0.3 mg/l) were recorded at the upstream, dam, sewage effluent and downstream sites; this could not have been coincidence. This could be attributed to human error during handling water samples and carrying out the analysis.

The sewage effluent contained the least concentrations of suspended solids throughout the study period. This could be attributed to the sewage treatment processes which removed them. Processes such as sedimentation and flocculation played a significant role of removing suspended solids within the sewage stream. During August 2011, the recorded suspended solids concentration of the sewage effluent was 7.2 mg/l. This value was not as high as would be anticipated considering the free-flowing sewage stream as a result of non-functional electrical equipment. This was the time when there was an electricity-cut at the sewage treatment plant.

During February 2012 the municipal workers were on a wage-increase strike, the grit removal areas were blocked and the screenings were left to fill beyond the capacity of the collecting bins. The entire screen-removal area was a foul-smelling nuisance. The flies and beetles were loudly buzzing around the area in celebration of the fresh and decaying faecal matter that was in that area. This incidence led to the increase of the concentration of suspended solids in the sewage effluent. A high concentration of 55 mg/l was recorded at that time.

Seasonal and spatial variations in water temperature were observed. The upstream site and canal were shallow in nature which exposed water therein to environmental influences to a better degree. In both sites, the water was slow-moving and turbid hence the observed high water temperatures during spring, summer and autumn. During winter, these sites harboured cool water. The dam water was relatively cooler than in other sites because of the mixing phenomenon that happened with underlying water layers. November, December 2011 and January 2012 were the hottest months for 2011/2012 summer season.

The sewage effluent caused thermal pollution to the water downstream; the effluent temperatures were warmer (an average of 2.2 °C) during winter and cooler during summer. The biota in the downstream site of the receiving stream may have received some misinformed cues from these anthropogenic water temperature variations. If this was a common water temperature regime at this site, long term impacts of the sewage effluent would be the disruption of natural varieties and communities of vegetation and biota in Sepanespruit.

Spatial DO concentrations of water were expressed in Sepanespruit. Due to high water temperatures in the canal and upstream site during summer, low concentrations of DO were recorded. The high water DO at the dam could also be the result of oxygen that was produced by phytoplankton during photosynthesis and the cool water temperatures observed. Leaking of

sewage from a manhole and nutrients from domestic wastes reduced DO concentrations in the upstream water. During April (2012) when the aerator was functional, the DO concentration in the sewage effluent increased abruptly. High concentrations of suspended solids were observed to reduce concentrations of DO in water.

The canal water contained high concentrations of COD because high concentrations of oxygen would be required to oxidise the organic matter of the sewage that flowed in the canal. The trampling and faecal matter of livestock on the wetland and the canal may have increased nutrients in water and thereby increased concentrations of COD. The sewage effluent contained high COD concentrations when there was electricity cut-off at the sewage treatment plant and low COD concentrations when the aerator was functional. The changes in COD concentrations of water were not seasonal but rather dependent on the amount of organic matter in water. High concentrations of NH_3 were associated with high concentrations of COD in water.

The pH variations of the dam water displayed seasonal variations in which the highest pH was recorded during summer. A positive correlation was observed for the dam water between pH and chlorophyll *a* concentrations. High pH values were recorded for the sewage effluent during periods when there was electricity cut-off at the sewage treatment plant. The high pH values that were observed at the dam were the impacts of sewage effluent and the canal water. Seasonal variations were not observed in other sampling sites. However spatial variations were such that the dam water had the highest pH values throughout the study period.

The canal water showed episodes of high EC concentration during the study period, this was attributed to the salts in the raw sewage that the canal carried. Seasonal variations were not explicitly expressed but high EC concentrations were generally observed during winter months. Evaporative losses during the dry winter period increased concentrations of salts in water hence high EC concentrations. For periods in which the sewage effluent was not disinfected prior sampling, low EC concentrations were observed. Excessive amounts of chlorine that were added to the sewage effluent for disinfection increased EC concentrations. The domestic wastes that were observed on the upstream site increased littering and suspended solids in water.

The pipe networks of potable infrastructure were being installed in the Kopi area during October 2011 to January 2012. This construction development was about 100m away from the dam. The dust that was created caused a significant increase of suspended solids in water. Exceptionally low concentrations of suspended solids were recorded during March at all sampling sites as a result of continued low rainfall. During March when municipal workers (including the sewage treatment works workers) were on a wage-increase strike, high concentrations of suspended solids (55 mg/l) were recorded. It is however worth noting that the

sewage effluent was otherwise quite competent in the removal of suspended solids in the effluent. Seasonal variations were expressed in which the summer and spring concentrations were higher than during other seasons.

5.2 NUTRIENTS: Ammonia, Nitrites/Nitrates and reactive Orthophosphate

5.2.1 Ammonia (NH₃)

The sewage effluent was low in ammonia concentration (NH₃), the range content varied between 0.08 mg/l and 1.75 mg/l (excluding the August and December concentrations). During August 2011, the highest sewage effluent NH₃ concentration of 27.49 mg/l was recorded. During December 2011, a high NH₃ concentration of 8.52 mg/l was also observed. The lowest recorded NH₃ was 0.1 mg/l during April 2012 at the sewage effluent.

The canal which is a rain or storm water-diluted pathway of raw sewage had the highest concentrations of NH₃ for the entire period. The highest recorded NH₃ for the entire study period was 38.35 mg/l in the canal water during September 2011. The NH₃ of water at the downstream site ranged between 0.9 mg/l and 7.47 mg/l except for a high concentration of 18.81 mg/l that was recorded during August 2011.

The NH₃ concentrations of water at the dam were the lowest of all other sampling sites for the entire study period. The upstream water was also low in NH₃ ranging on average from 2 – 6.4 mg/l. During November 2011 and April 2012, high episodes (12.78 mg/l and 8.07 mg/l respectively) of NH₃ occurred in the upstream site. Figure 5.11 shows changes in water NH₃ concentration in all sampling sites over a period of 12-months.

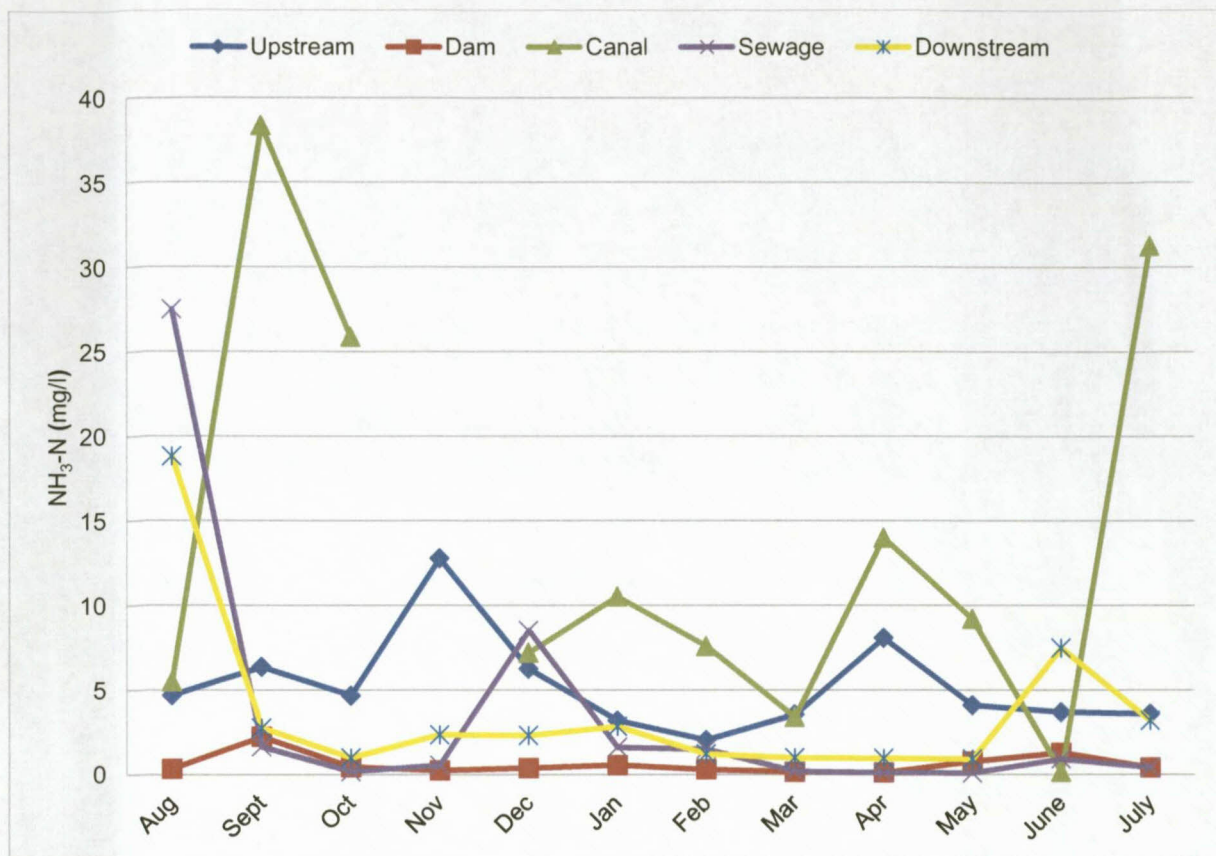


Figure 5.11: The water variation of $\text{NH}_3\text{-N}$ content within Sepanespruit for a 12-months period

The toxicity of ammonia to aquatic biota is directly related to the concentrations of dissolved oxygen (DO), the levels of carbon-dioxide in water, total dissolved solids and metal ions present in water. Ammonia can be adsorbed onto suspended sediments and colloidal particles. The toxicity of ammonia is dependent on water temperature and pH (DWAf, 1996b).

The conversion of ammonia to nitrates/nitrites (the process of nitrification) occurs in aerobic conditions. Nitrates are less toxic to biota and become readily available as nutrients to water plants and algae. It is therefore advisable within the sewage treatment process to increase oxygen content of water in order to maximise the process of nitrification. At the time of sampling during April and June 2012, an aerator was functioning at the plant which could have fairly facilitated the process of nitrification, this could account for the low NH_3 concentrations observed. On the contrary though, the corresponding concentrations of $\text{NO}_3^-/\text{NO}_2^-$ were high which may further buttress that the conversion of ammonia into nitrates occurred.

High levels of NH_3 indicate low levels of DO (DWAf, 1996b). This fact was confirmed during August 2011, at the sewage treatment plant, the highest water NH_3 of 27.49 mg/l was recorded and the low DO of 1 mg/l was subsequent. The sewage effluent contained high NH_3 of 8.52 mg/l during December 2011, the corresponding low DO of 5.82 mg/l was observed. The recommended effluent standards as stipulated in the National Water Act, section 39 of 1998 are

such that the NH_3 content of sewage effluent should not exceed 6 mg/l. In both instances, August and December 2011 the high NH_3 content of sewage effluent can be attributed to power failure. The sewage treatment works' management had not paid up the electricity dues and so there was a power cut. During that time, the sewage treatment processes were almost non-functional and so the poor-quality sewage effluent was released into the receiving stream. During December though, sampling was done a day after electricity was supplied back to the plant after a four-day cut-off. This information was collected on personal communication with operation staff.

Biochemical transformation of organic substances such as domestic wastes and sewage that was escaping from a manhole within the stream could be accountable for high NH_3 concentrations in the water upstream (DWAF, 1996b). For these reasons, the upstream section of the stream periodically contained high NH_3 concentrations. The high concentrations of NH_3 in the canal and downstream water can be associated with livestock trampling and their faecal matter.

The NH_3 concentrations of water did not display seasonal variations at all points along Sepanespruit. The spring average (10.27 mg/l) and maximum (38.35 mg/l) were the highest average NH_3 concentrations. The recorded concentrations were not significantly influenced by changes in seasons; associated temperature changes and rainfall. The NH_3 concentrations in Sepanespruit were more a result of point pollution such as sewage effluents during August and December 2011.

Table 5.12: The minimum, maximum and average NH_3 content of water through the seasons within the study period along Sepanespruit

Seasons	NH_3 in mg/l		
	minimum	maximum	average
Summer	0.16	25.85	3.88
Spring	1.65	38.35	10.27
Winter	0.08	31.25	4.65
Autumn	0.10	14.00	6.21

The ammonia rich upstream water was bio-filtered before it flowed into the dam. This accounted for the good quality of water in the dam. The dam water contained NH_3 in the range 0.16 – 1.28 mg/l which was fairly lower than the DWAF recommended limit of 7 mg/l for aquatic environments. The NH_3 concentration in the downstream water was lower than the recommended limit except during August 2011; an extremely high NH_3 concentration of 18.81 mg/l was recorded. This abrupt increment may be ascribed to the effects of the sewage effluent

which contained extremely high NH_3 concentrations of 27.49 mg/l at that time. August was the time in which the sewage stream was flowing almost unchecked as a result of the power-cut.

The canal water was high in NH_3 content for the rest of the study period; the least recorded NH_3 was 0.13 mg/l during June 2012. The canal water contained high NH_3 because it is raw sewage water. Exceptionally high concentrations of NH_3 were recorded during September (38.36 mg/l), October (25.85 mg/l) and July (31.25 mg/l). These were the months in which high COD concentrations and low DO concentrations were also recorded. These observations can be ascribed to that the times of sampling coincided with the periods in which high quantities of rich and raw sewage flowed in the canal.

Most of the recorded NH_3 concentrations were toxic relative to the target water quality standards for aquatic ecosystems as stipulated by DWA in DWAF (1996b). The water upstream during November was at 24.5 °C and pH 7.76; the recommended NH_3 concentration (based on temperature and pH) should be below 1.7 mg/l but a value of 8.07 mg/l was recorded. During April 2012, the concentration of NH_3 of 6.39 mg/l was recorded instead of 0.39 mg/l of the recommended value (DWAF, 1996b). These results indicated that NH_3 concentrations were toxic to aquatic biota.

5.2.2. Nitrates/nitrites ($\text{NO}_3^-/\text{NO}_2^-$)

Nitrates and nitrites occur together in the environment; inter-conversions between these two forms of nitrogen occur very readily; hence that organic nitrogen parameter was denoted in this study as nitrates/nitrites ($\text{NO}_3^-/\text{NO}_2^-$). However, nitrates are the most common form of nitrogen in aquatic environments (DWAF, 1996c).

On average, the sewage effluent contained high concentrations of nitrates/nitrites ($\text{NO}_3^-/\text{NO}_2^-$) but the canal $\text{NO}_3^-/\text{NO}_2^-$ concentration (11.29 mg/l) during May 2012 was the highest recorded value. The average nitrite/nitrate content of all sampling points throughout the study period was 2.56 mg/l.

The minimum recorded nitrates/nitrites (0.05 mg/l) occurred during November 2011 and April 2012 at the upstream sampling site. During May at the dam and during June 2012 at the site downstream, minimum nitrates/nitrites concentrations (0.05 mg/l) were recorded. The nitrate/nitrite content of dam water was the lowest throughout the study period; it ranged between 0.05 mg/l and 1.26 mg/l but during June 2012, a high value of 4.31 mg/l was recorded. The water at the upstream site also contained low nitrites/nitrates concentration with a range of 0.05 mg/l and 2.47 mg/l except during August 2011 in which, a high value of 4.04 mg/l was recorded. Figure 5.12 shows the changes in water $\text{NO}_3^-/\text{NO}_2^-$ in all sampling sites along Sepanespruit throughout the study period.

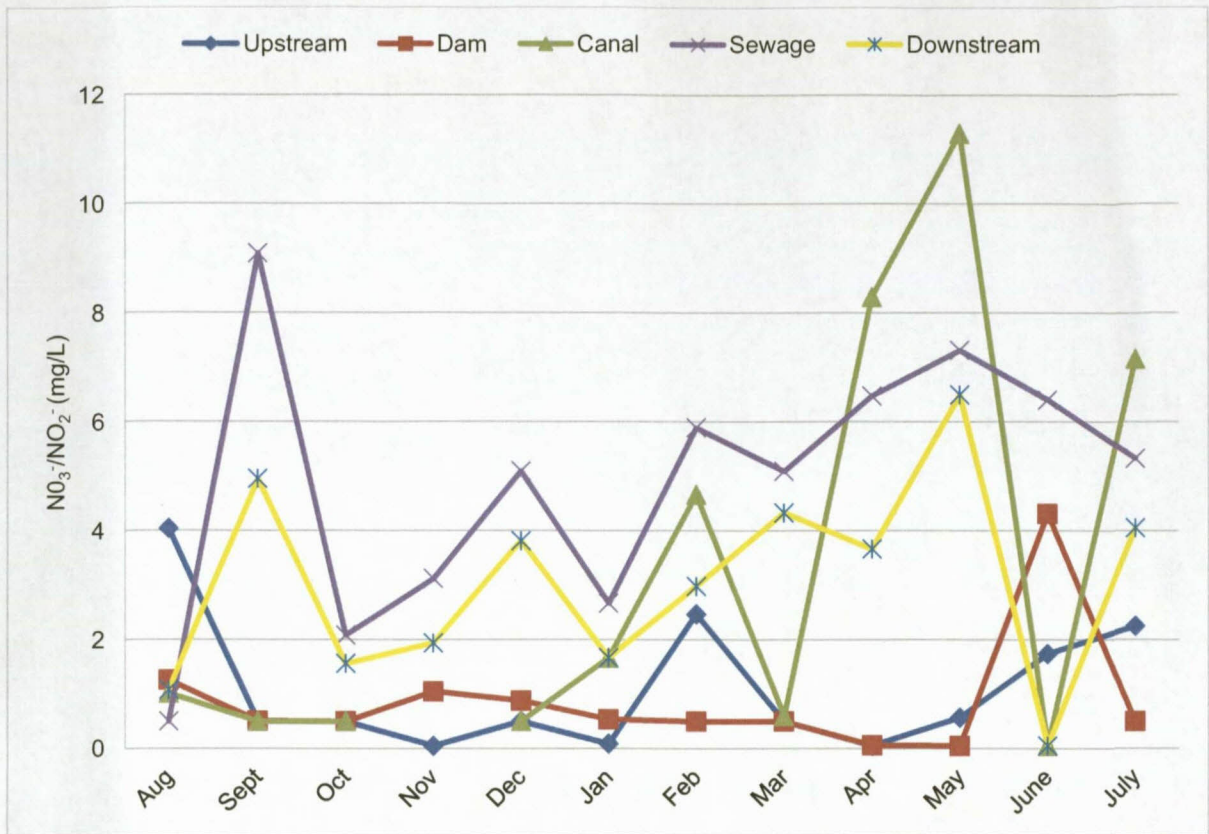


Figure 5.12: The nitrates/nitrites content of water at all sampling points for 12-months

Roos and Pieterse (1995) suggested that most of the annual loads of soluble nutrients such as phosphorus and nitrogen are transported during periods of discharge. They further pointed out that sources of nitrates in streams are surface run-off from the catchment areas after rainfall. The low $\text{NO}_3^-/\text{NO}_2^-$ and PO_4^{3-} in Sepanespruit can be attributed to low rainfall occurrences during the study period; from August 2011 to July 2012. Low rainfall reduces nutrient loading as a result of decreased erosion and leaching (Horne and Goldman, 1994).

The concentrations of nitrates/nitrites in water did not show much seasonal changes but during summer, there were generally low concentrations of nitrites/nitrates in water in all the sampling sites (Table 5.13). An increase in water nitrites/nitrates was expected during the rainy season but it rained fairly little during February 2012; it was generally a dry summer period.

Table 5.13: The minimum, maximum and average nitrites/nitrates of water in different seasons

Nitrates/Nitrites in mg/l			
Seasons	minimum	maximum	average
Summer	0.05	5.89	1.94
Spring	0.50	9.09	3.11
Winter	0.05	11.29	3.27
Autumn	0.05	8.29	3.71

Sepanespruit water complied with the set $\text{NO}_3^-/\text{NO}_2^-$ concentrations of less than 15 mg/l for aquatic ecosystems (DWAF, 1996b). A low concentration of $\text{NO}_3^-/\text{NO}_2^-$ (0.5 mg/l) was recorded for the sewage effluent during August 2011 when there was a power-cut. At this stage, high concentrations of PO_4^{3-} and NH_3 were recorded; the corresponding $\text{NO}_3^-/\text{NO}_2^-$ and DO concentrations were low. These results confirmed that the sewage stream was flowing through the sewage treatment process unprocessed. The process of nitrification was slow or almost absent since the aerators were also not functioning.

The sewage effluent generally contained high concentrations of nitrates/nitrites throughout the study period. This observation was expected since it has been certified that conventional treatment processes in South Africa do not completely remove nitrates from the sewage stream. The highest $\text{NO}_3^-/\text{NO}_2^-$ concentration was recorded at the canal during May, in which case a high DO concentration was also observed. More oxygen was added to the canal water as it moved along the canal since it was a windy day, hence the observed high concentration of $\text{NO}_3^-/\text{NO}_2^-$ and the corresponding low NH_3 concentration. This could have been a chance occurrence from faecal matter and trampling of livestock. Oxidation of plant and animal debris increases concentrations of nitrates/nitrites in water (DWAF, 1996c).

The concentrations of $\text{NO}_3^-/\text{NO}_2^-$ at the dam have been low throughout the study period because the bio-filtration process that removed nitrates before the water flowed into the dam from the upstream site.

Low concentrations of $\text{NO}_3^-/\text{NO}_2^-$ (0.05 mg/l) were recorded at the upstream site during November 2011 and April 2012. The upstream water ranged between 0.05 and 2.47 mg/l in $\text{NO}_3^-/\text{NO}_2^-$ concentrations except for a high 4.04 mg/l concentration that was measured during August. The sources of nitrates/nitrites in the water upstream were urban run-off, occasional leakage of sewage from a manhole and nutrients from domestic wastes. Since 2011/12 was a dry year, significant nutrient enrichment from urban run-off was not experienced.

5.2.3. Orthophosphate (PO_4^{3-})

On average the orthophosphate (PO_4^{3-}) concentration of water was low in all sampling points except for in the canal. The canal contained exceptionally high amounts of phosphates. The highest recorded phosphate was 315.8 mg/l which occurred in the canal water during December 2011. The lowest recorded orthophosphate was 0.1 mg/l which occurred at several sampling points at different times; during June 2012 in the canal, during May at the upstream, dam and sewage sampling sites. High PO_4^{3-} concentrations were recorded during August 2011 (9.65 mg/l) and December 2011 (7.27 mg/l). On several instances, high PO_4^{3-} concentrations were recorded for the downstream water; 7.05 mg/l during August, 12.71 mg/l during December 2011 and 21.13 mg/l during June 2012. The upstream and dam sampling sites contained commendably low PO_4^{3-} concentrations throughout the study period. Figure 5.13 shows the concentration of concentration of phosphates.

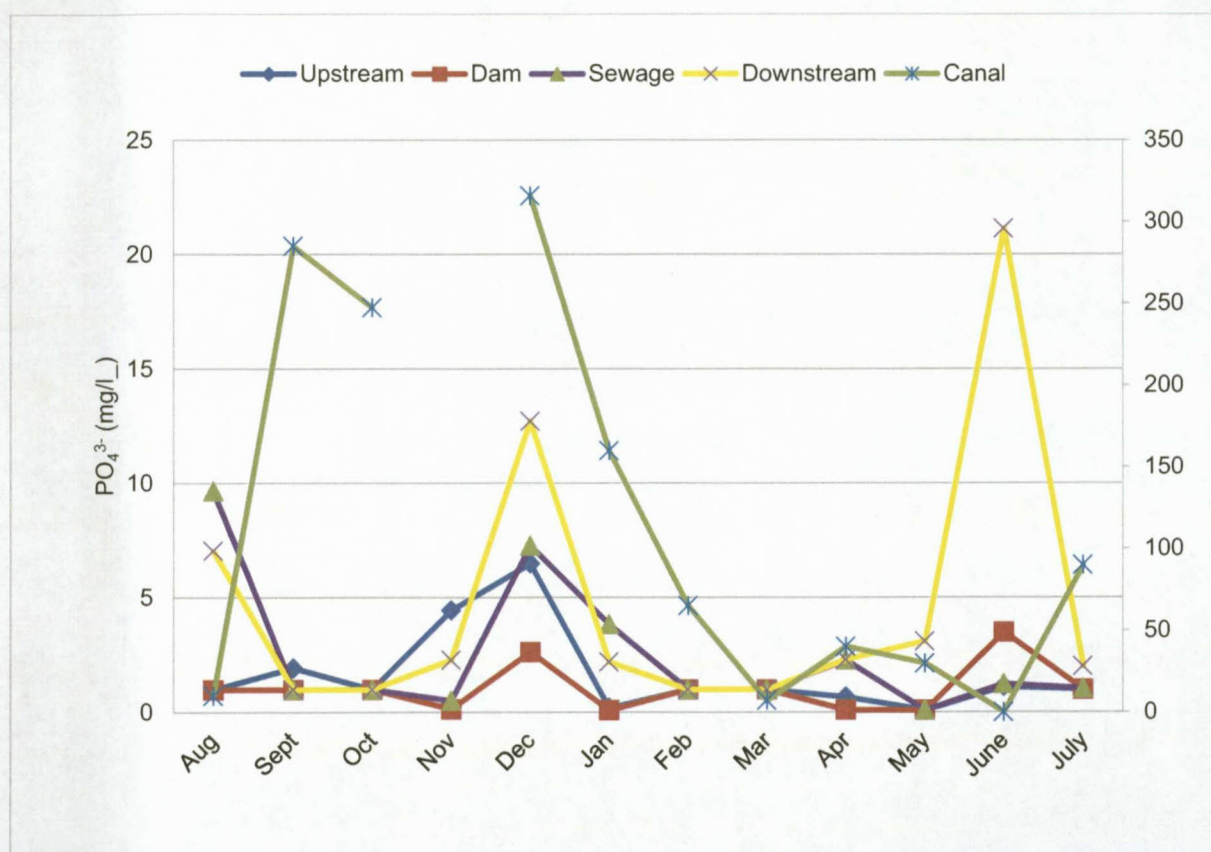


Figure 5.13: The Ortho-phosphate concentrations in Sepanespruit for the 12-months period (August 2011 – July 2012). The canal and downstream concentrations are plotted on the secondary axis whose PO_4^{3-} range is 0 - 300 mg/l.

During summer months, there were high concentrations of water orthophosphates; during October (247.5 mg/l), December (315.8 mg/l) and January (159.8 mg/l). A big gap was observed between the minimum and maximum values of orthophosphates during summer and

spring seasons. Table 5.14 shows the variations in orthophosphate concentrations of water during different seasons.

Table 5.14: The minimum, maximum and average orthophosphate values of water in Sepanespruit for a 12-months period

PO ₄ ³⁻ in mg/l			
Seasons	minimum	maximum	average
Summer	0.1	315.8	29.3
Spring	1	285.0	58.0
Winter	0.1	90.0	9.2
Autumn	0.1	7.3	9.1

The PO₄³⁻ concentrations of water at the upstream site were lower than anticipated considering it received urban run-off (though in small quantities), occasional sewage leakage and nutrients from domestic waste. The highest recorded PO₄³⁻ at the upstream site was 6.49 mg/l during December 2011 which could be attributed to a once-off source of phosphates such as soapy constituent of the domestic wastes. The low PO₄³⁻ concentrations in the dam water can be explained by bio-filtration process which occurred as the water flowed from the upstream site.

During August and December 2011, there was no power to drive electrical equipment at the sewage treatment plant. High PO₄³⁻ concentrations of 9.65 mg/l (during August) and 7.27 mg/l (during December) were recorded since domestic sewage is characterised by high quantities of phosphates from household soaps and detergents. High concentrations of NH₃-N were also recorded during August and December 2011. The concentration of PO₄³⁻ in the canal water was very high throughout the study period except during June in which a low (0.01 mg/l) was recorded. The range of PO₄³⁻ concentrations in the canal water was 0.1 – 315.8 mg/l. These findings confirm that raw sewage contains high phosphate concentrations.

The PO₄³⁻ concentration of water downstream was high (7.1 mg/l) during August 2011. This could be the impact from the poorly treated sewage effluent during that time. During December, a high PO₄³⁻ concentration (12.7 mg/l) was observed at the downstream site. This could be a dual impact of the sewage effluent and canal water since they were both high in PO₄³⁻ concentrations during that period. Exceptionally high PO₄³⁻ concentrations were recorded at the canal during September (285.0 mg/l), October (247.5 mg/l), December (315.8 mg/l) and July (90.0 mg/l). During the same months, high concentrations of COD, NH₃, EC were also recorded for the canal water. These pollution indicators can be ascribed to the high episodes of faecal

matter that flowed in the canal during those times. The times of sampling could have coincided with the periods just after fresh disposal at the source manhole.

Increased nutrient loads from phosphorus and nitrogen cause eutrophication in receiving waters (Meixler and Bain, 2010). The canal sampling site was severely polluted because of excessive nutrients that came from the source manhole. The downstream site was also relatively enriched with nutrients from the sewage effluents, canal water and livestock faecal matter. The upstream site looked significantly disturbed and aesthetically compromised; during summer and spring seasons, foul smell was detected and midges were noted. The stream at this sampling site occasionally received sewage from a manhole leak, urban-run-off, livestock faecal matter and organic wastes that emanated from domestic wastes. Water at all sampling points except the canal water was low in phosphates; fitted within the recommended range for aquatic ecosystems in the South African Water Quality Guidelines.

During August and December 2011, there was a power-cut at the sewage treatment plant which led to the release of an insufficiently treated sewage into the receiving stream. High concentrations of NH_3 and PO_4^{3-} were recorded for the sewage effluent. At this time, the stream water was contaminated with excessive nutrients in which case eutrophication was encouraged to the water downstream

The canal water was a source of nutrients to the Sepanespruit; high concentrations of NH_3 and PO_4^{3-} were pumped into the stream. There were episodes in which exceptionally high concentrations of NH_3 and PO_4^{3-} were recorded for the canal water during August and December 2011, and during June 2012; those were attributed to the coincidence in the time of sampling the time of sewage disposal at the source manhole. During those times, low concentrations of DO and $\text{NO}_3^-/\text{NO}_2^-$ were recorded.

The water quality of the downstream site was influenced by the canal water, the dam overflow and the sewage effluent. High NH_3 and PO_4^{3-} concentrations were observed at the downstream site during August 2011. This observation could be attributed to the impacts of the sewage effluent which was rich in these nutrients as a result of the power-cut during August. During June, high concentrations of NH_3 and PO_4^{3-} were observed which was considered to be an impact of the canal water. The canal during June contained high NH_3 and PO_4^{3-} .

The dam water contained low NH_3 , $\text{NO}_3^-/\text{NO}_2^-$ and PO_4^{3-} concentrations throughout the study period because of the bio-filtration process that occurred before water flowed into the dam. The upstream site contained high NH_3 concentrations (higher than 6 mg/l) during November 2011 and April 2012. High PO_4^{3-} concentrations were observed in the canal water during December 2011. These episodes were attributed to the occasional leaking of sewage from the manhole.

The concentrations of NH_3 and $\text{NO}_3^-/\text{NO}_2^-$ in water that exceed 5mg/l may be toxic to sensitive crops such as grapes; however there were not any grape plantations in the catchment of this stream. Most crops are negatively affected when irrigated with water that contains $\text{NO}_3^-/\text{NO}_2^-$ and NH_3 in concentrations that lie between 5mg/l and 30mg/l. Water that contains NH_3 and $\text{NO}_3^-/\text{NO}_2^-$ in concentrations beyond 30 mg/l may become toxic to crops if used for irrigation (DWAF, 1996d). Water that is used for livestock watering usually contains $\text{NO}_3^-/\text{NO}_2^-$ in concentrations less than 22 mg/l. However, toxicity of $\text{NO}_3^-/\text{NO}_2^-$ in livestock watering may begin at concentrations higher than 100 mg/l (DWAF, 1996c).

A negative correlation between NH_3 and $\text{NO}_3^-/\text{NO}_2^-$ was observed in Sepanespruit water. The concentrations of NH_3 , $\text{NO}_3^-/\text{NO}_2^-$ and PO_4^{3-} in Sepanespruit did not display seasonal trends. The high concentrations that were occasionally recorded were a result of events such as power-cut at the sewage treatment plant. In terms of $\text{NO}_3^-/\text{NO}_2^-$, Sepanespruit water was deemed fit for irrigation and livestock watering.

5.3. PHARMACEUTICAL CHEMICALS AND DYES

5.3.1. Dyes

The following dyes were identified in the sewage effluent during January 2012; Orange ii, Sudan i and Rhodamine B. These dyes are colorants and additives which are synthetically produced azo dyes (azo by virtue of a N-N double bond in their structure). The degradation products are said to be carcinogenic and teratogenic. The European Union and United States have banned the use of these chemicals as food additives (Fang *et al.*, 2008). The most probable culprit to this chemical contamination was suspected to be the meat-processing factory that released its thick reddish-brown chemical waste into the sewage stream. Two times during the sampling period, factory workers were captured disposing this chemical waste on one of the sludge drying lagoons within the treatment plant (Figure 5.14). This was an authorised method of chemical waste disposal which according to this study was considered a health threat to downstream water users. These chemicals were not removed by the conventional sewage treatment processes since they were identified in the sewage effluent.



Figure 5.14: Factory workers disposing-off waste at the Thaba-Nchu sewage treatment plant
(Picture taken: January 2012)

The meat processing factory that was associated with these chemical wastes is one of the biggest manufacturers and suppliers of branded russians, ham and polony and other processed meat products within the Mangaung Metro Municipality. Figure 5.15 shows some of the processed meat products that were disposed-off with the waste.

From personal experience and observations, and communication with local people, this brand is one of the most trusted and supported meat brands in Lesotho. There are huge commercial outlets of these branded products in Lesotho. These were specifically noted in the Mafeteng and Maseru districts.

To further confirm that those meat products from a factory in question were the sources of these chemicals, fresh branded products were bought from retail stores in Lesotho. Products that were bought were polonies, russians and ham. These products contained the same dyes as was identified from the sewage effluent which emanated from the factory in question.

It was interesting to note that meat products that contain health-threatening chemicals are consumed so generously in South Africa. It is astonishing that the same products are sold even beyond South African borders. It would be expected that the South African health inspectorate, especially the department that certifies the safety of foods should have picked up the presence

of these deadly chemicals in foods and perhaps formulated some legislative guidelines to ban the use of such chemicals as food colorants.



Figure 5.15: The details of the factory waste and the manhole through which factory waste joined the sewage stream for treatment (Picture taken: June 2012)

The manhole as shown in Figure 5.15 connects to mainstream sewage flow. For about two days after the factory waste was received at the sewage treatment plant, the sewage effluent would be released in a red-brown coloured state as shown in Figure 5.16. According to the sewage treatment plant personnel, this factory waste was received at least once every week. They further reported that the plant received two to three times of this factory waste during one week for periods when production at the factory was high. A further study on toxic quantities, effects on biota, dangers on animals' and human health of these chemicals is necessary. At this point, it can only be pointed out that such chemicals do exist in the treated sewage effluent and the suspect remains the meat processing factory in the immediate catchment of the stream.



Figure 5.16: The red-brown coloured sewage effluent at the exit point from the Thaba-Nchu sewage treatment plant (Photo taken: August 2012)

The sewage effluent was released into Sepanespruit which then went through the wetland. During periods when the sewage effluent was released in a stained state, even the water downstream would still show the red-brown colour (Figure 5.17).



Figure 5.17: The downstream site water was reddish in colour as a continual effect of the sewage effluent (Photo taken: August 2012)

5.3.2. Pharmaceuticals

Advances in the medical, agricultural and industrial fields have introduced additional chemicals from petrochemical and pharmaceutical industries into the environment. These chemicals may be washed directly into water ecosystems, as in the case of pesticides (Claassen, 2010). Some chemicals are introduced into water bodies indirectly via sewage effluents as evidenced by the findings of this study. Knowledge about the fate of these chemicals, their distribution and individual defects on human and animal is limited in South Africa. Claassen (2010) further reported that the break-down products of these chemicals are not sufficiently known and their persistence within the environment is greater than it was initially suggested by earlier researchers.

Davies and Day (1998) suggested that a thorough and detailed study of the components of the sewage stream may help to simulate activities that occur in the catchment. The types of medical drugs that were identified in the sewage effluent indicated (at least to some degree) the health state of people that live in the area that the sewage treatment works serve. The hypertension drugs, stimulants and anti-depressants suggest stress-stricken communities. It would have been more informative to measure the relative quantities of these drugs. That knowledge would have more clearly indicated drugs which were mostly used. The fact that the analysis was done once-off also makes it impossible to draw reliable conclusions. The following pharmaceutical

compounds and other chemicals as indicated in Tables 5.15 and 5.16 respectively and were identified in the sewage effluent. Classeen (2010) suggested that most herbicides, pesticides, pharmaceutical and personal care products are classified as endocrine disrupting chemicals.

Table 5.15: The category of pharmaceutical chemicals and their respective representative compounds that were present in the sewage effluent

Pharmaceutical chemicals	
Category	Compound's name
Antibiotics	Trimethoprim
	Nalidixic acid
Antidepressant	Amitriptyline
Insomnia	Temazepam
	Oxazepam
Antihistamine	Cetirizine
	Chlorphiramine
	Fexofenadine
Hypertension	Irbesartan
Stimulant	Nicotine
Analgesic	Tramadol
Psychostimulant	Amphetamine
Beta Blocker	Atenolol
Anticholinergic	Orphenadrine
Antiemetic	Metoclopramide
Antipsychotic drug	Sulpiride
Antiepileptic	Phenytoin
Anti-inflammatory	Indometacin

The fungicides, pesticides and herbicides that were identified in the sewage effluent could have been swept from small-scale subsistence farming that was practiced in the villages upstream of the part of the stream that formed this study.

Table 5.16: Other chemical compounds that were identified in the sewage effluent

Other chemicals	
Pesticides	Atrazine
Herbicides	Terbutylazine
	Tebuthiuron
Fungicide	Fluconazole

5.3.3 Conclusions – pharmaceutical chemicals and dyes

The following chemical compounds were also identified in the sewage effluent; pharmaceutical products, cosmetic products, herbicides, fungicides, pesticides were present in the sewage effluent. These chemicals are collectively known as endocrine disrupting chemicals. The sewage treatment processes did not remove these substances; they were released into the stream. Classeen (2010) reported that limited knowledge was available on the effects of these substances on human and animal health. These chemicals were not quantified but they could enter the human food cycle through irrigation of crops and bio-accumulation within fish, birds and livestock.

The following dyes were identified in the sewage effluent; Orange ii, Sudan i and Rhodamine B. These dyes were confirmed to have been produced by a meat-processing factory in the catchment. Workers from that factory were seen several times during the time when they were disposing-off dyes at the sewage treatment plant. Furthermore, branded products from that factory were bought from retail stores in Lesotho, they were confirmed to contain those dyes. These branded products are sold widely in central South Arica and in Lesotho.

5.4. MICROBIAL WATER QUALITY

5.4.1. *Escherichia coli* (*E. coli*)

For most of the time during the study period, Sepanespruit water contained *E. coli* counts that exceeded the maximum countable value of 2419 cfu/100ml. However, for all the months of the study period, the dam water contained *E. coli* in the range 1 cfu/100ml to 326 cfu/100ml but during December 2011, a high value of 1300 cfu/100ml was recorded. Very low *E. coli* counts (1 cfu/100ml and 2 cfu/100ml) were recorded at the dam during June and July 2012. A low *E. coli* value of 1 cfu/100ml was also recorded for the sewage effluent during December 2011. During April and May 2012, low *E. coli* counts were recorded for the canal water. During May 2012, the upstream water contained *E. coli* count (162 cfu/100ml) which was the lowest recorded count

for the upstream site. Figure 5.18 shows the changes in *E. coli* concentration of water in different sampling sites for the length of 12-months.

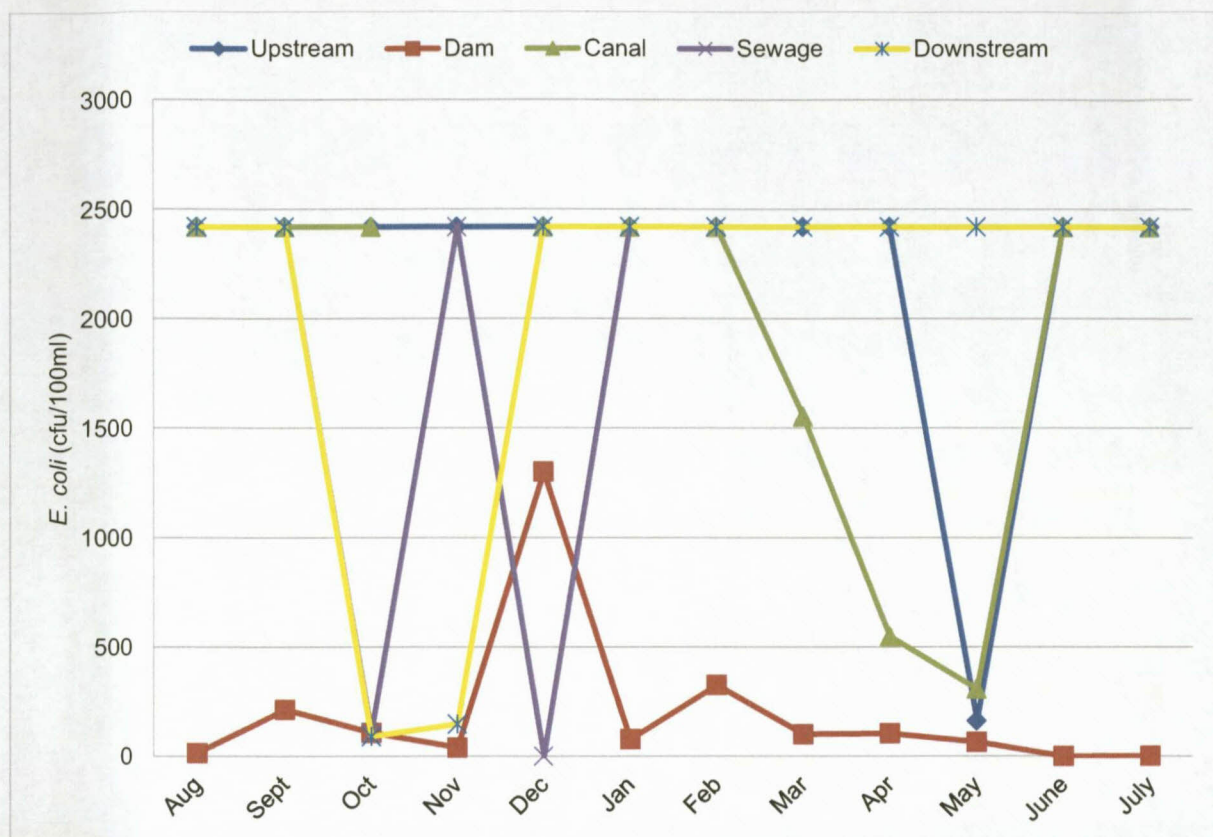


Figure 5.18: The *E. coli* counts in Sepanespruit water throughout the study period

5.4.2. Faecal coliform bacteria

The general pattern was that all other sampling sites contained high faecal coliforms but the dam water was relatively less polluted. The average faecal coliform counts along Sepanespruit were 1704 cfu/100ml. There were a few instances in which the faecal coliform counts did not exceed the maximum countable value of 2419 cfu/100ml. Very low faecal coliform counts were recorded during October (24 cfu/100ml) and December 2011 (1 cfu/100ml) for the sewage effluent. The canal water also had episodes of low faecal coliform counts during March 2012 (1733 cfu/100ml), during April 2012 (866 cfu/100ml) and during May 2012 the recorded count was 345 cfu/100ml. It was only during May at the upstream site that a low faecal coliform count of 345 cfu/100ml was recorded. At the downstream site, during October 2011 faecal coliform count value was 99 cfu/100ml. During November 2011, low faecal coliform counts (228 cfu/100ml) were recorded at the downstream site. A further low faecal coliform count (345 cfu/100ml) was recorded during June 2012 at the downstream site. For the rest of the months at the upstream site, canal site, sewage effluent and downstream site, maximum countable values (2419 cfu/100ml) for bacteria coliforms were recorded. The dam water generally contained low faecal coliform counts that were below 1000 cfu/100ml. However, during September and

December 2011, high faecal coliform counts of 2419 cfu/100ml and 1986 cfu/100ml respectively were observed. Figure 5.16 shows the variation of faecal coliform counts in Sepanespruit over a period from August 2011 to July 2012.

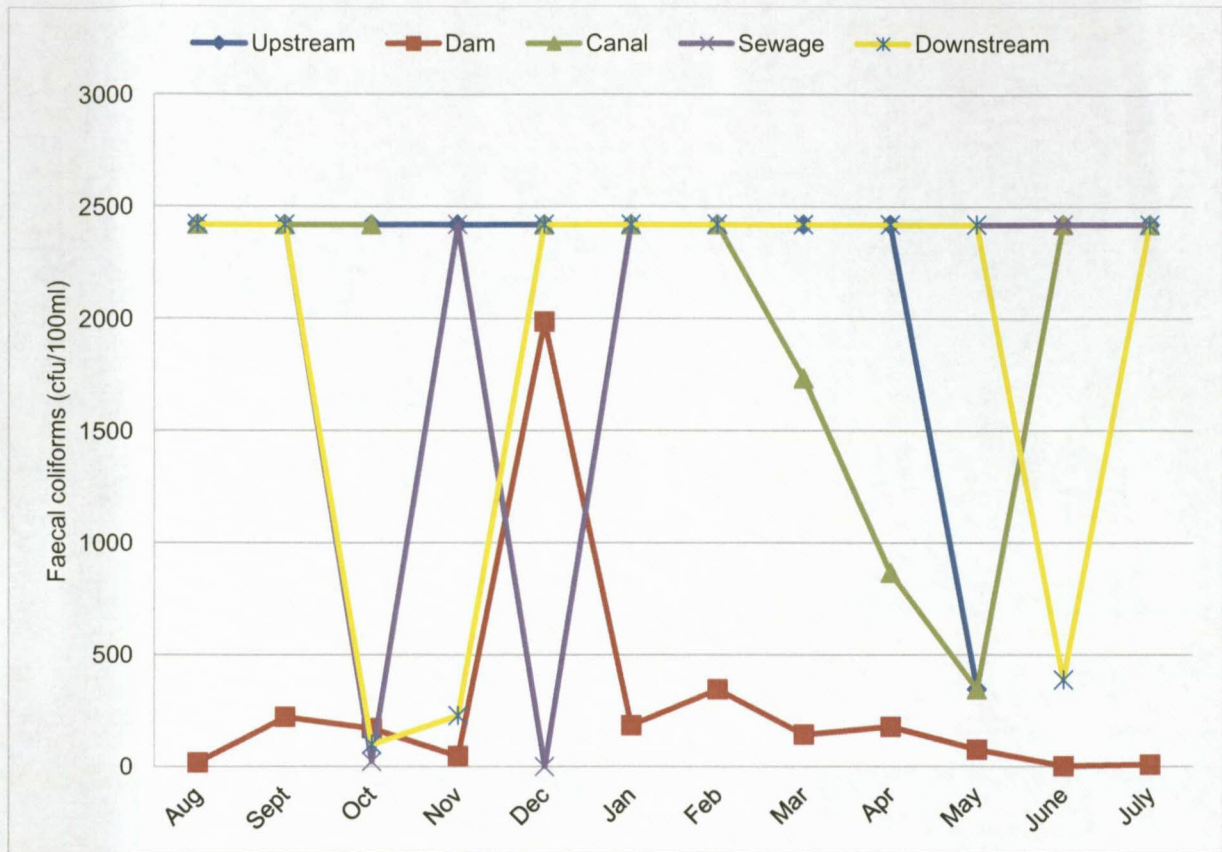


Figure 5.19: The faecal coliform counts of water at all sampling points along Sepanespruit for a 12-months period

5.4.3. Total coliform counts

During December 2011, the lowest total coliform count throughout the study period was recorded as 4 cfu/100ml (the sewage effluent). During October, low total coliform bacteria count of 108 cfu/100ml was recorded for the sewage effluent, while the downstream water contained 91 cfu/100ml during the same period. The canal water contained 649 cfu/100ml total coliform counts during April 2012. Excluding the exceptional cases named above, the sewage effluent, canal water, upstream and downstream water contained high total coliform counts, recorded as the maximum countable value of 2419 cfu/100ml throughout the study period. On the contrary, the dam water contained low total coliform counts (lower than 1000 cfu/100ml) except during December 2011, January, February and May 2012. Figure 5.20 shows the concentrations of total coliform counts in Sepanespruit water over a 12-months period

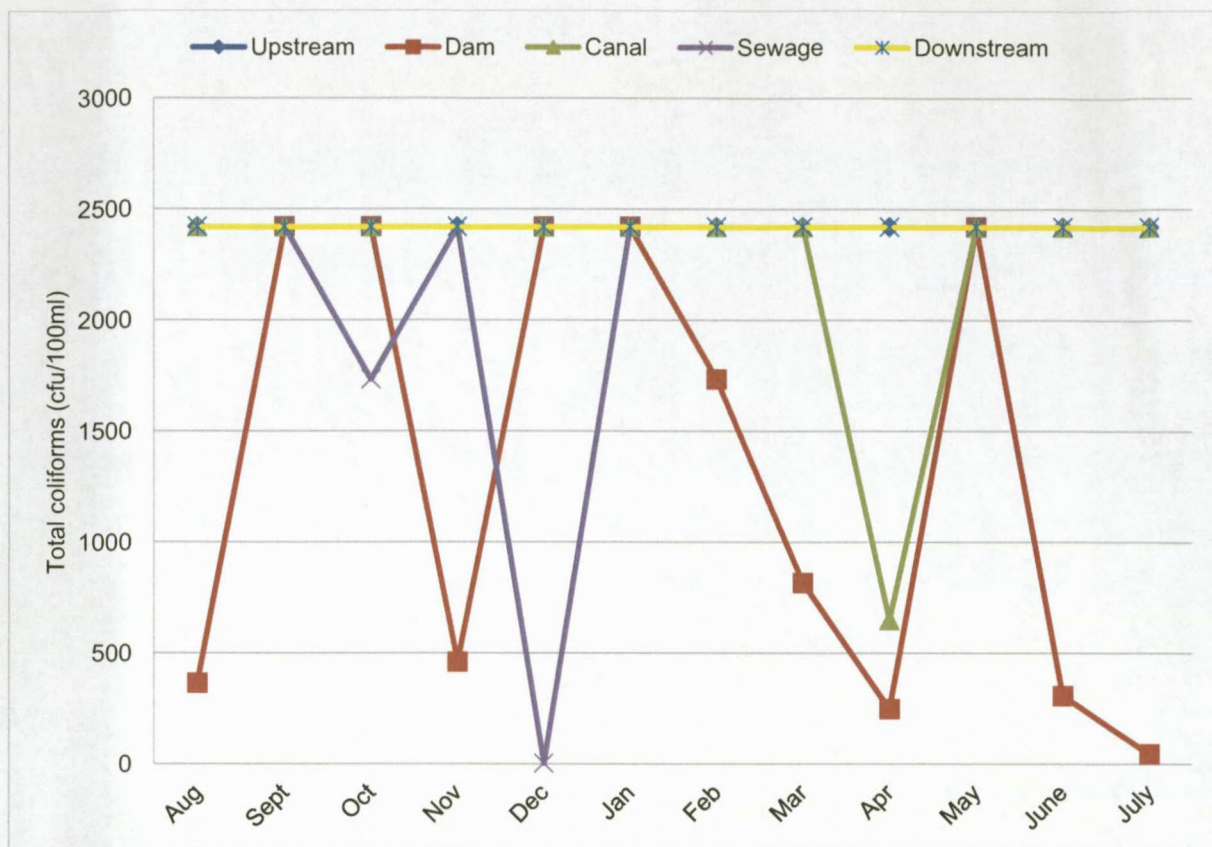


Figure 5.20: Total coliform counts in Sepanespruit water from August 2011 to July 2012

5.4.4. Sources of faecal pollution

Warm, shallow waters that contain high concentrations of organic carbon encourage the growth and re-growth of faecal coliform bacteria. Coyne and Howell (1994) undertook a study in which they investigated the ratio of faecal coliform to faecal streptococci ratio and water quality in the Bluegrain region of Kentucky. It was from this study that they concluded that the presence of organic carbon in water promotes growth of faecal coliform bacteria. Stewart and Skousen (2000) did a study in West Virginia in which they followed changes in water quality in an acid mine drainage stream over a period of 25 years. They also reported that the higher the quantities of carbon in water, the higher the resulting bacterial coliform counts. However, it was difficult to observe if there was any correlation between carbon concentrations in water and faecal coliform counts during this study because a maximum count of 2419 cfu/100ml was done for all bacterial counts. Total coliform, faecal coliform, and *E. coli* counts were made up to a maximum count of 2419 cfu/100ml. As a result of bacterial count limitations it was difficult to observe seasonal trends of microbial pollution in all sampling points but the dam. If water samples were diluted before bacterial counts were made, more precise results of the total number of coliforms could have been found. If for example, ten times (10x) dilutions were made, then the total coliforms that would be counted (perhaps 2419 cfu/100ml), would be multiplied by

10 in which the counts would be 24 190 cfu/100ml. The fact that the water samples were not diluted limited the extent of precision and accuracy of these results.

Factors such as sunlight intensity, length of day time, water temperature and salinity may influence the populations of faecal coliform counts (Davies and Day, 1998). During summer months, higher temperatures facilitate survival of faecal bacteria outside their host (Stewart and Skousen, 2000). A pattern that related to this observation was recorded at the dam during the study period. During winter months, lower faecal coliform counts were recorded. The summer season of the year 2011/2012 was characterised by low rainfall. The expected trend of stream water dilution during rainy seasons was limited; stream water was highly concentrated with microbial pollutants. That phenomenon may further account for the observed high coliform counts in Sepanespruit water. However, it is relevant to discuss that during rainy seasons, microbial pollution can still be high. Some bacteria get adsorbed onto sediment particles so a disturbance that rain water causes, help to redistribute bacteria back into the water column (Allan, 1995). Water samples that may be drawn during rainy seasons may also contain high bacteria counts.

Maseka and Ntengwa (2010) undertook a study in which they investigated the effects of effluents that contained zinc and nickel metals on streams and river water bodies. They made an interesting suggestion that domestic animals cause pollution in stream and river water systems that are accessible to them. They swim and drink from such water bodies. High concentrations of faecal pollution along Sepanespruit may therefore be partially attributed to domestic animals' activities including their faecal matter. Domestic animals that were noted along and in the stream were cattle, sheep, dogs and cats; parts of the stream that were investigated in this study flowed close to residential areas.

Maseka and Ntengwa (2010) further suggested that wild animals (in areas where they are present) are highly specific on the quality of water they drink. A similar suggestion can be made in the case of this study area. On personal communication with shepherds and local residents, there were some wild animals in the Selosesha and Thaba-Nchu area. The most commonly seen were reportedly wild cats, polecats and hares. These wild animals were reportedly spotted drinking water in the further downstream parts of Sepanespruit. However, it cannot be conclusively reported that this behavioural pattern was a result of better water quality preference. It could be a result of other factors such as a preference for less populated and quiet areas; in which case the downstream area would be a perfect spot. On the other hand, it could still be that wild animals visited the stream during the night time; when people could not see them. However a detailed investigation in this matter was not done during the study period.

5.4.5. Spatial bacterial counts in Sepanespruit

During some periods within this study period, the sewage effluent was not disinfected before it was released into Sepanespruit because the chlorine-dispensing equipment was not functional. On different occasions, the chlorine had not been replenished on time. During February, April and June 2012, the sewage effluent was released without prior disinfection. It can be simulated that extremely high concentrations of total coliform bacteria, faecal coliforms and *E. coli* were released during these months but it could not be expressed because the counts were limited to a maximum of 2419 cfu/100ml.

During October and December 2011, the period of sampling occurred just a few hours after the time in which the sewage effluent had just been disinfected. The recorded low concentrations of total coliforms, faecal bacteria and *E. coli* can be attributed to that coincidence. However, during December, extremely low concentrations of total coliform bacteria (4 cfu/100ml), faecal coliforms (1 cfu/100ml) and *E. coli* (1 cfu/100ml) were recorded at the sewage effluent. This trend can be ascribed to the fact that sampling was done too close to the time of disinfection. The quantities of chlorine that were added to the effluent were the same regardless of the flow volumes of the sewage effluent. December 2012 was one of the cases in which more than sufficient quantities of chlorine were added to the effluent. This incident demonstrates the drawbacks that incompetent and ill-skilled operators pose to total compliance of the treatment plant to effluent quality standards as set by the DWA. This incompetence of operational staff may have far-reaching impacts; the negative effects of over-chlorinated sewage effluents to the biota of the receiving stream cannot be ignored. There is a serious shortage in the capacity of sewage treatment plants' operational staff in South Africa. The Department of Water Affairs and Forestry (2007) reported that the need for trained, competent, qualified and experienced process controllers and mechanical/electrical maintenance staff is extremely critical. In order to ensure effective sewage treatment in South Africa, this need should be responded to with urgency.

From a national survey that DWAF had mandated WRC to institute, it was reported that 30 % of the plants needed immediate intervention otherwise they were environmental and health hazards. A further 66 % of the surveyed sewage treatment plants needed short to medium term intervention. Only about 4 % of the sampled sewage treatment plants could be termed adequately operated and maintained if 95 percentile compliance was executed as required by DWAF (DWAF, 2007).

The canal site contained slow-flowing, shallow water that contained raw sewage matter which in turn contained high concentrations of organic carbon. The concentrations of nutrients and bacterial counts in the canal water were dependent on the amount of carelessly disposed sewage on the source manhole. During September, October, December 2011 and July 2012,

the timing of sampling in the canal was coincidental with the time of sewage disposal at the source manhole. During those sampling periods, the canal water was characterised by high concentrations of COD, NH₃, EC and SS concentrations. It was simulated that the concentrations of total coliform bacteria, faecal coliform bacteria and *E. coli* were higher than the recorded 2419 cfu/100ml count.

During October 2011, the canal was dry; there were not any results therefore. During March, April and May 2012, faecal coliform bacteria counts and *E. coli* counts were lower than the maximum counted number of 2419 cfu/100ml. It was only during April that a total coliform count (649 cfu/100ml) was recorded. This observation could be a result of a chance occurrence in which there was a water flow with less counts of faecal bacteria. Low concentrations of EC, NH₃, SS were also observed during those months and extending to June 2012. This meant that during those times, the canal water was not as contaminated as during the rest of the study.

The upstream site contained low concentrations of faecal coliform bacteria and *E. coli* during May 2012. This could be attributed to a chance occurrence in which there was a dilution of the stream water by urban run-off perhaps. The impacts from the canal water and the sewage effluent were expressed in the downstream water. During October 2011 when excessive amounts of chlorine had been added to disinfect the sewage effluent, low faecal bacteria counts (99 cfu/100ml) and low total bacteria counts (91 cfu/100ml) were recorded. It was however astonishing to record high counts for *E. coli* during the same period (2419 cfu/100ml) at the downstream site. *E. coli* are bacteria that live in the intestines or colons of humans and animals and their counts in water quality studies indicate the extent of faecal pollution (Cunningham and Cunningham, 2008).

During November, low counts of faecal coliforms (228 cfu/100ml) and *E. coli* (148 cfu/100ml) were observed at the downstream site. It was possible that a few days before the time of sampling, excessive chlorine had been added to the sewage effluent in which case the impacts were expressed as low faecal bacteria counts at the downstream site. It was anticipated that low faecal coliform counts would be observed in the downstream water during December since the sewage effluent was overdosed with chlorine. The recorded total bacteria, faecal bacteria and *E. coli* counts were high (2419 cfu/100ml) in the downstream water. This observation can be ascribed to that at the time of downstream sampling; the highly disinfected sewage effluent had not reached the downstream site. The flow velocity of water could have been slowed down by the wetland purification processes as explained by DWA (2010). During June at the downstream site, low faecal coliform counts (345 cfu/100ml) were recorded. At the same time, high total coliform counts (2419 cfu/100ml) and *E. coli* counts were recorded. The low faecal coliform could be a result of chlorine overdose perhaps a few days before the time of sampling

or a result of cold June temperatures which suppress growth, development and reproduction of bacteria.

5.4.6. Seasonal variations in bacteria counts of water in Sepanespruit

The survival of total and faecal bacteria coliforms is dependent on the season of the year; during summer period when there are long periods and high intensity of sunlight, bacteria thrive optimally (Horne and Goldman, 1994). Stewart and Skousen (2000) suggested that during cold periods of the year when the water temperatures are low, the rates of faecal bacteria reproduction, growth and development become slowed down. Seasonal variations in total bacteria coliforms, bacteria coliforms and *E. coli* are clearly expressed at the dam. During winter and autumn months, low bacteria counts were observed as shown in Figures 5.17, 5.18 and 5.19. It was interesting to note that the average bacteria counts of the sewage effluent during summer were lower than the maximum countable value of 2419 cfu/100ml. This trend can be attributed to the relatively low sewage effluent temperatures during summer as a result of receiving cool sewage stream. Summer temperatures of the sewage effluent were generally 0.5 - 3 °C lower than water at the other sampling sites.

Table 5.17: The average seasonal averages of *E. coli* counts in water at 5 sampling sites along Sepanespruit from August 2011 to July 2012

<i>E. coli</i> (cfu/100ml)				
Sampling sites	Summer average	Spring average	Winter average	Autumn average
Upstream	2419	2419	1855	2419
Dam	326	214	21	105
Canal	2246	2419	1891	548
Sewage	1630	2419	2419	2419
Downstream	1652	2419	2419	2419

Table 5.18: The seasonal average faecal coliform counts in different sampling points along Sepanespruit from August 2011 to July 2012

Faecal coliform counts (cfu/100ml)				
Sampling points	Summer average	Spring average	Winter average	Autumn average
Upstream	2419	2419	1900	2419
Dam	480	222	28	179
Canal	2282	2419	1900	866
Sewage	1617	2419	2419	2419
Downstream	1667	2419	1911	2419

Table 5.19: The average seasonal total coliform counts of water in Sepanespruit from August 2011 to July 2012

Total coliforms (cfu/100ml)				
Seasons	Summer average	Spring average	Winter average	Autumn average
Upstream	2419	2419	2419	2419
Dam	1711	2419	785	248
Canal	2419	2419	2419	649
Sewage	1902	2419	2419	2419
Downstream	2419	2419	2419	2419

5.4.7. Effects of microbial pollution

The concentrations of faecal coliforms are usually in excess of 1 000 000 cfu/100ml in raw sewage. In deep unpolluted underground waters, faecal coliforms may be zero. In pristine surface waters, faecal coliform counts of 1 – 10 cfu/100 ml are common. Polluted water may contain anything between 10 – 10 000 cfu/100 ml depending on the degree of contamination (DWAF, 1996d). For water that is used for in-contact recreational purposes such as swimming, *E. coli* counts of 400cfu/100 ml pose a health risk. Faecal coliform counts in concentrations greater than 2000 cfu/ 100ml pose serious health threats (DWAF, 2001).

Faecal coliforms and faecal streptococci are non-pathogenic but their presence indicates the potential presence of water pathogens (Dallas and Day, 2004). In this study, the concentration of *E. coli* positively correlated with the concentrations of faecal coliform counts.

5.4.8. Water pathogens

The pathogens that have been identified in all the sampling sites were *E. coli*, *Shigella dysenteriae*, *Faecal enterococcus*, and *Faecal streptococcus*. It was only in the dam water that the counts for *E. coli* were lower than 1000 cfu/100ml, otherwise *E. coli* occurred in high concentrations in all sampling sites. *Shigella dysenteriae* was the second most common water pathogen and it occurred predominantly in the influent stream and canal water. *Faecal enterococcus* occurred in concentrations lower than 1000 cfu/100ml but its counts were significantly high in the sludge reaching just below 2000 cfu/100ml. *Faecal streptococci* occurred in concentrations lower than 200 cfu/100ml in all sampling sites but the influent stream contained relatively high bacteria counts (1000 cfu/100ml). *Staphylococcus aureus*, *Salmonella typhi* and *Salmonella enteritis* occurred in trace amounts whose counts were lower than 50 cfu/100ml. The other water micro-organisms that were investigated but did not occur in all of the sampling sites were: *Vibrio cholera*, *Entamoeba*, *Aeromonas*, *Klebsiella pneumonia* and *Listeria monocytogenesis*. Figure 5.21 shows the relative counts of different water pathogens in Sepanespruit during August 2012. The figures have been exerted to Logarithm scale in order to allow pathogens whose counts were low to also appear on the graph.

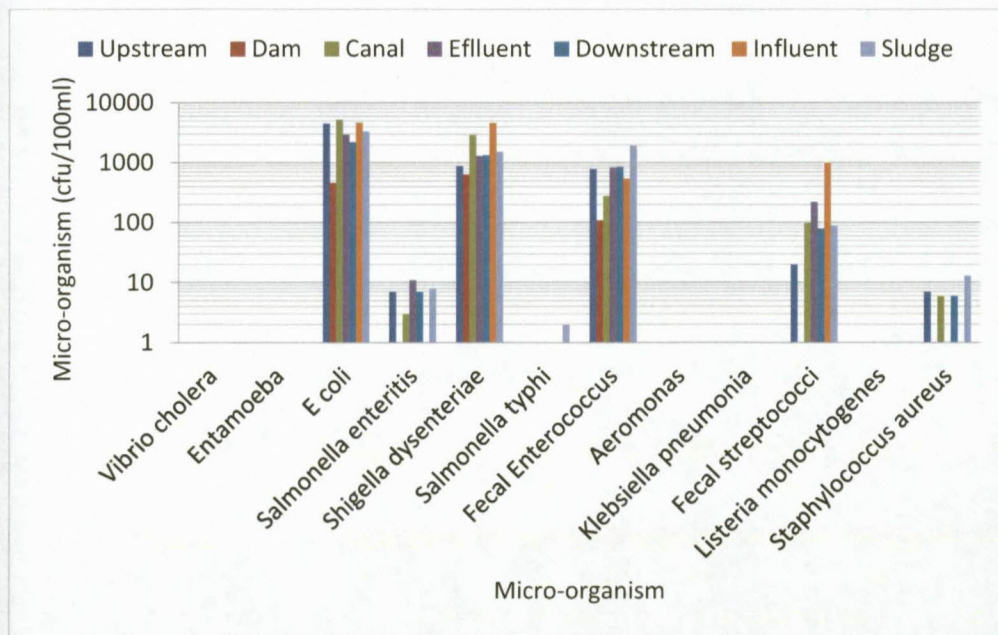


Figure 5.21: The microorganisms that were identified in Sepanespruit water in August 2012

The principal *Enterobacteriaceae* genera are *Escherichia*, *Klebsiella*, and *Enterobacter*. *Klebsiella* occur in most individuals but in low quantities. *Enterobacter* only occur in a small number of humans (Cabral *et al.*, 2010). Some pathogenic micro-organisms that are present in environmental waters which are indicative of pollution if found in high quantities (usually a few hundred cells per 100ml of sample) are *Aeromonas*, *Listeria*, *Shigella* and *Salmonella* (Fewtrell *et al.*, 1994)

Sewage effluents contain high quantities of diverse human pathogens. The bio-degradation products of some pathogens are potential contaminants to water resources and they have high chemical oxygen demands (Said *et al.*, 2003). All of the observed micro-organisms were of faecal origin which suggested that microbial pollution in Sepanespruit water could be associated with human and animal faecal matter. *E. coli* and *Shigella dysenteriae* occurred predominantly along Sepanespruit. Cabral *et al.* (2010) reported that *Shigella* was formed from *E. coli* during evolution. These micro-organisms occur within the human and animal intestinal tracts and outside of their host, they thrive under similar conditions. This explains why both *E. coli* and *Shigella dysenteriae* were recorded in high concentrations in all sampling sites but the dam.

Salmonella is a pathogenic micro-organism that is usually brought into water bodies with sewage effluents and storm water run-off. *Salmonella* usually causes infections in humans and animals through ingestion of crops that were irrigated with contaminated water or were fertilised with contaminated sludge. Both *Salmonella typhi* and *Salmonella enteritidis* occurred in quantities lower than 50 cfu/100ml in Sepanespruit. The water cannot conclusively be deemed safe to use for irrigation of crop plants since the analysis was done once. However, during that time, the water was good to be used; it could not confer typhoid and enteritis to crop consumers.

The prevalence of *faecal enterococci* and *faecal streptococci* in water is dependent on their origin; whether they are of human or animal faecal matter (WHO, 1979). These micro-organisms are usually used as indices of faecal pollution in recreational water (DWAf, 1996b).

The concentrations of micro-organisms in the influent were expected to be higher than in any sampling site. The anticipated results were only observed with *Shigella dysenteriae* and *Feacal streptococcus*. The results for *Feacal enterococci* indicated that the counts in the influent were lower than in the sewage effluent and the sludge. This could mean that there was temporal accumulation of these bacteria within sewage treatment stages and within the sludge column. This perhaps indicated that the sewage treatment processes were ineffective in eradicating these bacteria. It was however difficult to conclusively suggest that the sewage treatment facility was incompetent and ineffective in removing *Feacal enterococci* because the analysis was done just once.

The canal water contained high concentrations of *Shigella dysenteriae* and *E. coli* which was accounted for by the raw sewage that flowed in that channel of wastewater (referred to in this study as the canal). The *E. coli* concentration in the canal water was higher than in the sewage influent. This observation could be attributed to the fact that the influent sample was collected after grit removal and screening. Those processes could have reduced the concentration of *E. coli* relative to the untreated sewage that flowed in the canal.

5.4.9. Conclusions – water microbiology

The quality of water microbiology was determined by *E. coli*, faecal coliforms and total coliform counts. It was only at the dam that seasonal variations in microbial water quality were observed. For the other sampling sites, the counts reached the maximum number of counts that could be done. Water samples should have been diluted before counts were done in order to get more precise results. However, there were instances in which the maximum count of 2419 cfu/100ml was not reached. During October and December 2011 at the sewage treatment plant, the released effluent contained high concentrations of chlorine because the sampling period was just after disinfection; hence the associated low *E. coli*, faecal coliforms and total coliform counts. Due to incompetency of unskilled operational staff, the amount of chlorine added to the sewage effluent was usually more than sufficient. Knowledge about the quantity of chlorine that needed to be added to the effluent was lacking so a constant volume of chlorine was added to the effluent regardless of the volume of the effluent itself. During October though, sampling was done a few hours after the time of disinfection hence the bacterial counts were a little higher than the December counts. The chlorine overdose may have reached the downstream site at the time of sampling because the counts for faecal coliforms and total coliform bacteria were also low.

Total coliforms, faecal coliforms and *E. coli* counts at the dam displayed a seasonal variation in which the highest counts were observed during summer season and then spring and autumn. During winter low bacterial counts were observed. Bacteria grow and reproduce better during summer when there are sufficient quantities of sunlight (Allan, 1995).

The following pathogens were identified in water; *E. coli*, *Shigella dysenteriae*, *Faecal enterococcus*, and *Faecal streptococcus*. *Staphylococcus aureus*, *Salmonella typhi* and *Salmonella enteritis* occurred in counts of less than 50 cfu/100ml. *Vibrio cholera*, *Entamoeba*, *Aeromonas*, *Klebsiella pneumonia* and *Listeria monocytogenesis* were investigated but did not occur in Sepanespruit water.

5.5. PHYTOPLANKTON OF SEPANESPRUIT

The upstream and dam data sets have been plotted on the secondary graph which ranges from 0 - 200 µg/l because these sites were rich in chlorophyll a. On a general note, the content range of chlorophyll a in all sampling sites was 1 µg/l - 66 µg/l. High chlorophyll a occurrences were recorded during September 2011 in the upstream water (187 µg/l), in the dam water during November 2011 (93 µg/l) and during April 2012 at the sewage effluent (107 µg/l). The average chlorophyll a concentration of Sepanespruit water was 24.6 µg/l. At the downstream site, chlorophyll a was low; most of the times the recorded value was 1 µg/l except during August 2011 (21 µg/l), January 2012 (24 µg/l) and July 2012 (23 µg/l). Figure 5.22 shows that the

sewage effluent was low in chlorophyll *a* particularly in summer months. High occurrences of algae, forming a mat on water surface were noticed at the upstream site during summer months. The chlorophyll *a* analyses confirmed that high concentrations of algae occurred during summer months.

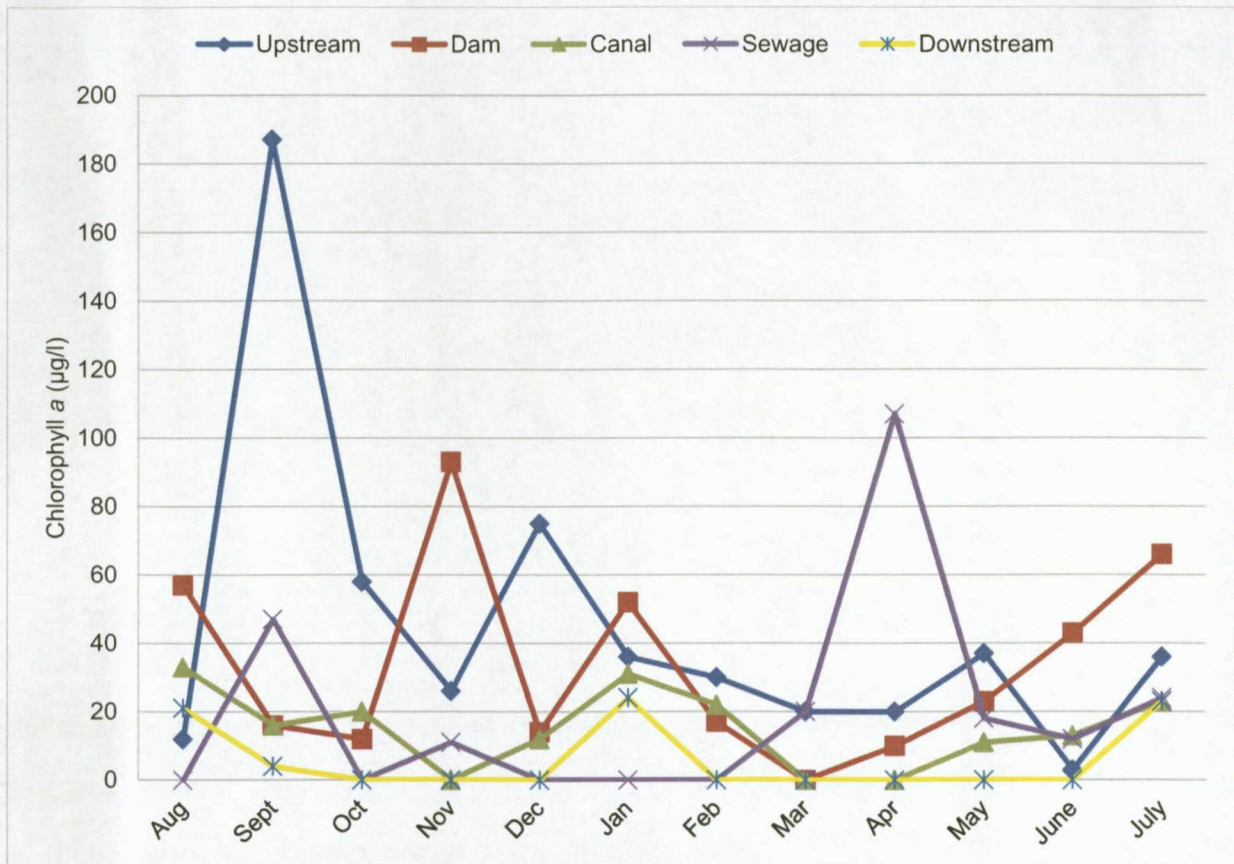


Figure 5.22: The concentrations of chlorophyll *a* of water at different sampling sites along Sepanespruit from August 2011 to July 2012

Horne and Goldman (1994) described phytoplankton as primary producers in water bodies. Phytoplankton ranges from small free floating algae to large stands of algal colonies. Wetzel (1983) reported that standing waters harbour more algae. The lotic environments do not contain much phytoplankton because of a continual water movement.

The occurrence of lakes or dams along the length of a river results in marked increases in phytoplankton abundances (Allan, 1995). The same reasoning can be extrapolated to account for the remarkable abundance of phytoplankton at Seroale Dam that occurs along the length of Sepanespruit. The presence of ponds, lakes, dams and impoundments play a vital role in breeding phytoplankton that may later flow in the river system. Seeding of phytoplankton is less favourable in moving water because of continuous movement, consumption and filtering effects of macrophytes when present. Rief (1939) in Allan (1995) indicated that the species composition of river plankton is to some extent influenced by differential settling and trapping. It

is however important to understand that it is the circumstances that allow reproductive increase of plankton population that determine overall abundance. Table 5.20 shows seasonal variations of chlorophyll *a* in water at different sampling sites.

Table 5.20: The minimum, maximum and average concentrations of chlorophyll *a* in all sampling sites along Sepanespruit from August 2011 to July 2012

Chlorophyll <i>a</i> in ($\mu\text{g/l}$)			
Seasons	minimum	maximum	average
Summer	1.0	93.0	20.1
Spring	1.0	187.0	19.0
Winter	4.0	66.0	22.9
Autumn	1.0	107.0	27.8

During summer months at the upstream site, high chlorophyll *a* concentrations can be associated with high NH_3 concentrations in water; 6.369 mg/l in September, 12.78 mg/l in November and 6.25 mg/l in December. The upstream water concentrations of PO_4^{3-} during November and December were 4.45 mg/l and 6.49 mg/l respectively. These nutrients (NH_3 and PO_4^{3-}) encouraged growth of high chlorophyll *a* concentrations during summer.

Koning (1998) suggested that low winter temperatures (10 - 15 °C) could be the limiting factor for algal growth regardless of high light availability and low turbidity. The minimum recorded winter temperature was 7.5 °C and the chlorophyll *a* was 4 $\mu\text{g/l}$. The highest chlorophyll *a* concentration that was recorded during winter was 66 $\mu\text{g/l}$ and the corresponding temperature was 17.9 °C, in which case temperature was probably not the limiting factor.

High water flow in streams and rivers is associated with low Chlorophyll *a* concentrations (Hynes, 1970). This phenomenon can be attributed to wash-out, dilution and high turbidity. The river environment is in a continuous state of motion and does not experience periods of stability as do lakes (Descy *et al.*, 1993). At the downstream site, chlorophyll *a* was low probably because of the relatively high water flow which did not allow for enough underwater attenuation to support algal growth. The sandy, turbid water which was sometimes colored red-brown by the dye that was released with the sewage effluent, might have contributed to less algal growth by scattering light and thereby allowing little light penetration into the water body. The most commonly recorded chlorophyll *a* concentration at the downstream site was 1 $\mu\text{g/l}$. Koning (1998) recorded that the water flow rates in both the Modder and Klein Modder Rivers were high and so little chlorophyll *a* concentrations were found.

However during August 2011, a high value of 21 µg/l was recorded at the downstream site. This was the time when the power was cut at the sewage treatment plant and the released effluent quality was poor. The nutrient-rich sewage effluent that was released into the stream was evidenced by high algal growth in the water downstream.

On the contrary though, Grobler and Davies (1981) indicated that in turbid, high-flowing rivers, it does occur that high concentrations of chlorophyll *a* are obtained. The sediments which are suspended in the turbid water column may act as direct sources of phosphorus to algae. This could explain the episodes in which high chlorophyll *a* concentrations of (24 µg/l) and (23 µg/l) were observed at the downstream site during January and July 2012 consecutively.

The most basic requirements for growth of algae are temperature, light, organic and inorganic nutrients (Horne and Goldman, 1994). In a lotic environment, water flow rates also regulate the temporal and spatial growth of algae. Dokulil (1994) suggested that river disrupting instances such as flood episodes affect the composition and biomass of phytoplankton. Hynes (1970) illustrated that some algal species require current to grow optimally.

Hynes (1970) further indicated that different algal genera have varying light intensity preferences. Chlorophyta require fairly large intensities of light in order to thrive well. In turbid systems, underwater light attenuation is dependent on the concentrations of suspended solids and the particle size thereof.

It is a difficult to divorce the effects of temperature on algal growth from those of light. Much algal respiration occurs in shallow waters due to higher water temperatures. A temperature increment of 5 °C can produce an intense growth of green algae when the community, light, flow, nutrients and grazers are kept constant (Cummins, 1974).

The optimum nutrient ratio and the nutrient loading concept are terms that define the intimate interactions between nutrients' dynamics and algal growth. The optimum nutrient ratio is the ratio at which one nutrient becomes a limiting growth factor relative to another one. Nitrogen and phosphorus are the major nutrients for most algal growth. Different algal species have varying preferences on the forms of N and P. Hynes (1970) indicated that algal growth increases at points within the river system where there are more nitrates (NO₃⁻) and phosphates (PO₄-P). Koning (1998) made a similar observation in the Modder River. Wetzel (1983) indicated that the limiting concentration of inorganic phosphates in water for algal growth is less than 3 µg (Phosphorus)/l.

The nutrient loading concept suggests that a relationship exists between the amount of nutrients that a water body receives and its trophic status. This concept models that the concentration of chlorophyll *a* in a water body can be calculated from the amount of phosphorus

that it receives. Particular caution must be taken when executing this concept because the chemistry of phosphorus in water is very dynamic.

The sewage effluent water was high in nutrients especially in summer but the chlorophyll a concentration was low. This could be attributed to high concentrations of chlorine in the sewage effluent; chlorine is toxic to living organisms (Davies and Day, 1998). On the other hand, it could be as a result of a short residence time of the sewage effluent and continual disturbances caused by sewage treatment processes such as constant motor rotations, the algal development was limited.

5.5.5. Algal division

Water samples were analysed to identify and quantify the following common fresh-water algal divisions: Chlorophyta, Bacillariophyta, Cyanophyta, Euglenophyta, Chryptophyta, Dinophyta and Crysophyta. The results indicated that Chryptophyta, Dinophyta and Crysophyta did not occur in any of the sampling sites. On the contrary, Chlorophyta occurred in all of the sampling sites. Figure 5.23 shows the percentage concentrations of algal divisions within different sampling sites.

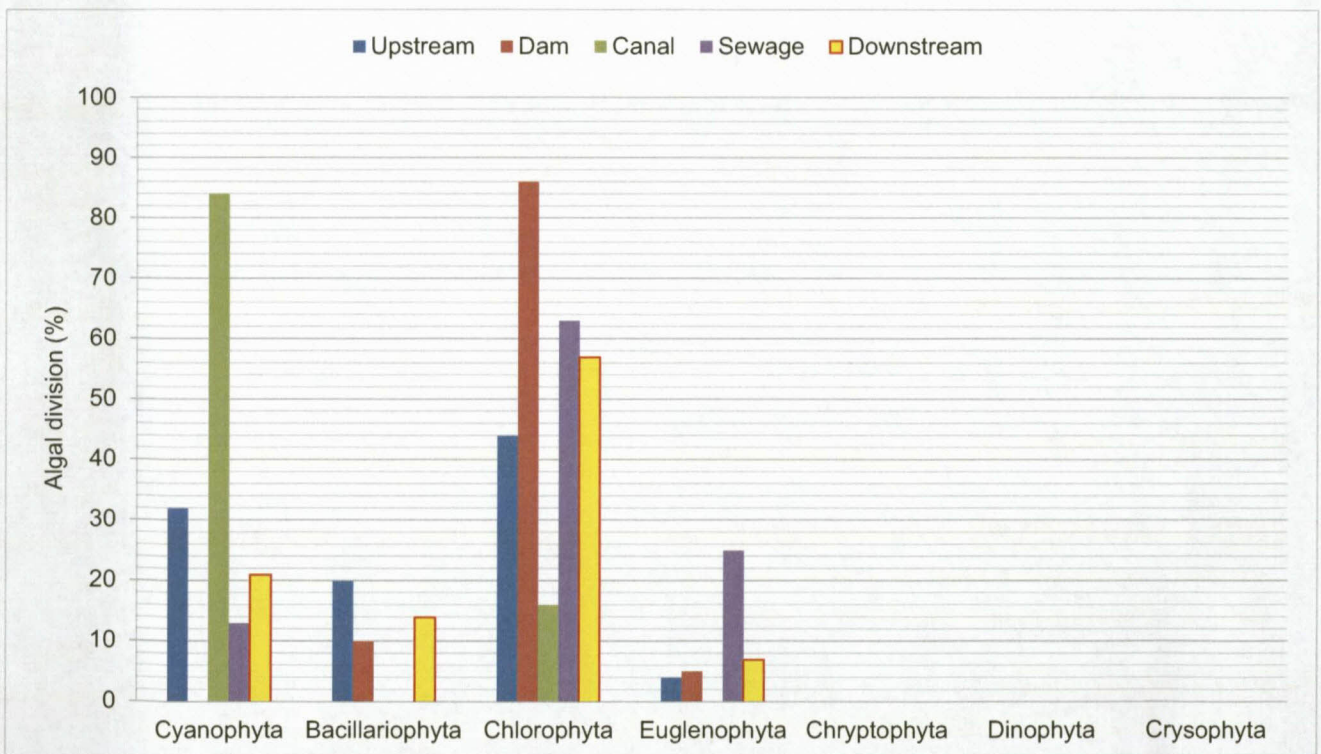


Figure 5.23: The algal assemblages in Sepanespruit at all sampling sites in June 2012

The following are the algal divisions (and the representative algal genera) were identified in Sepanespruit. The characteristics that Horne and Goldman (1994) and Canter-Lund and Lund (1995) used to identify and describe these divisions are as follows:

Bacillariophyta are golden brown diatoms which may be filamentous or unicellular.

Chlorophyta are green algae. They can be microscopic or macroscopic, filaments, colonies, or cells. Some are flagellated.

Cyanophyta (blue-green algae also known as cyanobacteria). They can be microscopic or macroscopic. They usually occur as filaments but there can be single cells or colonies.

Chrysophyta are yellow or brown-green in colour. They are microscopic filaments or colonies. Some are flagellated.

Cryptophyta (cryptomonads) occur in a variety of colours. They are microscopic, flagellated single cells.

Dinophyta are red-brown dinoflagellates. They are microscopic, flagellated single cells or chains. They have cellulose cell-walls (when they have cell-walls).

Euglenophyta occur in various colours, they are microscopic, flagellated single cells. *Euglena* sp. is common in water that is rich in organic matter. This species occurs in water that is low in dissolved oxygen. It is indicative of fresh water pollution. Bernhart and Clasen (1991) reported that *Euglena* sp. were usually isolated in portable water that was produced by Rand Water. These algae are different from inorganic suspended particles in that they change their shape and are mobile by means of flagella. This makes them difficult to remove by the coagulation-sedimentation process of potable water treatment. The presence of *Euglena* sp. in water makes it difficult to effectively treat such water before use.

The chrysophyta, cryptophyta and dinophyta did not occur in Sepanespruit water at the time of this analysis. The changes in trophic status, together with the levels and diversity of algal species are some parameters that are used to assess the effects of inorganic nutrients on aquatic ecosystems. The amount of light that penetrates the water, water temperature and the concentration of available nutrients determine the concentrations and diversity of algal species in water.

The phytoplankton of lotic systems is usually dominated by diatoms in spring and autumn (Descy *et al.*, 1993). Allan (1995) also suggested that diatoms, especially centric diatoms are dominant river phytoplankton however he differed with Descy on the seasons of enormous abundances. Allan (1995) reported summer and spring as seasons of greatest diatom dominance. At this point, it is important to consider that algal diversity and seasonal patterns vary from one ecosystem to the next; geographical locations and climatic conditions might have played a role in this case.

Green algae and cryptomonads may flourish optimally during summer months. During periods of low discharges, succession that leads to dominance of cyanobacteria occurs (Descy *et al.*, 1993). Koning (1998) recorded the occurrence of pinnate and centric diatoms (Bacillariophyceae) during all seasons of the year in the Modder and Klein Modder Rivers. Vos (2002) observed that green algae (Chlorophyta) occurred in large numbers in Loch Logan water throughout the year. She also indicated that *Chlorella*, *Chlamydomonas*, *Chlorococcum* and *Oocystis* also occurred throughout the year. Euglenophyta were also present throughout the year in Loch Logan. Vos (2002) found that Cyanophyta rarely occurred during the winter in Loch Logan, but they were observed in Sepanespruit during June 2012 when this analysis was done.

Leupold (1988) assigned values to algal genera in order to indicate the extent of pollution in a water sample in which algae occur: algal genera pollution index score. According to this index score, the following genera score as follows: *Euglena* – 5, *Chlamydomonas* – 4, *Nitzschia* and *Navicula* – 3 and *Phacus* – 2.

During dry seasons of the year, there was a decrease in water turbidity which allows more light to penetrate the water column and thus encourage photosynthesis. This is why summer months were favoured by the growth of more phytoplankton.

The dam water contained the highest concentrations of phytoplankton since phytoplankton seeding, growth and development occurs better in standing water (Descy *et al.*, 1993). Chlorophyta, Bacillariophyta, Cyanophyta, Euglenophyta, Chryptophyta, Dinophyta and Crysophyta were noted at different areas within the stream. Chlorophyta and Cyanophyta occurred in all sampling sites with high concentrations. The algal divisions: chrysophyta, cryptophyta and dinophyta did not occur in Sepanespruit water at the time of this analysis.

5.6. BIOFILTRATION

The use of bioswales, phytofiltration (vegetation filter buffers) and constructed wetlands is a feasible means of wastewater polishing (after conventional wastewater treatment) (Jurries, 2003). These methods become most effective when the soils have been prepared to function optimally in the bio-filtration process. The soils must not be compacted to promote good root development of the overlying vegetation. The Cation Exchange Capacity (CEC) and Anion Exchange capacity (AEC) of the soils must be considered, pH, EC, and organic matter. For a bio-filter that is designed to remove positively charged ions as pollutants such as Copper (Cu), Cadmium (Cd), Iron (Fe), Manganese (Mn), Aluminium (Al) and Mercury (Hg) the soil should be negatively charged. The recommended CEC is a minimum of 15 meq/100mg of soil (Jurries, 2003).

It is imperative to carefully consider conditions that would have to be maintained to effectively remove pollutants using vegetation, soils and biological organisms (Jurries, 2003). The

retention of heavy metals in a bio-filter is influenced by the pH of the soil. The optimal pH for the bio-filtration process is between 6.5 and 8.5 for effective results (Jurries, 2003). The EC influences the ability of vegetation and microbial food chain to process pollutants and nutrients. An EC of about 4 micromho/cm is less appropriate for good plant and biota growth. Biofiltration processes are regulated by micro-organisms; they convert, stabilise and convert organic carbon and other nutrients (Jurries, 2003).

The capacity of *Typha capensis* to remove phosphorus from wastewater is in the order of 80%. Cattails are good for removing pollutants from storm-water but are invasive and tend to take over the area. They have a dominant cycle that extends for a year or more (Jurries, 2003).

Many particles that are suspended and dissolved in storm water are positively charged. There is a positive charge at the base of the vegetation in a bio-filter that attracts and settles these negatively charged particles and causes them to settle out. Soil filters out pollutants that flow through the soil subsurface. The vegetation consumes pollutants and absorbs them into their plant matter (Jurries, 2003).

Native plant species are an appropriate option (over exotic plant species) for bio-filtration functions. This is because they provide a year round vegetation cover without a need to supplement with irrigation or fertilisation. Native plant species also provide high habitat value to indigenous birds and other animals (Jurries, 2003).

Phragmites australis (common reed) is a widely distributed gramineaceous species. It occurs from tropical regions to latitudes higher than 70°. It is typical in low-lying wetlands (McKee and Richards, 1996). It is usually used in wastewater treatment because it tolerates environmental pollutants such as heavy metals which include lead and cadmium (Máthé *et al.*, 2000). The common reed occurred naturally along the length of Sepanespruit around the dam and in the stream between the upstream site and the dam. The near-oligotrophic water of the dam water can be ascribed to the bio-filtration processes that were carried out by the reeds before water flew into the dam.

Ramprasad (2012) undertook a study in which he experimentally studied the effectiveness of *Phragmites australis* for wastewater treatment. He concluded that the use of this common reed for sewage treatment was remarkably good in the reduction of the following water quality parameters: pH, BOD and COD. The reeds also fairly reduced the concentration of total soluble solids from wastewater.

Hares and Ward (1999) undertook a study in which they compared the heavy metal content of motorway storm water following discharge into wet bio-filtration and dry detention ponds along the London Orbital (M25) motorway. It was from this study that they commented the

effectiveness of *Typha capensis* in the process of particulate matter settling out, as part of wastewater treatment. They further reported the good removal efficiencies of heavy metals by *Typha capensis*. The specific heavy metals that were reduced from the sewage stream were: Manganese, Cobalt, Chromium, Copper, Zinc, Molybdenum, Cadmium and Lead.

5.7. VEGETATION CLASSIFICATION

The classification of vegetation along Sepanespruit (using TWINSpan) produced one plant community and two sub-communities. The *Paspalum dilatatum* community was associated with the stream margins, its flood plains and immediate catchment. The two plant sub-communities were the *Acacia karroo* sub-community and *Paspalum distichum* sub-community. The stream consisted of disturbed banks and nutrient-rich water which nourished the plant species it hosted.

1. *Paspalum dilatatum* – *Rumex crispus* community
 - 1.1 *Acacia karroo* sub-community
 - 1.1.1 *Sporobolus fimbriatus* variant
 - 1.1.2 *Sesbania punicia* variant
 - 1.2 *Paspalum distichum* sub-community
 - 1.2.1 *Pennisetum clandestinum* variant
 - 1.2.2 *Verbena bonariensis* variant
 - 1.2.3 *Cyperus longus* variant

The classified data is presented in the form of a phytosociological table (Table 5.21) at the back of this document.

1. *Paspalum dilatatum* – *Rumex crispus*

The member species of this community were: *Paspalum dilatatum*, *Rumex crispus*, *Ciclospermum leptophyllum* and *Panicum coloratum*. The most dominant member of this community was *Paspalum dilatatum* which is a tufted perennial grass with short rhizomes. This grass grows on sandy to clay soils but prefers fertile soils hence it was found on the disturbed banks of the dam and the downstream site. *Paspalum dilatatum* can tolerate overgrazing due its rhizomatal growth form (Moore and Wiley, 2006). At Seroale Dam, *Paspalum dilatatum* was noted on eroded banks on which local fishermen trampled in order to catch fish. On the same area, further anthropogenic disturbances were observed in the form of pools in which fish were held after being caught (pools encircled in yellow) on Figure 5.24. This community is composed of members that were present in different niches along Sepanespruit.



Figure 5.24: The eroded banks of Seroale Dam on which *Paspalum dilatatum* and the pools were observed

Rumex crispus is a perennial herb which can reach a height of 160 cm. Its stems have smooth surfaces and thick node areas. This herb has been shown to contain secondary metabolites that may play a role in the treatment of cancer (Duke, 2003). This herb occurs on disturbed areas at the edge of the roadside, riparian areas and agricultural lands. It prefers soils that contain high nitrogen and it can become invasive (Nkechinyere, 2007). *Rumex crispus* was also observed on the marginal zones on the upstream site of the stream. Clusters of this herb have been encircled in yellow on Figure 5.25.



Figure 5.25: An upstream site harbours the perennial herb (*Rumex crispus*) encircled in yellow. Note: the *Acacia karroo* is pointed with a red arrow while the *Sesbacia punicia* is pointed with a yellow arrow

Ciclospermum leptophyllum is a weed that is characteristic of disturbed areas. It is an erect terrestrial herb that can grow up to 50 cm in height. It has distinctively ovoid fruits that are dark brown in colour. It was found on the banks of the stream at the downstream site and upstream.

Panicum coloratum is a drought-tolerant tuft grass which is also palatable to livestock. It is a variable perennial which can grow up to 1m in height. It is palatable to cattle and makes good hay. It responds quite rapidly to nitrogen and prefers fertile soils hence it grew healthily along the canal. *Panicum coloratum* stands out by its distinctive white midrib and grey-blue leaves.

1.1. *Acacia karroo* sub-community

The member species of this sub-community were *Acacia karroo* and *Asparagus laricinus*. This sub-community was observed on the upstream and downstream sites of Sepanespruit. When these species grow together they form a thicket which is characterized by dominance of these woody species. This thicket is palatable to game. *Acacia karroo* is a tree that can grow up to 15 m in height while *Asparagus laricinus* is a small deciduous shrub which has clustered leaves and was observed to inhabit areas that were disturbed. The areas that are circled with red on Figure 5.26 indicate the sparse thickets of *Acacia karroo* on the marginal and riparian zones of the upstream site.



Figure 5.26: The *Acacia karroo* shrubs on the marginal zones and riparian zones of the upstream site

1.1.1 *Sesbania punicia* variant

The members of this variant were identified as *Sesbania punicia* and *Phragmites australis*. This variant was observed on the canal and upstream sites. *Sesbania punicia* is a leguminous shrub that grows up to a height of 4m. It formed thickets in riparian areas of the upstream,

downstream sites. It is also known to inhabit wetland areas and eventually exclude native species. (Hunter and Platenkamp, 2003) also reported that this species alters water flows in rivers and streams. *S. punicia* grows timeously and produces large amounts of seeds which are capable of long ranged dispersal via water currents (Hunter and Platenkamp, 2003). *S. punicia* was observed both at the upstream (as shown by a yellow arrow on Figure 5.25 and (a red arrow) on at the canal (Figure 5.27).



Figure 5.27: *S. punicia* at the canal site (shown by a red arrow)

Phragmites australis (also known as the common reed) occurred in thick monotypic stands in the stream. The common reed was observed in a niche between the upstream sampling site and the dam. It occupied a similar habitat with *Typha capensis* but they did not occur in an intermingled manner. The common reed is usually observed to dominate in wetland areas and riparian sites because it prefers areas that have high water tables or habitats that are frequented by floods. *Sesbania punicea* - *Phragmites australis* variant was observed at the dam.

The circumference of the dam was surrounded by reeds, more specifically the *Phragmites australis* as can be seen on the far ends of the dam (pointed to by red arrows) (Figure 5.29)



Figure 5.28: Dam vegetation showing stands of *Phragmites australis* (circled in red and shown by red arrows) and *Paspalum dilatatum* on the disturbed dam bank

1.1.2 *Sporobolus fimbriatus* variant

The character species of this variant were *Sporobolus fimbriatus* and *Eragrostis chloromelas*. *Eragrostis chloromelas* is a grass that is resistant to drought even though its palatability to livestock is low. It grows from spring to summer and autumn. It was observed in the area around the dam. *Sporobolus fimbriatus* is commonly found in open woodland and grassland. This species prefers to grow in shallow pans, however it has variable habitats because it has also been found on rocky hillsides, disturbed areas and shady locations.

1.2. *Paspalum distichum* sub-community

The dominant species was *Paspalum distichum* which is a salt-loving perennial which usually occupies salt seepage areas. It is adapted to marshy and saline soils. It is palatable to livestock and difficult to completely graze out. It also tolerates water-logged soils (Carr, 2010). *Paspalum distichum* inhabited a niche along the raw sewage canal because it is resistant to extreme salt conditions. It was observed to grow by itself perhaps as because the other species could not withstand the extreme conditions of water enrichment. *Berula erecta* formed part of this sub-community. It is a perennial aquatic plant which may appear submerged in rivers and stream. It also occurs as an emergent species at the edges of lakes, ponds and rivers. It was observed at the upstream site as shown on Figure 5.33. *Cyperus eragrostis* is a sedge with tufted stems that

grows on riparian zones. The members of this sub-community were identified along mainly in and on the margins of Seroale Dam, the downstream site and the canal.



Figure 5.29: Monotypic growth of *Paspalum distichum*. Note: The water in the canal is discoloured due to pollution caused by sewage

1.2.1. *Pennisetum clandestinum* variant

Also known as Kikuyu, *Pennisetum clandestinum* is a creeping grass that forms a dense turf and is tolerant of heavy grazing. It was observed on the margins of Sepanespruit and on the area close to the stream. This grass was observed in high abundances in the area around the dam, the wetland area and the downstream site. The area circled yellow on Figure 5.29 shows *Pennisetum clandestinum* on the disturbed banks of the downstream site growing on its own (monotypic). This phenomenon is brought about because the other less competitive species that are specific in their niche requirements have been swept out. *Pennisetum clandestinum* has a wide magnitude of habitats on which it can grow; hence it was able to displace other species on the marginal zones on the stream as shown on Figure 5.30.

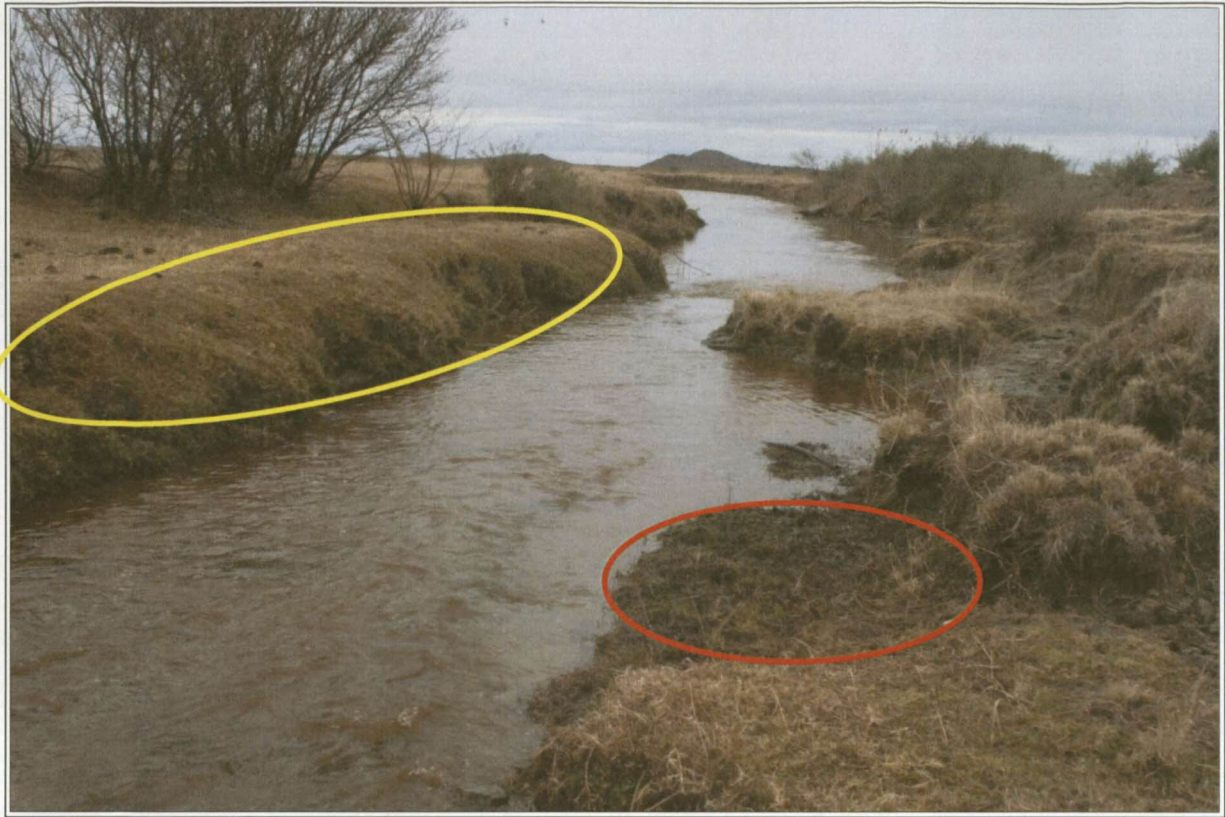


Figure 5.30: The monotypic growth of *Pennisetum clandestinum* (circled yellow) on one bank and monotypic growth of *Paspalum dilatatum* (circled red)

1.2.2. *Verbena bonariensis* variant

This variant is composed of three member species: *Verbena bonariensis*, *Xanthium spinosum* and *Cirsium vulgare*. These plants are characteristic of disturbed areas and they invade an area quite easily. *Verbena bonariensis* is a rapidly growing, tall and erect perennial herb that was widespread on the wetland area, the upstream site, the dam and the canal. It is a drought and heat tolerant plant species that is commonly found along roadsides and other disturbed areas. Left unchecked, this weedy herb takes precedence and may out-compete native species. *Xanthium spinosum* was declared by McRae and Auld (1988) to be among the world's worst weeds; it competes with pasture and crops. It was sparsely available in the wetland. It is indicative of very disturbed areas. It was recorded on the upstream site, downstream and the wetland. *Cirsium vulgare* is an invasive thistle that is adapted to wet habitats. It was recorded at the wetland even though it had a low cover abundance (<5 %). Lamp and McCarty (1981) reported that when *Cirsium vulgare* is left unchecked, it grows into thick stands that make human and animal movement almost impossible.

1.2.3 *Cyperus longus* variant

The members of this variant were: *Cyperus longus*, *Typha capensis*, *Rorippa nasturtium-aquaticum* and *Gomphostigma virgatum*. The members of this variant were observed around

the dam while *Rorippa nasturtium-aquaticum* was identified in the upstream water, almost submerged. This variant was dominated by the sedge *Cyperus longus* (Figure 5.31). It was observed growing on swampy areas; it withstands water-logged soils. *Typha capensis* is a reed that is characteristic of wetlands. *Rorippa nasturtium-aquaticum* is a branched perennial herb with stolons that run in water (Figure 5.33). *Gomphostigma virgatum* is a perennial shrub that was found growing in running water. This species is also reported to inhabit areas that are defined by shallow soils and boulders or in sandy soil (Figure 5.32).



Figure 5.31: The margins of the dam surrounded by *Cyperus longus*, an arrow points to the stand of this species



Figure 5.32: The margins of the dam showing *Gomphostigma virgatum* (indicated by a red arrow)



Figure 5.33: The upstream site showing *Rorippa nasturtium-aquaticum* (circled yellow) and *Berula erects* (circled red).

The *Cyperus longus* variant was composed of reeds, sedges and aquatic herbs. These inhabited the wetland area, the upstream and dam banks. The variant *Verbena bonariensis* was composed of members that are indicative of high disturbances. These plant species were observed at the dam, the upstream, downstream and within the wetland area.

The vegetation along Sepanespruit was classified into one community which was further divided into marginal zone vegetation and riparian vegetation. Marginal zone vegetation was closely associated with the stream; there was lower zone and upper zone vegetation. The riparian vegetation was observed a few meters away from the stream banks. The ecological drivers that influenced the observed division of the community can be associated with soil depth, moisture gradient, degree of disturbance and organic matter. The marginal zone vegetation was composed of one sub-community of *Paspalum distichum* and three variants whose dominant species were; *Cyperus longus*, *Verbena bonariensis* and *Pennisetum clandestinum* respectively.

The member species of this sub-community were observed at the dam, the upstream site and the wetland area.

The riparian vegetation constituted another sub-community which was dominated by *Acacia karroo*. The two variants of this sub-community were dominated by *Sesbania punicia* and *Eragrostis chloromelas* respectively.

The marginal and lower zones of the stream were expected to receive more water during floods when the urban-runoff increased but for the year 2011/2012, low rainfall was received so flooding was not observed. The downstream site however received occasional high volumes of water (small episodes of flooding) from the sewage effluent; this could have influenced the vegetation structure of the observed downstream site. The marginal zones of the downstream site were covered by monotypic vegetation of *Pennisetum clandestinum* on some parts and clusters of *Paspalum dilatatum*.

5.8. THE EFFICIENCY OF THE SEWAGE TREATMENT PLANT

The efficiency of the sewage treatment plant was determined on the basis of the sewage flow and the quantity of the sewage received. The functioning of different unit processes was also noted throughout the study period. The sewage effluent quality and the methods of sludge handling were also considered in order to confer an informed score on the efficiency of the sewage treatment plant.

Both the influent and effluent meters were non-functional throughout the period in which the study took place. On personal communication with the plant operators, this problem had lasted for over two years. It was difficult to keep track of the volumes of influent and effluent. However, the operators reported that during rainy seasons, the sewage influent overflowed and filled the entire sewage treatment plant campus. This was a serious health hazard to the workers who would have to handle and sweep the remains of raw sewage back to the sewage treatment facilities after such episodes of overflow. Further-apart, the sewage stream would pass into the receiving stream in a poorly treated state during such times. The functioning of the sewage treatment during such times turned into an illegal operation, a health hazard and an environmental disaster.

The Thaba-Nchu sewage treatment plant had the hydraulic capacity of 6 ML/day (DWAF, 2007) and served a population of more than 70 000 people (stats SA, 2011). These values conferred this plant over-burdened. One of the major factors that led to the release of poor sewage effluent was that the volume of sewage received was more than what the sewage processes could handle. The sewage stream could not be retained long enough within different unit facilities because there was more sewage coming in.

It was only during two times throughout the duration for the study period that one of the aerators was working, the entire time, they were non-functional. The sewage was not fully aerated before it was processed; this could have sabotaged the efficiency of sewage treatment because aerobic bacteria were denied a fair chance of degrading organic matter within the sewage stream. The electric motors that spun the wings and flips of the mixers were non-functional time and again. The mechanical personnel would fix them but that would not last; the equipment was groaning with age. The expansion of the sewage treatment plant and the replenishment of the machinery and equipments was a pressing need at this sewage treatment plant.

The operational staff members were illiterate, unskilled and lacked understanding and knowledge in terms of the deep science that lies behind the functioning of the sewage treatment processes. The dose of chlorine that was added to the sewage effluent was constant regardless of the volume of sewage effluent; a fair evidence of incompetence. A knowledgeable operator would regulate the volume of a disinfectant on the basis of the effluent volume. During December 2011, water samples were drawn at the time when disinfection had just been done. Low *E. coli*, faecal and total coliform bacteria counts were noted and high EC concentration also followed. Chlorine increased the concentrations of ions in water hence the observed high EC concentrations. During October 2011, sampling was done a few hours after the time of disinfection, the impacts of excess chlorine were observed in the downstream water in the form of high EC concentrations.

The quality of the sewage effluent was poor. The DO concentrations of the sewage effluent were lower than the DWA's recommended effluent standards of 9.09 mg/l (at 20 °C) for all the seasons except during April when the aerator was functioning. The DWA recommended EC concentration for effluents is 70 mS/m, while the COD concentration should not exceed 75 mg/l, the Thaba-Nchu sewage treatment plant was not always compliant. The sewage effluent was a source of nutrients to the receiving stream, the concentrations of NH_3 and PO_4^{3-} were each higher than the target value of 1 mg/l for most of the time. DWA demands that bacteria pollution in the form of *E. coli*, faecal coliforms and total coliforms should not be present at all in the sewage effluent but high counts of 2419 cfu/100ml were recorded for the sewage effluent (except during December 2011 when the sampling time coincided with disinfection time). The sewage effluent was sometimes coloured and had some odour. The target effluent quality values that have been used above were adopted from the government gazette of 18 May 1984; the target values for different parameters are in agreement with the recommended sewage effluent standards as stipulated by DWAF (1996).

The sludge produced was not pressed; it was only dried out in the sludge lagoons. The dried sludge was dug out manually and disposed-off just outside the boundaries of the sewage treatment plant. This method of sludge disposal was unsustainable, unhealthy and

environmentally unsafe. The sludge was analysed and it was found to contain high quantities of pathogens and bacteria. The place where sludge was disposed-off was accessible to children and animals; that could be a pathway in which medical problems (that are associated with faecal matter) such as diarrhoea and gastro-enteritis could pass. Plastics, papers and rags were seen trapped and hung within the sludge beds. Once the sludge dried out, the plastics were let loose and they caused serious pollution. Some of the plastics could be blown by winds into the stream.

5.9. WATER LEGISLATION

Access to clean water is a fundamental human need. It is expressed in the Bill of Rights (The Constitution of the Republic of South Africa, Act No. 108 of 1996) as a basic human right. Water quality is fundamental to environmental conservation, and in its preamble the South African National Water Act (Act No. 36 of 1998) recognises that the protection of water quality is necessary to ensure sustainability of the nation's water resources in the interest of all water users.

The purpose of the Water Act is to ensure that the country's water resources are protected, developed, managed and sustainably used. It further depicts that water resources must be used in such a state that will meet basic needs of the present and future generations; this is stated in the National water Act No 36 of 1998.

Part 26 of this the national Water Act No 36 of 1998 demands that a person transporting waste must ensure to responsibly offload it, not causing pollution to the environment and not compromising health and well-being. Figure 5.34 below shows a piece of land, just outside Thaba-Nchu sewage treatment plant that has been intensely polluted by the careless spillage of raw sewage. The municipal waste transporters spilled sewage and thereby polluted an area of about radius 10m with sewage.



Figure 5.34: An area of radius 10m that has been polluted by raw sewage (Picture taken: October 2011)

Section 28 (1) of the National Environmental Management Act, 1998 means to enforce responsibility to every South African water user. It stipulates that every person who caused significant pollution or degradation of the environment must implement reasonable measures to prevent such pollution and degradation from occurring, continuing or recurring. In such cases whereby such harm to the environment is authorised by law or cannot reasonably be avoided or stopped, it must be minimised.

The South African Water Act demands that in a case where a wastewater effluent cannot be treated at the local municipal sewage treatment works, it must be treated at its source. This Act further stresses that sewage effluent must be treated to such a degree that it can be safely discharged directly back into the environment. The Department of Water Affairs and Forestry has compiled specifications regulating the quality of sewage effluents prior to discharge. These guidelines are given in The Government Gazette No. 20526 of 8 October 1999.



Figure 5.35: The reddish-brown sewage effluent released from the Thaba-Nchu WWTP (Picture taken: August 2012)

Part 5 of National Environmental Management: Waste Act, 2008 in the Government Gazette No. 32000, Volume 525 of March 2009 stipulates that any person who stores waste must ensure that the containers are not corroded, there is no leaking and there are no spillages. It means that any industry or waste-handlers that cause environmental pollution are violating the law and can thus be charged. Figure 5.36 below shows a reddish line in the middle of the road which marked the waste-leakage onto the road from the factory up to the sewage treatment works.



Figure 5.36: The line in the road is food dye that marked the continuous leakage of waste on the road (Picture taken: June 2012)

It is paradoxical to recognise the strictness of water and environmental laws in South Africa and yet it has so severely polluted water bodies.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

In terms of nutrients; the canal, upstream and downstream sites were deemed eutrophic. The reed bed of *Phragmites australis* and *Typha capensis* filtered the water before it flowed into the dam; hence the dam water was rendered oligotrophic. Bacteria pollution was profound in Sepanespruit; the total coliforms, faecal coliform bacteria and *E. coli* counts were higher than the maximum number of counts (2419 cfu/100ml) that the laboratory could do. However, the dam water was not polluted because of the bio-filtration process. Seasonal variations in terms of bacterial counts were observed at the dam; high counts during summer.

The sewage effluent released warm water (an average of 2.2 °C warmer than the stream water) during summer months. During winter, the sewage effluent was a source of cooler water to Sepanespruit. During August and December 2011, the sewage effluent was a complete nuisance to the wetland and downstream site. There was a power-cut to the sewage treatment plant in which case, the sewage stream flowed almost untreated through the sewage treatment process. The sewage effluent was a source of high concentrations of NH_3 and PO_4^{3-} to the downstream water. Electrical conductivity, chemical oxygen demand and bacterial counts were high in the sewage effluent which became a source of pollution to the downstream water, especially during August 2011.

During December 2011, the effects of power-cut were to some extent counteracted by the high doses of chlorine to the sewage effluent. During this time, the bacteria counts in the sewage effluent were low (1 cfu/100ml for *E. coli*, 1 cfu/100ml for faecal coliforms and 4 cfu/100ml for total coliforms). However, the sewage effluent still contained high NH_3 and PO_4^{3-} during December. For the periods in which the sewage effluent was improperly treated, the effects were also evident in the downstream water in the form of nutrient enrichment and bacteria pollution.

During February 2012, municipal workers (including sewage treatment's handy men) went on a strike in which they protested about their salary scales and other labour related matters. During this period, the screening bins were over-flowing and the manually operated duties of the sewage treatment plant such as raking out escaped screenings and removing grit were neglected. But the quality of the disposed effluent did not deteriorate because the treatment processes continued to operate even though they were unchecked. During April 2012, one of the aerators was functioning in which case the concentrations of dissolved oxygen in the sewage effluent were exceptionally high (16.24 mg/L). The concentrations of COD and NH_3

were subsequently low. However, the sewage treatment processes were very effective in the removal of suspended solids and chlorophyll *a* from the sewage stream.

The sewage effluent that was released into Sepanespruit was sometimes red-coloured. This was an incompliant disposal of wastewater according to legal requirements of wastewater or effluents purification as stated in the government gazette of 18 May 1984. That legislation requires that an effluent should not have odour and colour before it is disposed into the environment.

The canal of raw sewage was the worst point source of pollution to the stream. During September, October, December 2011 and July 2012, it was suspected that the time of sampling coincided with the time at which the municipal tanker-trucks had disposed-off the sewage at the source manhole. The flow was high in the canal and associated results indicated high counts of *E. coli*, faecal coliforms and total coliform bacteria. The concentrations of electrical conductivity, chemical oxygen demand, suspended solids, NH_3 and PO_4^{3-} were also very high in the canal water.

The impacts of the sewage effluent and the canal water were evidenced by the monotypic growth of plant species such as *Paspalum distichum*, *Paspalum dilatatum* and *Pennisetum clandestinum* on different niches along the canal and the downstream site. This monotypic growth reduced the biodiversity of plants along Sepanespruit. *Paspalum distichum* is adapted to habitats that are high in nutrients and it usually inhabits seepage areas (Carr, 2010).

On the basis of influent quantities and flow, unit process performances, sewage effluent quality and sludge processing and handling, the investigations of this study revealed that Thaba-Nchu sewage treatment plant was not compliant to the recommended standards as set by the DWA through the department of waste management.

The part of Sepanespruit that formed this study was mostly used for livestock watering, fishing, subsistence irrigation and small-scale commercial irrigation. In terms of nutrient enrichment, the water was eutrophic and unfit for livestock watering and irrigation. Sepanespruit contained high concentrations of pathogens; higher than 1 000 cfu/100ml which is a value above which the health defects of pathogens can be expressed. The physic-chemical parameters such as EC, COD and DO concentrations also indicate that the water is not fair for agricultural use namely; livestock watering and irrigation.

The dam water was fairly safe to use for recreational purposes such as fishing; it contained low concentrations of nutrients (NH_3 , PO_4^{3-} and $\text{NO}_3^-/\text{NO}_2^-$), high DO and low COD concentrations. The phytoplankton was abundant in the dam which was good to feed and nourish the fish. However, the dam water rarely contained high concentrations of *E. coli*, faecal coliforms and

total coliform bacteria counts, this was observed during December. The dam water was also used by local people for religious and traditional cleansing ceremonies; these activities may be accompanied by some 'muti' portions that are dropped in water. However, such water contaminants are usually much localised and their impacts may not cause significant harm since they were not every-day activities. The methods by which fish were handled were not hygienic; the fish were held in pools and then dried out in the sun on the grass while being salted in preparation for it to hit the market.

6.2 RECOMMENDATIONS

This project was a comprehensive environmental in which investigations into alternative sewage treatment options and critical analysis of different unit processes were made. The assessment of operational efficiency and the economic implications that would be borne by the wastewater authority have been explored. Cradle-to-grave approaches in which the repercussions of production and consumption are considered when an assessment is made have also been considered in this study. The goals and scope of this project were carefully calculated before its start. The processes involved were critically analysed. The findings of this study would be valuable for use as a foundation in the expansion of the Thaba-Nchu sewage treatment works.

It is however worth noting that the department of water affairs has considered fitting an artificial wetland to improve the sewage effluent quality before it flows into the downstream site of Sepanespruit. The data that was collected during this study may be used as baseline information which will guide the specifications such as capacity of the artificial wetland.

An integrated approach to environmental problems is advisable because a wide spectrum of authorities have each a role to play. A combined effort from watershed associations, soil and water conservation bodies (Ministry of Environmental Affairs, at municipal and district levels) would alleviate or combat the problems associated with disposal of improperly treated sewage effluents into the environment.

The manhole at which the canal originated stood to evidence the carelessness and ignorance of municipal workers. The fact that they disposed-off sewage in such a hurried and negligent manner showed lack of ethical and moral principles. This profound pollution could have been stopped or it could not have happened at all if the waste management team and their associated law enforcement officers within the department of water affairs effectively carried out their routine assessments. Sewage treatment and accompanying waste management duties do not receive priority attention within the stake-holding department; this has allowed further pollution. When this careless dumping of sewage has stopped, it would be advisable for the area to be rehabilitated back into a grassland area.

The inlet facilitates grit removal which is basic for protection of mechanical equipment and reduction of blockages. At the Thaba-Nchu sewage treatment works, the screens were always timeously and appropriately removed. It is however important to point out that the screens were disposed-off just outside the treatment works, which was an inappropriate disposal site. It is essential to dedicate a landfill site on which the screens can be carefully disposed-off. Neutralisers, flocculation agents and precipitation agents were not used at the Thaba-Nchu treatment plant; addition of these chemicals to the sewage stream would improve the quality of sewage effluent.

It would be important to treat sludge before it is disposed-off. This would reduce odour problems and further retard the breeding of pathogen that are carried in the sludge. This would be an environmentally-viable solution to sludge nuisances especially because within this study area, it was disposed-off as heaps along the terrain and it has been interrupted by foot paths. This sludge also steals away the aesthetic value of that piece of land that would otherwise be a rich arable land like its surrounding areas.

An alternative sampling site should be allocated for safe disposal of wastes from a meat processing factory which dumped the thick liquid waste as part of the sewage stream. This waste contained dyes and chemicals that could not be removed by conventional treatment processes. Those chemicals are most probably a health hazard to biota downstream; especially because they were identified as endocrine disruptors and potential carcinogens. The department of health should beef up their inspection and assessment routine works. The dyes that were identified in the processed meat samples (bought from the retail shops) are toxic to human health. Sudan i, Orange ii and Rhodamine B are some of the dyes that have been banned in many countries because of their proven carcinogenic nature.

It would be advantageous to improve the usefulness of the wetland in order to polish the quality of stream water before it flows further downstream. Wetlands are economical alternatives to wastewater treatment plants. For example, Congaree Swamp in South Carolina was used for waste water treatment which would otherwise require \$5 million to be completed (U.S. Environmental Protection Agency, 2003).

In order to ensure a good quality of sewage effluent at this plant, the municipality would have to invest in sewage infrastructure to expand the existing plant. Extensive training is needed to the operational staff in order to obtain good quality effluent. The infrastructural, mechanical and electrical operations of plants present serious challenges to unskilled labourers. This plant was functioning with limited operational information; they could not recognise it when there was inconsistency in the figures of flow levels for example.

One of the major problems within the sewage treatment plant was poor management of resources. It was unethical that for many times, the management failed to pay electricity dues on time to an extent that the power supply would have to be cut to the sewage plant. Perhaps limited knowledge in terms of the far-reaching impacts of poor sewage effluents to the receiving stream ecology contributed to the observed negligence and reluctance in timeous payment of electricity dues.

More initiatives in which environmental education is disseminated should be put into place. School children and their teachers should be equipped with information to help them better understand the environment and to take good care of it. The disposal of domestic waste that was observed at the upstream site indicated that local people did not completely understand the importance of keeping the stream clean.

Pollution assessment and monitoring should be done in river systems on a regular basis. It would be possible to timeously identify water quality threats and execute appropriate pollution mitigation methods. These efforts help to inform decision-makers on the types of mitigation methods they need to deploy. It is appropriate to designate streams by types of use (e.g. fishing, livestock watering, and irrigation) and assess water relative to intended use.

The assessment and monitoring of phytoplankton and fish species in this study would have given a more profound and inclusive indication of the end-point of pollution. The assessment of the variety, communities and populations of phytoplankton and fish in water is an imperative and indispensable water quality indicator tool. These variables would indicate the differences in water quality along Sepanespruit. The data thereof would be used to decide whether or not immediate conservation or mitigation measures are necessary. The population and varieties of fish would further inform the decision makers within water authority boards and departments the types of conservation techniques that would be viable.

Management of pollution issues need an assessment of landscape-scale patterns of pollution sources for developing mitigation strategies (Meixler and Bain, 2010). It is important to create spatially explicit models that can be used for landscape pollution assessment and conservation strategy development. These models would be particularly advantageous because they can simulate the impacts to water quality across variable spatial regions. These models can cover small water niches to the entire watersheds over varying time scales. Through using models, it is possible to track changes in pollution given past and present conditions and to foretell the future changes in water quality considering variations in management practices. These models would also help conservation authorities to recognise areas of priority in terms of implementing mitigation or conservative measures. However many models require extensive hydrological

expertise for organising input data, handling data processing and reprocessing and conducting model calibration.

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ANNEXURE A

Species list

All species names conform to Germishuizen and Meyer (2003).

Eudicots

Apiaceae

Berula W.D.J. Koch

B. erecta (Huds.)

**Ciclospermum* Lag.

C. leptophyllum (Pers.) Sprague

Cruciferae

Rorippa L.

Nasturtium-aquaticum (Hayek.)

Fabaceae

Sesbania Scop.

*S. *punicea* (Cav.) Benth.

Acacia Mill.

A. karroo Hayne.

Polygonaceae

Rumex L.

R. crispus L.

Asteraceae

**Xanthium* L.

*X. *spinosum* L.

**Cirsium* Mill. emend. Scop.

C. **vulgare* (Savi) Ten.

Buddlejaceae

Gomphostigma Turcz

G. virgatum (L.f.) Baill.

Verbenaceae

**Verbena* L.

V. **bonariensis* L.

MONOCOTS

Asparagaceae

Asparagus L.

Asparagus larycinus (Burch.)

Cyperaceae

Cyperus L.

C. **eragrostis* Lam.

C. *longus* L.

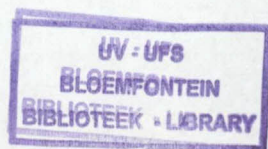
Poaceae

Eragrostis Wolf

E. chloromelas Steud

Panicum L.

P. coloratum L.



Paspalum L.

P. dilatatum Poir.

P. distichum L.

Pennisetum Rich.

P. clandestinum Hochst. Ex Chiov.

Phragmites Adans

P. australis (Cav.) Steud.

Sporobolus R.Br.

S. fimbriatus (Trin.) Nees

Typhaceae

Typha L.

T. capensis (Rohrb.) N.E.Br.

Table 1: A Phytosociological table of the wetland and riparian vegetation of the Sepanespruit

Community no.:	1				
Sub-community no.:	1. 1		1. 2		
Variant no.:	. 1	. 1. 2	1. 2. 1	1. 2. 2	1. 2. 3
Sample plot no.:	3 3 3	2 2 2 2	2 1 2 2 2 2 3	3 4 3 3 4	1 2 1 3 3 3 1 1 1 1
	6 5 4	7 6 9 8	4 9 2 3 5 0 0	7 1 8 9 0	5 1 4 1 3 2 6 3 8 7
Nr of species per plot					
Species group A:					
Sesbania punicia	1 1 2	.....	.....	.....	.....
Phragmites australis	1 1 1	.....	.....	.....	..... 3
Species group B:					
Eragrostis chloromelas	.....	1 + . r	.....	. + .....	.....
Sporobolus fimbriatus	.....	. 2 r .	.....	..... + .....	.....
Species group C:					
Acacia karroo	2 . 2	1. 2 1 1	.....	.....	.....
Asparagus laricinus	1 . +	2 1 1 1	.....	.....	.....
Species group D:					
Pennisetum clandestinum	2 . .	. . 1 1	2 3 3 1 3 3 1	.....	. 1 . 1
Species group E:					
Verbena bonariensis	.....	.....	.....	1 a + + +	.....
Cirsium vulgare	.....	.....	.....	r . . + r	.....
Xanthium spinosum	.....	.....	.....	1 + . + r	.....
Species group F:					
Cyperus longus	.....	.....	. + + . . . .	.....	2 + 2 + + 1 + 2 + +
Typha capensis	.....	.....	..... 2	.....	1 . . 2 1 1 + 1 . .
Rorippa nasturtium-aquaticum	.....	.....	.....	.....	1 . r . . . + . . +
Gomphostigma virgatum	.....	.....	.....	.....	. + 1 . . . + 2 . .
Species group G:					
Paspalum distichum	.....	.....	1 1 2 . + + 1	3 1 3 4 . b	1 1 1 . . . 2 4 + 1
Berula erecta	.....	.....	r + + + + r 1	. r + . 1	+ + + r 1 . . . + +
Cyperus eragrostis	+ + .	.....	. 1 + + + .	. + . . +	+ + . + + . + . . .
Species group H:					
Paspalum dilatatum	1 + +	+ . . +	+ + + 1 1 + .	1 2 3 1 +	+ 1 2 . . 1 1 1 + +
Rumex crispus	. . .	+ + r +	1 . 1 1 1 . .	1 + r + 1 +
Ciclospermum leptophyllum	. . .	. . r .	r . . r r . .	. r r . .	. . . . . . . . . .
Panicum coloratum	. . .	+ . . .	. . . . . . .	. + . +	. . . . . . . . . .