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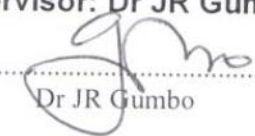
**SCHOOL OF ENVIRONMENTAL SCIENCES
DEPARTMENT OF HYDROLOGY AND WATER RESOURCES**

**An Assessment of Water Quality of the Wetland Downstream of Makhado
Oxidation Pond and Its Potential Effects on Irrigation Waters**

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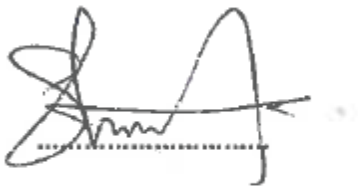
Co-supervisor: Prof WM Gitari

**A Dissertation submitted to the Department of Hydrology and Water Resources,
University of Venda, for the fulfilment of the requirements for the degree of
Master of Earth Sciences in Geology**

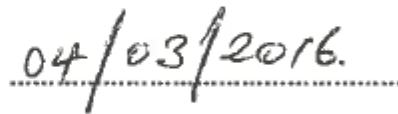
February 2016

Declaration

I, **Shibambu CS**, do hereby declare that this dissertation project submitted to the University of Venda for the fulfilment of Masters' Degree in the Department of Hydrology and Water Resources, School of Environmental Sciences, is my own independent work. This work has not been submitted before to any institution by me, or any other person in fulfilment of requirements for any qualification.



Signature



Date

Dedications

I would like to dedicate this project to my wife Marcia and my children Mpfuxelelo, Muhluri and Andzile. May the almighty GOD bless them

Acknowledgement

I would like to thank Dr Jabulani Gumbo and Prof WM Gitari my supervisor and co-supervisor during this work that provided me with helpful guidance. Let me also acknowledge the assistance from Mr. Glen Pindihama during the sampling period.

The climatic data was provided by the ARC-Institute of Soil, Climate and Water in Pretoria, South Africa.

Academic output

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List of abbreviations and acronyms

AMD	Acid Mine Drainage
CYN	cyлиндросpermopsin
DWA	Department of Water Affairs
DWAF	Department of Water and Affairs and Forestry
DOC	Dissolved Organic Carbon
DTR	diurnal temperature range
EC	Electrical Conductivity
TDS.....	Total Dissolved Solids
DO.....	Dissolved Oxygen
KM.....	Kilometer
WWTW	Wastewater Treatment Works

Abstract

Wetlands are known of their pollution reduction characteristics due to their flat topography and dense vegetation which capture pollutants on the settling sediments. Three processes take place on the captured pollutants in the sediments, the physical, chemical and biological processes, which facilitate the removal of pollutants from the wetlands. This research was carried out in order to assess the Water Quality of wetland downstream of Makhado oxidation ponds and its potential effects on Irrigation Waters by determining the Physical-chemical parameters (pH, Dissolved Oxygen, temperature, electrical conductivity and turbidity); the nutrient levels (Nitrates, phosphates, nitrites, bromide) and heavy metals. The water samples were collected from the effluent discharge of Makhado oxidation ponds (upstream), the middle section of the wetland (midstream) and downstream of the wetland. The climate data for the study was also used assess the contribution to variation in the physical-chemical parameters during their passage through the wetland. The use of waters in the wetland by subsistence farmer's was also assessed to determine their farmer's perception on wastewater reuse, sustainability, water quality, health hazards and crop yield. At the discharge and midstream point, the physical parameters tested were found to be mostly outside the target water quality range of irrigation water set out by DWAF but are within the DWAF guidelines for discharge of wastewater. The exceptions were with total dissolved solids which were higher than 25 mg/l guideline value of the said standards. The anions were analysed by Ion chromatography and showed spatial variation in content and seasonality. The nutrients (nitrates, nitrites and phosphates) and chloride were higher than the DWAF guidelines for discharge of wastewater. The heavy metal content in the wetland was analysed by ICP-OES and varied throughout the wetland. The following metals were reduced during their passage in wetland and were within DWAF guidelines: zinc, lead, cadmium and total chromium. Iron and manganese were reduced during the drier season but were above the DWAF guideline values during the wet season. Also the metal contents in the wetland are out of the target water quality range of the same standards bringing forth the risks of toxicity in the wetland. The anion analysis also suggests that the wetland is becoming a nutrient rich environment bringing forth risks of eutrophication. Nitrite concentrations did not conform to the South African

Water Guidelines on target water quality ranges for irrigation water. Farmers have expressed a positive opinion on wastewater use for irrigation since there are loads of nutrients. The presence of nutrients in wetland may contribute to development of harmful algal blooms.

Key words: Wetlands, Physical parameters, Anions, Metal removal, harmful algal blooms, subsistence farming

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CHAPTER 1: INTRODUCTION

1.1 Background

The quality of water resources in South Africa is increasingly becoming threatened by eutrophication problems with 35% of the total water storage being eutrophic or hypertrophic (Harding et al., 2009). Although eutrophication is the natural process of water bodies' aging, it is mostly exacerbated by anthropogenic activities. Such activities include the introduction of nutrients rich materials into water bodies. Phosphorous and nitrogen are mostly the culprits when discussing the nutrients rich sediments in water resources.

Sources of these nutrients are both point and nonpoint sources. Point sources are those sources where pollutants find their ways into water resources via an identified particular point. Such sources may include storm water drainages, industrial effluents, feedlots and wastewater treatment works while non-point sources may include washed fertilizers from agricultural lands (Makhera et al., 2010).

From a South African perspective, nutrient rich materials in wastewater treatment works (WWTW) alone are in higher concentration than in nonpoint sources (Chamier et al., 2012). Chamier et al. (2012) indicate that in South Africa, only 7.4% of wastewater treatment works (WWTW) were awarded the green drop certification. About 92.6% of the South African WWTW may be said to be noncompliant and their continued operation raises the risks of eutrophication in South African freshwater resources. Progressive eutrophication triggers massive production of cyanobacteria blooms (Oberholster et al., 2009). In South Africa, cyanobacteria blooms have become an increasing problem in water resources (Oberholster et al., 2009).

Gigantic occurrence of cyanobacteria in fresh water resources is a global environmental problem which emanates from continued extreme anthropogenic water contamination with organic nutrients such as phosphorous and nitrogen (Blahova et al., 2007). Cyanobacteria pollution of water is highly associated with health impacts and has in other cases been followed by fatal incidents of animals that may have consumed water polluted with cyanobacteria (Masango et al., 2008).

1. 2 Problem Statement

The Makhado oxidation ponds are found in the Makhado Township and they receive treated municipal wastes for further treatment through the interaction with the sunlight and bacteria. Although these ponds were meant to discharge water that is in acceptable standards according to the DWA (1984) water quality guidelines for effluent discharge, water quality changes are extremely evident along the receiving wetland on the downstream of the Makhado township oxidation ponds. It is also noted that on the upstream of the ponds a different environment exists where water may be said to be visibly clear in terms of colour and has good odour. As one traverses downstream the wetland, visible development of different algal blooms are prevalent. However, few kilometers further down, water becomes clear again like it was upstream.

Some of the locations are being used as dumping sites by local residents and disposable baby wrappers are visible. The odour and colour of water is of a serious concern. The study area is dominated by several standing pools of water for few kilometers along the reach on the downstream of the ponds and used disposable baby wrappers accumulate in some of the pools.

The development of algal bloom in the pools is of a serious concern. These blooms are also trapped in the weeds and other plants which are hugely dominating and threatening the survival of this wetland. The massive prevalence of these plants may even suggest their favourable conditions of growth which mostly may be nutrients.

1.3 Research Questions

Wastewater treatment works are a major contributing factor to the production of nutrient rich materials and heavy metals. Such waste contains phosphorous, nitrates and nitrites. The load they carry also has the microbial content which means the presence of *E. coli* and faecal coli form. However, the content cannot be ascertained. The level of heavy metal in the wastewater load that is passing through the wetland is also not known. It remains unclear in the study area the impacts of water quality on the crop yield. It is also not unclear if the crops that farmers are planting may have been influenced by the water quality of the area or whether farmers do not take water quality issues in to consideration before deciding on the types of crops. It is also not clear if crops irrigated with water poisoned with algal bloom is safe for human consumption or not. It is yet to be determined the types of species that could have been produced in the blooms that are found in waters of these wetlands.

1.4 Objectives of the Study

1.4.1 Major research objective

- To determine the effects of the effluent discharge from Makhado Township oxidation ponds on the adjacent wetland and its potential effects on Irrigation Waters from the adjacent river

1.4.2 Specific Objectives

The specific objectives were answered in the following chapters 4 to 7.

1.5 Motivation of the Study

The study will bring about the most alarming issues on these wetlands with regard to toxicity of water in the study area. The physical-chemical parameters are associated with the conditions of the production of cyanobacteria species which are in the forefront of eutrophication processes. These parameters will be determined and assessed on their contribution to the production of the toxins. This study may detect the early warning systems to health hazards that are associated with the water on the wetlands. Depending on the outcome of the study, some form of alarm will be

raised to the farmers and the community at large about the hiding dangers in those wetlands.

1.6 Description of the Study Area

The study area lies within the Makhado Local Municipality of the Vhembe District Municipality of the Limpopo Province. It is situated about 40 km northeast of Makhado and about 65 km northwest of Thohoyandou. It lies along the Musina-Thohoyandou road as shown Figure 1 below. The study area is a wetland area adjacent the Makhado oxidation ponds along a permanently flowing river. This river is a tributary to the Nzhelele River which is a perennial stream feeding to the greater Limpopo River.



Figure 1: Location of the study area

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Water resources in South Africa are, at a global scale, are very scarce and limited (Pindihama et al., 2011). This is due to the fact that they are unevenly distributed throughout geographic regions with differing climatic regions and high evaporation rates due to hot climatic conditions. South Africa mostly experiences summer rainfall with an annual average of 464 mm while the world's average rainfall is 860mm per annum (DWAF, 2004).

In South Africa, freshwater resources are deteriorating due to the impacts of anthropogenic activities (Pindihama et al., 2011) and some of the country's water bodies are already hypertrophic (Harding et al., 2004). Examples of hypertrophic water bodies in the country include the Hartbeespoort dam in the North West Province (Harding et al., 2004). This dam has since in the 1970's been in the hypertrophic state. This is due to the enormous prevalence of the cyanobacteria bloom, commonly known as the Blue green algae, which is mainly the product of high nutrients loads deposition in to water resources.

Phosphates (PO_4^{3-}) and nitrates (NO_3^-) are the main contents of nutrient-rich sediments as well as waste water material from wastewater treatment works (WWTW). The sources of these phosphorus and nitrogen are both point and non-point sources. Point sources may include industrial pollutants through pipelines and non-point sources may include agricultural areas where pollutants are carried away by runoff and or infiltration into groundwater.

Industrial and agricultural pollutants common in South Africa are: agricultural fertilizers on massive irrigation lands, silt, toxic metals, litter, hot water, and pesticides. However, some of the most common pollutants come from urban waste water, particularly from informal settlements which lack sewage and water purification facilities.

The resulting pollution contributes to serious health problems to both humans and livestock. For example, typhoid, cholera and gastroenteritis are transmitted by water contaminated with untreated sewage. Gastroenteritis is one of three main causes of death among South African children under the age of five. Between 1980 and 1987, about 500 000 to 1 000 000 South Africans contracted cholera (UWC, 2001). Even wild animals in the Kruger National Park have not been spared from the effects of eutrophication (Oberholster et al., 2009). Deaths of animals have been reported many times in South Africa due to cyanobacterial pollution. Cyanobacteria produce toxins that affect liver and nerves in animals.

2.2 Factors Promoting Cyanobacterial Blooms

The proliferation of cyanobacteria blooms and their production of toxic algal toxins are often related to environmental parameters (Oberholster et al., 2003). Such factors include physical and chemical factors. Physical factors include temperature and light while chemical factors include nitrogen, phosphorous, iron and zinc.

Annually, about 50% to 90% of nutrient-rich materials from WWTW end up deposited in different water resources. Continued high nutrient inputs degrade the ecological ecosystems and give rise to tolerant species community development (Chamier et al., 2012). The transportation of nutrient rich sediments in a particular stream is largely influenced by physical, chemical and biological processes (Chamier et al., 2012). During the transportation of sediments in a stream, there is retention and transformation of sediments. Chamier et al. (2012) indicate that there are first to third order streams in nutrient retention.

Cyanobacterial prefer warm environments because cold environmental conditions are detrimental to their survival (Oberholster et al., 2003). Robarts and Zohary (1987) reported that microcystins are very much limited in areas of temperatures below 15 °C (Oberholster et al., 2003). Temperature and mixing in a water body may be affected by climatic conditions (Oberholster et al., 2003). Chemical parameters such as dissolved organic carbon (DOC), pH and nutrients as well as the biological processes may as well be affected by climate (Oberholster et al., 2003). These conditions have the capability of accelerating the eutrophication process. It has already been reported that there is a

close relationship between cyanobacteria and temperature and that that relationship may be affected by climate change (Oberholster et al., 2009).

Phosphorous recycling is more prevalent in warmer water environments and phosphorous release from lake sediments and mineralization are highly temperature dependent (Oberholster et al., 2009). The relationship between the cyanobacteria growth rate and water temperature may be affected by climate change (Oberholster et al., 2009). Climate change is described as changes in temperature averages and the massive impact will be due to the increased temperature variables. These changes reduce favorable conditions of cyanobacterial bloom formations (Oberholster et al., 2009). The conditions are becoming increasingly unpredictable, which calls for effective early warning systems and risk management strategies (Oberholster et al., 2009).

Climate change has brought about the decrease in diurnal temperature range (DTR) and Oberholster et al. (2009) reported that there is strong evidence that DTR has decreased over the past several decades in many regions on the globe. The DTR is defined as the mean monthly difference between the minimum and maximum daily temperatures (Oberholster et al., 2009). This evidence implies that the world is becoming warmer, as suggested by climate change; and the overall analysis indicates that depending on the surface temperature of water bodies, environmental conditions are increasingly becoming favourable to cyanobacterial developments.

There exists a relationship between the ratios of nitrogen and phosphorous and the composition of phytoplankton assemblages (Oberholster et al., 2003). While certain broad categories support the prediction of which algal division may predominate, other biophysical features and attributes should not be excluded from the equation. Oberholster et al. (2003) note that it is becoming increasing apparent that the phytoplankton assemblages may be significantly altered through biomanipulation and without changes to ambient availability of the nitrogen and phosphorous.

Certain metals such as iron (Fe^{2+}) and zinc (Zn^{2+}) produce favourable conditions for the production of toxins (Oberholster, et al., 2003). Cyanobacteria require Fe^{2+} for the photosynthesis, nitrogen assimilation, respiration and chlorophyll synthesis (Oberholster

et al., 2003). Zinc is important for the hydrolysis of phosphate, the replication and transcription of nucleic acids, hydration and dehydration of carbon dioxide (CO₂) (Oberholster et al., 2003).

2.3 The production of algal toxins and their associated health impacts

Makhera et al. (2010) note that when there are massive growths of cyanobacteria in the river, cyanotoxins are also produced and that cyanobacteria blooms mostly occur in eutrophic freshwater systems. The mostly wide spread cyanotoxins is the microcystin-LR (Makhera et al., 2010). Cyanobacteria are dominant phytoplankton group in eutrophic freshwater resources and they are especially abundant in shallow, warm, nutrient-rich water and can grow to form thick scums with the potential to change the colour of water and therefore creating blooms (Oberholster et al., 2003). Makhera et al. (2010) indicate that microcystin-LR is mostly associated with *Microcystis*, *Anabaena*, *Oscillatoria* and *Nostoc* which form scums in water bodies. Microcystin-LR (L for leucine and R for arginine) (Gumbo et al., 2008) are cyclic heptapeptides containing specific amino acid and water bodies that are found to contain microcystin-LR are facing serious water quality challenges (Makhera et al., 2010).

Water polluted with *Microcystis*, *Anabaena*, *Oscillatoria* and *Nostoc* is less fit for use and is associated with health impacts on animals and human life. Cyanobacterial blooms affect water quality by changing the pH, affecting biodiversity, production of odour and cyanotoxins (Blahova et al., 2007). The ingestion of these toxins may cause illness and even death. Microcystins are major concerns for drinking water supply at a global scale (Gumbo et al., 2008). From a health perspective, microcystins are associated with liver damage.

Microcystins are water soluble and chemically stable compounds that cause acute hepatotoxicosis and promote chronic liver tumour (Blahova et al., 2007). The seriousness of the health concerns about microcystins has prompted the World Health Organization (WHO) to develop guidelines value of 1.0 µg/l for microcystins-LR in drinking water (Gumbo et al., 2008). Oberholster et al. (2003) indicate that there have

been many reports of intoxication of fish, birds, and other animals by cyanobacteria toxins. Blahova et al. (2007) indicate that the first toxicity poisoning was recorded in Australia in 1979 and also that there are recent reports of *Cylindrospermopsis raciborskii* in Europe. *Cylindrospermopsis raciborskii* is a producer of cylindrospermopsin (CYN), a hepatotoxin that affects the functions of kidney and liver (Janse van Vuuren & Kriel, 2008; Sinha et al., 2012) In South Africa cyanobacterial toxins have been recorded in most cases (Oberholster et al., 2009).

CYN are dominantly produced within the cells of *Cylindrospermopsis raciborskii* (Blahova et al., 2007). In the Czech Republic, analysis of cyanobacterial toxins from reservoir samples indicates that 75% of the reservoir contains cyanobacteria producing these hazardous toxins (Blahova et al., 2007).

Cyanobacteria include *Microcystis*, *Anabaena* and *Oscillatoria* and are responsible for the production of toxins such as microcystins (Oberholster et al., 2003). They are responsible for the production of two types of the families of toxins and cyclic peptide hepatotoxin and the alkaloid neurotoxin and consumption of water contaminated with them may result in serious illnesses such as hepatoenteritis, symptomatic pneumonia and dermatitis.

Until 1994, cyanobacterial blooms were confined to the northern parts of the Limpopo Province and animal deaths due to hepatotoxins were reported (Oberholster et al., 2009). After the reported cases of cyanobacterial bloom in the Limpopo Province, another case was reported in Western Cape Province in the Malmesbury-Darling Region and this marked the first case ever to be reported outside the borders of Limpopo and Western Cape became the second province in the country (Oberholster et al., 2009). However, in both cases, losses of livestock have been reported where filaments of *Nodularia spumigena* were found in the drinking water supplies (Oberholster et al., 2009). Examination revealed that filaments of *Anabaena* were also present. Filaments of *Oscillatoria* were found to be growing on the walls of the reservoir from which livestock were drinking and this was the case of water quality related problem due to *Oscillatoria* poisoning (Oberholster et al., 2009).

From the Western Cape Province the problem of cyanobacterial bloom extended to other parts of the country. In the Northern Cape in the Orange River system downstream the confluence with the Harts River, the first incident of fish kill was reported due to the bloom of mixed species of *Cylindrospermopsis raciborskii*, *Anabaena* and *Oscillatoria* and this incident marked the first report of the occurrence of species of *Cylindrospermopsis* bloom (Oberholster et al., 2009).

From a water quality perspective, the species of *Cylindrospermopsis* is of a significant concern in South Africa due to its ability to produce potent hepatotoxins alkaloid cylindrospermopsin and the neurotoxin toxin (Oberholster et al., 2009). The freshwater cyanobacteria of tropical origin are not only found in the sub-tropical water resources but also in the temperate regions (Oberholster et al., 2009). Water pollution by cyanobacterial intoxication from *Microcystis* blooms have caused dozens of fatalities and was recorded also in the Kruger National Park of South Africa and the Lake Nhlanguzane (Oberholster et al., 2009). In both 2005 and 2007 Lake Nhlanguzane has witnessed a number of serious fatalities to animals due to cyanobacterial intoxication from *Microcystis* blooms (Oberholster et al., 2009) and during this period of animal intoxication, the surface temperature of the water in the lake was between 19 °C and 21°C (Oberholster et al., 2009).

Mpumalanga Province reported its first ever massive bloom of *Microcystis* species in the Loskop Dam in March 2008 since its construction in 1937; and these intoxications resulted in the fish kill (Oberholster et al., 2009). Other incidents were reported on the border of South Africa and Botswana in the same year where mortalities of animals such as impalas were noted (Oberholster et al., 2009).

2.4 Wetlands as possible agents in bioremediation of algal toxins

Wetlands are characterized by their generally flat topography and dense vegetation and they have become very important environments with the ability to reduce water pollution and high sediment load deposited into water resources (Cwikel, 1998). As water flows heavy with sediments, through wetlands, the sediments are trapped and deposited into

the wetlands thereby reducing the load that eventually reach water resources such as lakes, streams and groundwater thereby reducing the load that contributes to siltation.

Because of their generally flat topography, water flows very slowly in wetlands; therefore it increases deposition of sediments and organic matter. Because of the soil chemistry in wetlands, carbon compounds that are deposited in wetlands decompose very slowly. In this manner, wetlands serve as a relatively permanent resting place for carbon compounds (Cwikel, 1998). This function of wetlands can help to trap carbon that would otherwise accumulate in the upper atmosphere and contribute to global climate change. Furthermore, there is a strong tendency of heavy metals and other toxic chemicals to attach to the sediment particles found in surface water runoff. Wetlands can trap these human-induced pollutants and remove them from the water column (Cwikel, 1998).

However, when the natural ability of wetlands to function as filters is overstressed from human inputs, the wetland and its functions can be destroyed. In fact, when overloaded, wetlands can actually become sources of pollutants, exporting materials that have been filtered and stored resources (Cwikel, 1998).

There are four (4) ways by which sediments are trapped into wetlands:

- (i) Nutrients uptake by plants.
- (ii) Adsorption in to sediments,
- (iii) Deposition of organic materials, and
- (iv) Chemical precipitation

2.4.1 Nutrient uptake by plants

The most significant of these are the nutrients uptake by plants and adsorption onto sediments. Plants' nutrients uptake occurs primarily during the growing season; the same time when lakes and streams are sensitive to nutrients input resources (Cwikel, 1998).

As indicated earlier on, apart from contamination by heavy metal and sediment load, South Africa's fresh water resources are also threatened by the presence of harmful algal bloom (HAB), which also is a global environmental problem (Gumbo et al. 2008). HAB are also known as the cyanobacteria and are very much capable of the production of *Microcystis* which releases poisonous substances known as cyanotoxins (Gumbo et al., 2008).

The treatment of water contaminated with dissolved cyanotoxins is very difficult and expensive (Pindihama et al., 2011); and this brings a necessary need for low cost but effective means to deal with their removal. Mechanical and physiochemical methods have been developed in attempts to manage and control cyanobacterial bloom development and were met with limited success (Gumbo et al., 2008). The chemical methods involved the use of algicides such as copper, Reglone A, potassium permanganate, chlorine and Simazine (Gumbo et al., 2008). Copper sulphates or organo-copper compounds have been used to control HAB in raw water supplies intended for domestic uses (Gumbo et al., 2008). These chemicals induced cyanobacterial cell lysis but their use has often been associated with negative environmental impacts since the toxins would be released in the surrounding environments (Gumbo et al., 2008). These algicides are also toxic to other aquatic organisms. They accumulate in the sediments and buildup to harmful concentration and may have long-term negative impacts on the ecology of the concerned aquatic ecosystem (Gumbo et al., 2008). These impacts motivate for an environmentally sound approach on the treatment of cyanobacterial pollution.

Pindihama et al. (2011) indicated the effectiveness of the use of bioaccumulation potential of some naturally occurring aquatic plants (Macrophytes) in the removal of toxins released from cyanobacteria. This method is known as the "Green Liver Concept". This concept applies the use of macrophytes, which are plants growing in lakes, streams and ponds (Pindihama et al., 2011). They appear in different shapes and sizes and throw floating on the surface of the water body growing below the surface of the water body (Pindihama et al., 2011).

It is reported that there are approximately 58 aquatic plant species in the South African water impoundments and that each of these have the potential to be used for in-situ bioremediation for cyanobacteria toxins found in freshwater bodies (Pindihama et al., 2011).

Oberholster et al. (2003) also report that microcystins can be biodegraded by complex natural populations of micro-organisms of diverse ecosystems. Such diverse ecosystems may include lake sediments, sewage sludge, natural waters and biofilms (Oberholster et al., 2003). In the natural ecosystem, there are predatory microorganisms that are antagonistic towards particular nuisance organisms (such as weeds and cyanobacteria) and thus providing the natural means of their controlling (Gumbo et al. 2008). The microbial population that is capable of a means of controlling the nuisance organism by prevention, termination and regulation are known as microbial herbicides (Gumbo et al., 2008).

2.4.2 Removal of metals in wetlands environments

There are several processes that are known to be taking place in wetlands environments and their role in reducing metal concentration and neutralizing the acidity of influent water have been examined. These processes include physical, chemical and biological Processes (Gazea et al., 1995).

2.4.2.1 Physical removal processes

This process involves the settling and sedimentation of particles and has been efficient in the removal of metals in water (Sheoran and Sheoran, 2006). When heavy metals are in wetland environments, whether water is a flowing body or stagnant water body, they undergo a particular transformation (Sheoran and Sheoran, 2006). They may be transported from water to the biota or from the biota (substrate) to water and in the process heavy metals are filtered and retained in the wetland. In stagnation of very low flowing water particles that are denser and heavier than water, they will settle out (Sheoran and Sheoran, 2006). The particles that are lighter than water will go under sedimentation only after flocculation and in wetland flocculation is enhanced by high pH,

concentration of suspended matters, ionic strength and high algal concentration (Sheoran and Sheoran, 2006).

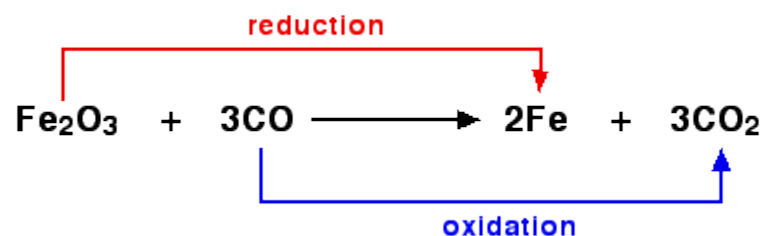
2.4.2.2 Chemical processes

There are a wide range of chemical processes that are involved in wetlands with regard to the removal of heavy metals and they are: adsorption, sorption and oxidation and hydrolysis of metals (Sheoran and Sheoran, 2006).

Sorption is the most important chemical removal process in wetland environments. It results in short-term retention or long-term immobilization of several classes of contaminants. It is transfer of ions from water to the soil i.e. from solution phase to the solid phase. Sorption actually describes a group of processes, which include adsorption and precipitation reactions (Sheoran and Sheoran, 2006).

Oxidation in chemistry is defined as a process by which elements gain oxygen and lose hydrogen while reduction is a process whereby elements lose oxygen and gain hydrogen. This is the most important metal removing mechanism. It is a reaction process that eventually results in the precipitation of dissolved metals. In constructed wetlands iron (Fe) and manganese (Mn) in AMD have successfully precipitated through this reaction (Gazea et al., 1995).

The following is an example of the oxidation and reduction of Iron (Fe):



(The reaction process is adapted from Gazea et al. 1995)

Adsorption is a process whereby heavy metals are adsorbed into the sediments and captured in the soil particles by cation exchange or chemisorptions (Sheoran and Sheoran, 2006). Cation exchange involves the physical attachment of positively

charged ions (cations) to the surfaces of clay and organic matter by electrostatic attraction (Sheoran and Sheoran, 2006). Unlike organic pollutants which will decompose, heavy metal remains as metal atoms in the sediments and more than 50% of the heavy metals can be easily adsorbed onto particular matter in the wetland and thus be removed from the water component through sedimentation (Sheoran and Sheoran, 2006).

2.4.2.3 Biological processes

Biological removal is the most important process in wetlands and its most important pathway is by plants uptake (Sheoran and Sheoran, 2006). There are a number of categories of plants found in wetland environments, which include emergent, surface floating, or free floating rooted leaves, sub-merged macrophytes and trees (Sheoran and Sheoran, 2006). These plants use both leaves and roots to extract pollutants (as nutrients). Those with their roots systems submerged under water have the ability to extract their nutrients from sediments where metal atoms are captured.

2.4.3 Removal of organic compounds in wetlands environments

Wastewater treatment plants are capable of discharging wastewater that is characterized by the presence of organic compounds such as pharmaceuticals and personal care products (PPCPs) and faecal coliform (Llorens et al., 2009). The pharmaceuticals include the Nabuprofen, Naproxen, Diclofenac, Ketoprofen, Clofibrac acid, Carbamazepine and the personal care products include the Galaxolide and Tonalide and their use are in fragrance (Llorens et al. 2009). A study carried by Llorens et al. (2009) indicates that these pharmaceuticals may be removed at the average rates of 34% and 96%.

Seasonal changes have a role to play in the removal of ammonium through nitrification and biological assimilation processes. The removal is high in warm months and low during cold months and wetlands have shown 80% efficiency removal capacity from water and wetlands have shown good capacity in removing a large range of the above mentioned compounds (Llorens et al., 2009).

2.4.4 Removal of algal toxins in wetlands environments

Since wetlands environments are characterized by their generally flat topography and the presence of densely populated macrophytes, water flow out of wetlands is generally slow and this provides time for the sediment loads and organic matter carried in water entering the wetland to settle (Cwikiel, 1998).

Because of the soil chemistry in wetlands, carbon compounds that are deposited in wetlands decompose very slowly. In this manner, wetlands serve as a relatively permanent resting place for carbon compounds (Cwikiel, 1998). This function of wetlands can help to trap carbon that would otherwise accumulate in the upper atmosphere and contribute to global climate change. Furthermore, there is a strong tendency for heavy metals and other toxic chemicals to attach to the sediment particles found in surface water runoff. Wetlands can trap these human-induced pollutants and remove them from the water column (Cwikiel, 1998).

Macrophytes appear in many shapes and sizes and some grow completely in water while others have their leaves floating on the water surface (Pindihama et al. 2011). Metals, nutrients and organic pollutants can be degraded chemically and mineralize into harmless biological compounds by plants (Pindihama et al., 2011). These plants remediate organic compounds by direct uptake of contaminants followed by transformation, transport and their accumulation in a non-phytotoxic form (Pindihama et al. 2011). However, it is important to note that this nontoxic form is not necessarily nontoxic to human being. There are 58 aquatic plant species in and around South Africa and any of these are potential candidates for the in-situ bioremediation of algal toxins found in fresh water bodies (Pindihama et al., 2011).

CHAPTER 3: MATERIALS AND METHODS

3.1. Preamble

Three sampling points were designed and water samples were collected from these points. These points were described relative to their location in the wetland. They are the upstream point, midstream point and the downstream point. Samples were collected on monthly basis for a period of twelve months starting from November 2013 until October 2014.

At each point, on site measurements of physical parameters were conducted and three water samples collected for laboratory analysis on metal contents and microcystins. Samples for microcystins were collected using amber bottles while white plastic bottles were used for metal samples. Amber bottles were ideal since they prevent light penetration in the sample. Light penetration would encourage the growth of microcystins in the samples and this would have spoiled the samples.

The water samples were stored in the cooler bag and transported to the University of Venda laboratory where they were stored in a refrigerator in a temperature below 0 °C until further use.

CHAPTER 4: THE GENERAL PHYSICAL QUALITY OF WATER THROUGHOUT THE WETLAND

4.1. Introduction

The natural wetland is located downstream of Makhado oxidation ponds (Figure 2a) and is dominated by the reed plant *Phragmites australis*. Water quality samples were collected from the discharge point in to the wetland, midstream point and the downstream point, which is the outlet from the wetland. These samples were measured of their physical parameters in triplicate and the materials and methods and results are discussed below.



Figure 2: The location of Makhado oxidation ponds (A) and middle section of the wetland (B)

4.2 Materials and methods

4.2.1 On site testing of Physical Parameters

Physical parameters tested on site were the following:

pH, Turbidity, Dissolved Oxygen DO, Electrical Conductivity EC, Temperature, Total Dissolved Solids TDS, and Light. All measurements were done in triplicate and the average was then taken.

4.2.2 Instruments

4.2.2.1. The Multimeter

The Crison MM40 Multimeter was used to record the levels of pH, electrical conductivity (EC) total dissolved solids (TDS) and temperature. Before measurements were recorded, the Multimeter was calibrated according to the manufacturer's guide.

For the Multimeter to take the reading the probes would be inserted in the water and give the meter time to stabilize then readings would be recorded. The probes would then be taken out of water and dry them and again inserted back in the water, wait for the probes to stabilize and then record the reading. This step would be repeated 3 times so as to record data in triplicate.

4.2.2.2 The Turbidity meter

The Orbeco TB200 portable turbidity meter was used to measure turbidity. Before measurements were recorded, the turbidity meter was calibrated according to the manufacturer's guide. The meter measured turbidity in nephelometric turbidity units (NTU). A sample was collected in to clear bottle provided together with the meter. The bottle was then inserted in the meter for the meter to read the NTU. The turbidity meter sampling bottle would then be removed from the meter, shake the bottle, wipe it with a cloth provided together with the meter and insert back in the meter. Then value would then be recorded. This would be done 3 times so as to get the data in triplicate. Turbidity is the measure of clearness of water. High turbidity would mean less clear water.

4.2.2.3 The Dissolved Oxygen (DO) meter

The Crison Oxi45 dissolved oxygen meter was used to measure dissolved oxygen in water. The DO meter was calibrated according to the manufacturer's guide before data were recorded. The probes connected to the meter would be inserted in water and give the meter to stabilize and then the reading would be recorded. The probes would then be removed from water and allow them to dry and again insert in water and allow the meter to stabilize and record the reading. This would be repeated 3 times so as to record the data in triplicate.

4.2.3 Data analysis

The differences in water quality parameters between input (upstream) and output (midstream and downstream) for the wetland were determined using a paired samples t-test and ANOVA. The statistical methods were implemented using Microsoft *Excel* 2010 and the level of significance for all tests was set to $p < 0.05$.

4.3 Results and discussion

The variations in each of the different physical water quality variable starting with discharge of effluent from Makhado township oxidation ponds (discharge) which was the upstream into the wetland, through the middle section and downstream of the wetland are discussed. There was variation in the pH values of the water quality during the passage through the wetland (Figure 3). The highest pH reading of 9.07 was recorded in August 2014 at the discharge point which is a point of effluent entry in to the wetland. In the same month the midstream point, which is the point adjacent to the discharge point, recorded a pH value of 7.76 while the downstream point recorded 7.67. The lowest reading of 5.43 was recorded in November 2013 at the midstream point. At the same time the discharge recorded 7.6 while the downstream point recorded 8.22. According to the paired t-test analysis of the discharge and midstream sections ($p = 0.21$), midstream and downstream points ($p = 0.28$) and discharge and downstream sections ($p = 0.92$). Therefore there is no significant change in pH through the wetland.

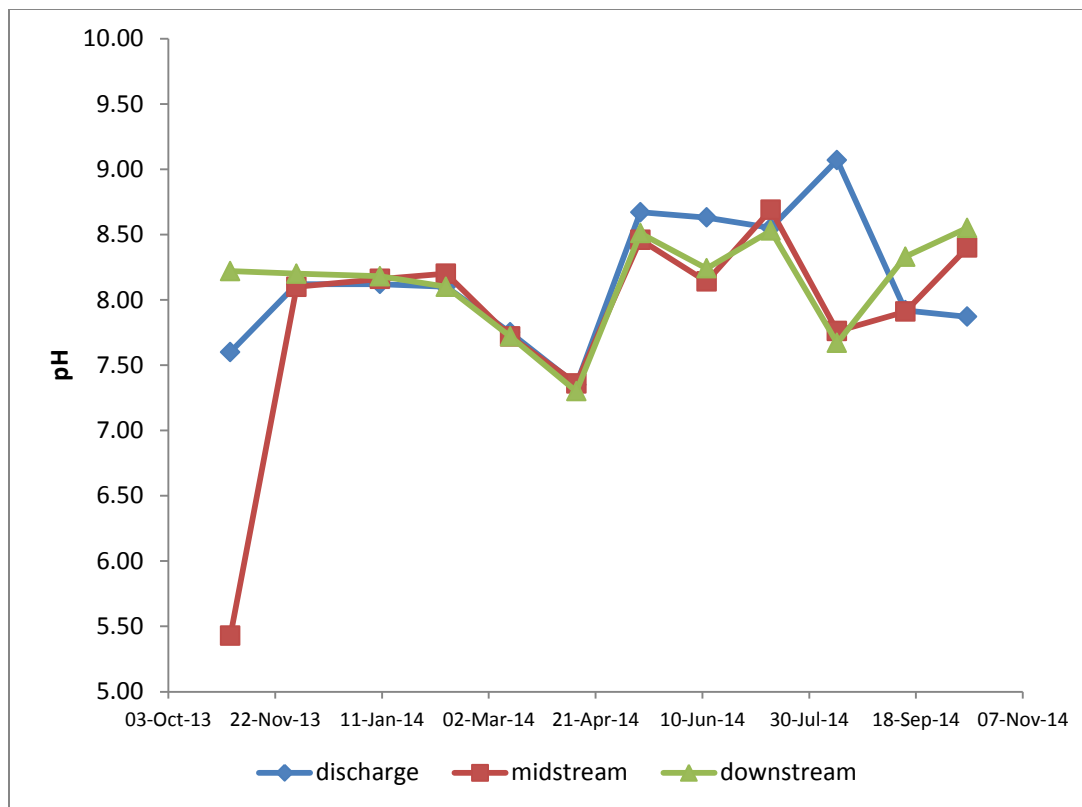


Figure 3: Variation in pH concentration through the wetland

The wetland upstream and downstream pH results were in the range of 7.35 - 9.07 and 7.30 - 8.55 respectively. The mean wetland upstream and downstream pH results were 8.15 ± 0.50 and 8.13 ± 0.38 . Thus the pH results were within to the Department of Water and Sanitation guidelines values for wastewater discharge of pH range of 5.5 to 9.5 (DWA, 1984). The pH values recorded the minimum of 7.3 and the maximum of 9.07 throughout the wetland. Cyanobacteria find their favorable grow conditions at a pH range of 7.4 to 8.0 (Rai and Rajashekar, 2014). Cyanobacteria species are able to adapt in acidic environment, but however, as the surrounding environment become more acidic their growth rate is affected (Rai and Rajashekar, 2014). The pH levels in the wetland were found to be in the range that promotes the development and growth of cyanobacteria (DWA, 1996b). The mean pH results are within the guideline values of 6.5 to 8.4 for irrigation waters as this will not cause crop foliar damage (DWA, 1996a). For pH > 8.4 there is evidence of foliar damage and the crop quality is visible such it may affect its marketability and consumer acceptance.

There was variation in the electrical conductivity (EC) values during the passage through the wetland (Figure 4). The discharge point recorded the highest value of EC at 1488 $\mu\text{S}/\text{cm}$ while the midstream point recorded a value of 1802 $\mu\text{S}/\text{cm}$ on the same month. The downstream point EC value of 965 $\mu\text{S}/\text{cm}$ was lower as compared to the upstream points on the same month. According to the paired t-test analysis of the discharge and midstream sections ($p= 0.49$), midstream and downstream points ($p= 0.11$) and discharge and downstream sections ($p= 0.28$). Therefore there is no significant change in electrical conductivity through the wetland.

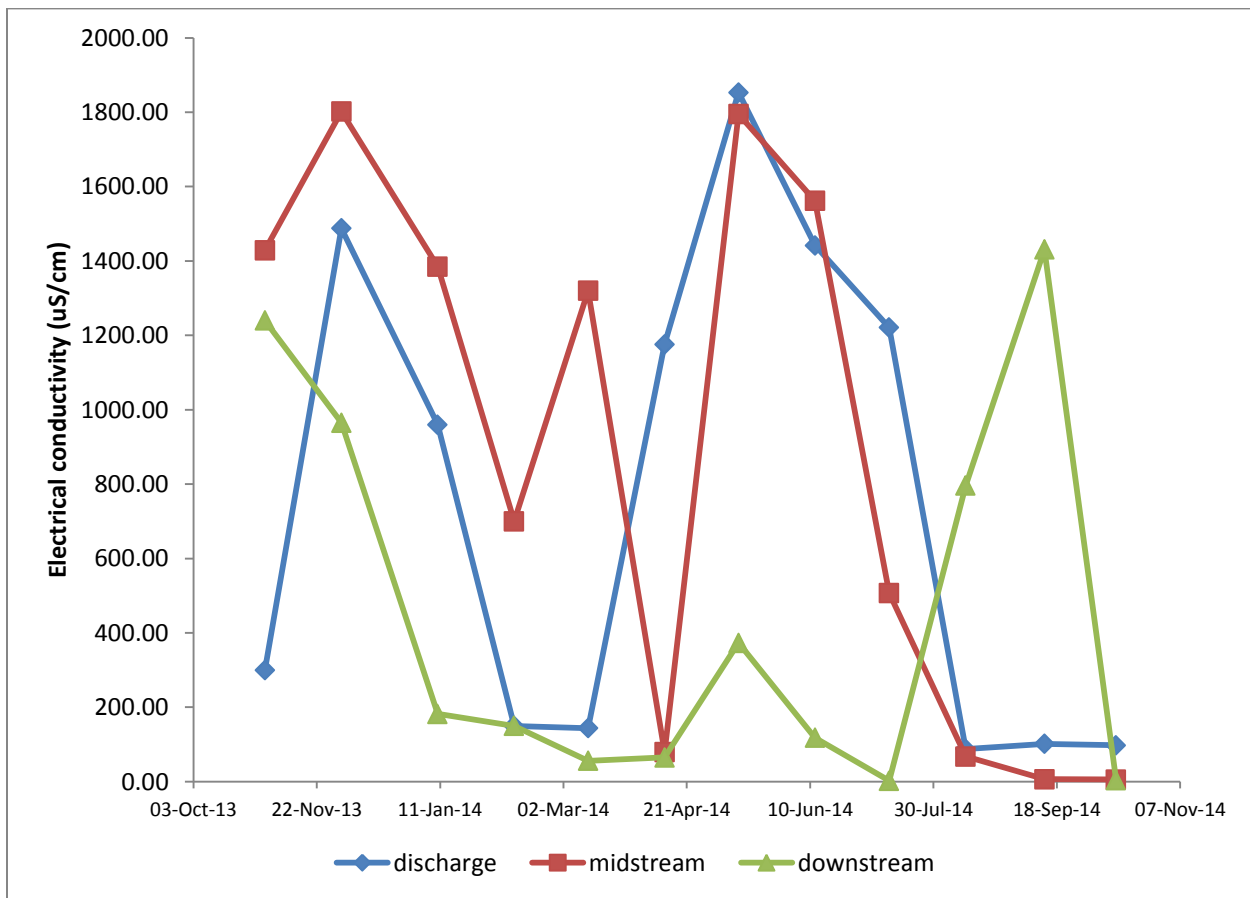


Figure 4: Variation in electrical conductivity ($\mu\text{S}/\text{cm}$) through the wetland

The wetland upstream and downstream electrical conductivity results were in the range of 87.8-1853 and 2.3-1431.0 $\mu\text{S}/\text{cm}$ respectively. The effluent discharge of Makhado oxidation ponds contributes to the upstream inflow to the wetland. The mean wetland

upstream and downstream electrical conductivity results were 751.8 ± 667.5 and $448.6 \pm 0.518.0$ $\mu\text{S}/\text{cm}$. Thus the electrical conductivity results did conform to the Department of Water and Sanitation guidelines values for wastewater discharge of electrical conductivity range which should not exceed 2500 $\mu\text{S}/\text{cm}$ (DWA, 1984). However for irrigation purposes, the acceptable EC range should be below the 400 $\mu\text{S}/\text{cm}$ guideline value for less sensitive crops according to DWAF (1996a).

There was variation in the total dissolved solids (TDS) values of the water quality during the passage through the wetland (Figure 4). The highest value of 1173.7 mg/l was recorded on the discharge point (upstream of the wetland) and lowest value of 2.0 mg/l was recorded on the downstream point. According to the paired t-test analysis of the discharge and midstream sections ($p= 0.63$), midstream and downstream points ($p= 0.07$) and discharge and downstream sections ($p= 0.22$). Therefore there is no significant change in total dissolved solids through the wetland.

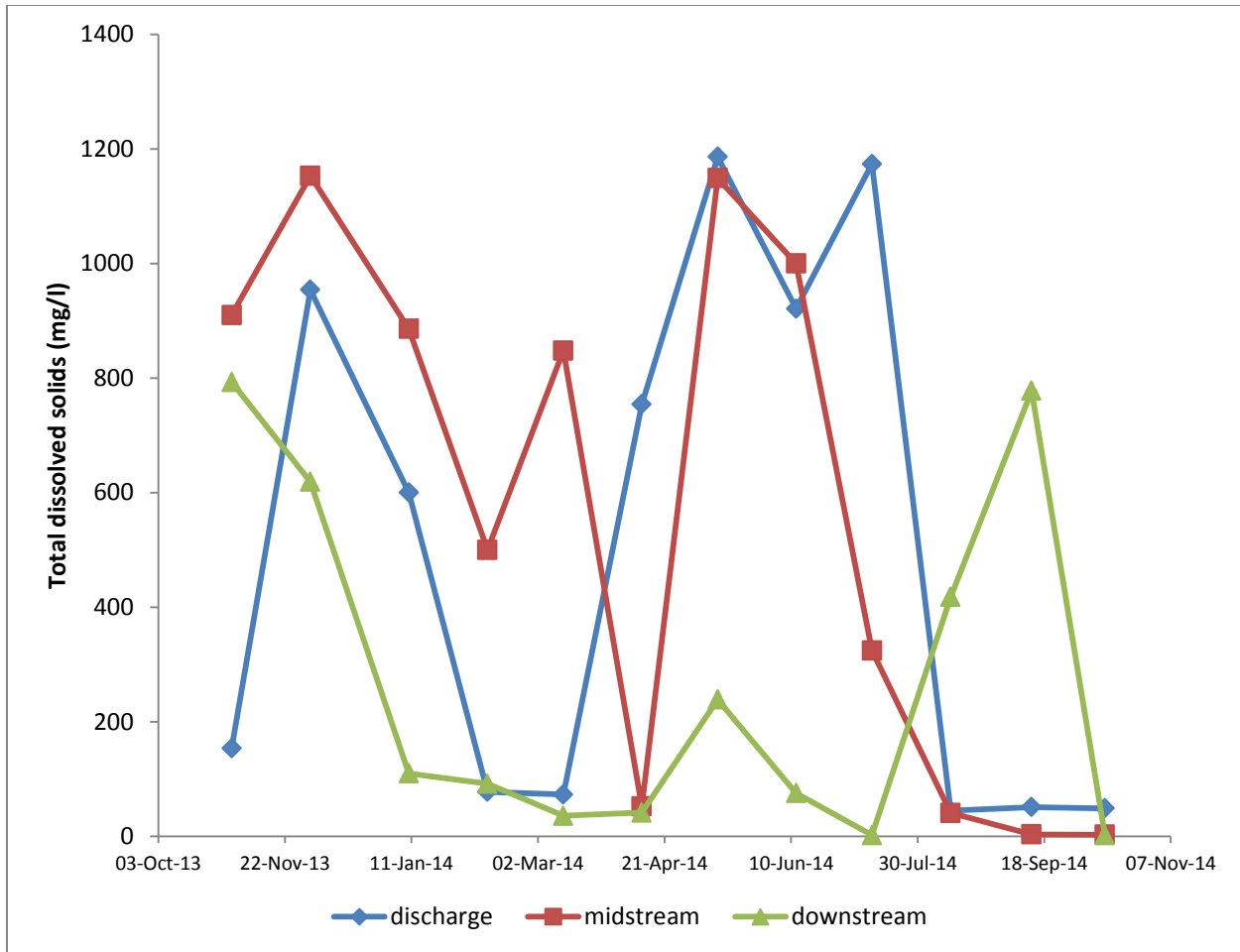


Figure 5: Variation total dissolved solids (mg/l) through the wetland

The wetland upstream and downstream total dissolved solids results were in the range of 44.9-1186.0 and 2.0-793.0 mg/l respectively. The mean wetland upstream and downstream total dissolved solids results were 503.2 ± 474.3 and 267.2 ± 304.8 mg/l. Thus the total dissolved solids results did not conform to the Department of Water and Sanitation guidelines values for wastewater discharge of total dissolved solids which should not exceed the maximum value of 25 mg/l (DWA, 1984). Total dissolved solids were much higher than DWAF acceptable standards. However for irrigation purposes, the acceptable TDS range should be below the 2600 mg/l guideline value for less sensitive crops according to DWAF (1996a). Some cyanobacteria have abilities to grow abundantly in salty water environment while freshwater environments with more trophic localities provide their desirable habitants (DWAF, 1996b; Chorus & Bartram, 1999).

There was variation in the turbidity values of the water quality during the passage through the wetland (Figure 6). The discharge point recorded the highest values of turbidity throughout the sampling period with a value of 299.17 mg/l in August 2014 which coincided with low rainfall. This may imply the high turbidity levels were due to sewage discharge from Makhado oxidation ponds. The lowest values are observed on the downstream point with value of 2.74 mg/l in September 2014.

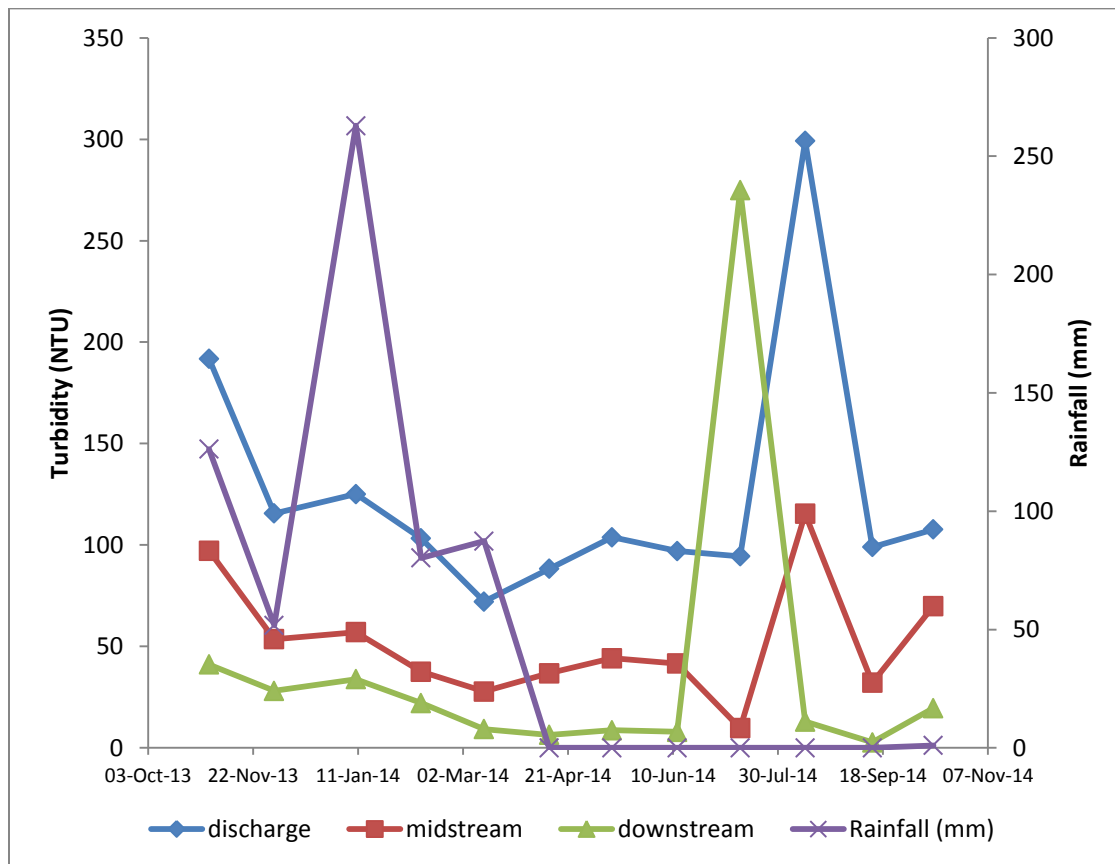


Figure 6: Variation in Turbidity through the wetland

According to the paired t-test analysis of the discharge and midstream sections ($p=0.00$), midstream and downstream points ($p=0.63$) and discharge and downstream sections ($p=0.01$). Therefore there was a significant change in turbidity levels between inflow and outflow indicating that the wetland was having a positive effect in reducing turbidity. The wetland inflow and outflow turbidity results were in the range of 72-299 NTU and 3-275 NTU respectively (Figure 6). The mean wetland inflow and outflow turbidity results were 125 ± 62 NTU and 39 ± 75 NTU.

Most cyanobacteria are aerobic and autotrophic and they can generate their own food from inorganic substances through sunlight in the presence of oxygen (DWAF, 1996b). They need carbon dioxide (CO₂), inorganic substances and light in a water environment to survive (Chorus & Bartram, 1999). Turbidity measurements were high at the discharge points in which case sunlight penetration could be reduced thereby reducing the rate of cyanobacteria self-generation of food by affecting photosynthesis. Due to the canopy and high turbidity in the upstream point and midstream point, it is expected that the life processes of the cyanobacteria were affected.

There was variation in the dissolved oxygen (DO) values of the water quality during the passage through the wetland (Figure 7). The high DO levels that were experienced in the discharge points also coincided with high rainfall in the months of November to March 2013. Thus high DO was probably due to oxygen enrichment from the rains that had fallen the previous days. According to the paired t-test analysis of the discharge and midstream sections ($p= 0.89$), midstream and downstream points ($p= 0.03$) and discharge and downstream sections ($p= 0.00$), there was a significant change in dissolved oxygen levels between inflow and outflow indicating that the wetland was having a positive effect in increasing the DO levels.

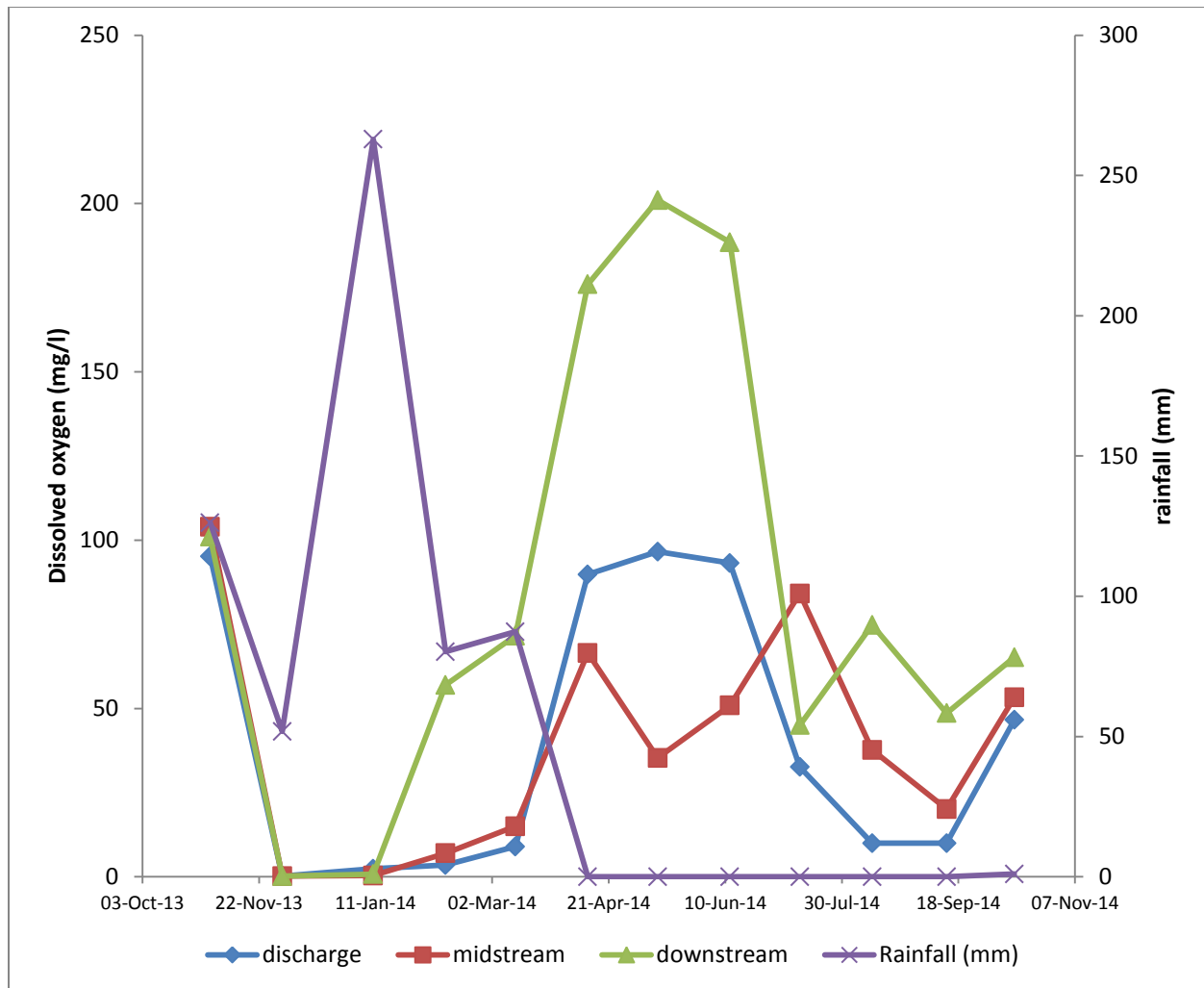


Figure 7: Variation in dissolved oxygen (mg/l) concentration through the wetland

The wetland upstream and downstream dissolved oxygen results were in the range of 0.2-96.6 mg/l and 0.2-201.0 mg/l respectively. The mean wetland inflow and outflow dissolved oxygen results were 40.8 ± 41.3 mg/l and 85.8 ± 68.3 mg/l. Thus dissolved oxygen results did conform to the Department of Water and Sanitation guidelines values for wastewater discharge general limits of at least 75% at the inflow. However, at the outflow the values are above the minimum of the general limits (DWA, 1984). The general limits requires that DO should be at least 75% saturation and this is equal to 750 mg/l. The presence of the cyanobacteria from the upstream points through to the midstream point may have contributed to the depletion of dissolved oxygen (DWA, 1984).

1996b. However, DO levels are observed as increasing on the downstream point due to the absence of cyanobacteria.

There was variation in the water temperature values of the water quality during the passage through the wetland (Figure 8).

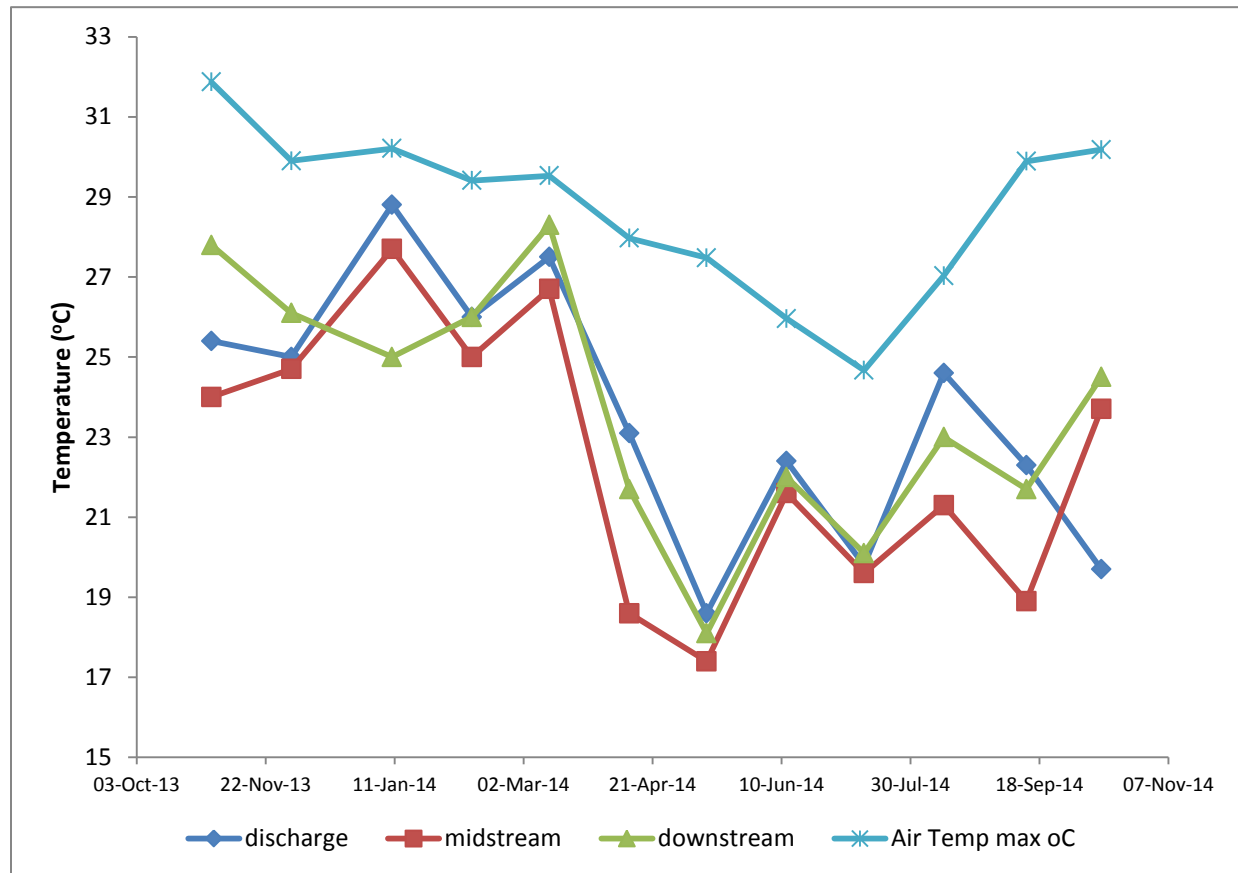


Figure 8: Variation in water temperature (°C) through the wetland

The water temperature reached a maximum of 28.8 °C at the discharge point in January 2014. The air temperature was also higher during the same month of January (Figure 8). According to the paired t-test analysis of the upstream and midstream sections ($p=0.08$), midstream and downstream points ($p=0.02$) and discharge and downstream sections ($p=0.89$). Therefore there was no significant change in water temperature change in the wetland.

The air temperature also influenced the water temperature discharge, midstream and downstream sections of the wetland. According to the paired t-test analysis of the discharge and midstream sections ($p= 0.00$), midstream and downstream points ($p= 0.00$) and discharge and downstream sections ($p= 0.00$).

The wetland discharge and downstream water temperature results were in the range of 18.6-28.8 °C and 18.1-28.3 °C respectfully. The mean wetland discharge and downstream water temperature results were 23.6 ± 3.2 °C and 23.7 ± 3.1 °C. Thus the temperature results were within to the Department of Water and Sanitation guidelines values for wastewater discharge of water temperature which shall not exceed 35 °C (DWA, 1984). The water Temperatures in the wetland are recorded between 17°C and 28.8°C, which are warmer temperatures. Cyanobacteria species grow well in temperatures ranging between 16°C and 27°C (DWA, 1996b; Rai and Rajashekar, 2014). With warmer temperatures in the wetland, favorable conditions for the development and thriving of the cyanobacteria are provided for through the wetland.

4.4 Conclusion

There were generally no significant changes through the wetland on the physical parameters. Their contents in water did not conform to the DWA (1984) guidelines on wastewater discharge. However, it has been noted that these physical parameters were within the limits for irrigation water guidelines and therefore irrigating with this water has could be good. Although there is no significant change in physical parameters through the wetland, DO has been noted to be increasing from discharge point through the midstream point and the discharge point. The physical parameters in the study area have been found to promote the growth and development of cyanobacteria.

CHAPTER 5: THE CHANGE IN THE LEVELS OF HEAVY METALS THROUGH THE WETLAND

5.1 Introduction

Variations in concentrations of various heavy metals in through the wetland were recorded on the discharge point, midstream point and the discharge point. Water samples were collected these points and were delivered to the University of Venda laboratory for preparations and were then delivered to the University of Stellenbosch Laboratory for analysis. The preparations of samples, the methods of analysis and the results are therefore presented below.

5.2 Materials and methods

5.2.1. Water sampling and preparation

Water samples were collected in to the 250ml white bottles and stored in the cooler bag and be transported to the university of Venda laboratory. Once in the laboratory samples were filtered through Sartorius membrane filter nylon, 0.45 μ m (Germany) in to a glass tube and the tube would be sealed using a Para film paper. Samples were preserved by adding a 0.5 ml of nitric acid using the micro-pipette. Prepared samples were then delivered to the University of Stellenbosch laboratory for analysis.

5.2.2 ICP MS analysis

The heavy and trace metals such as Zinc, Copper, vanadium, Chromium, Manganese and Platinum were analysed using Inductively-Coupled Plasma-Mass Spectrometry (ICP-MS) and Inductively-Coupled Plasma-Absorption Emission Spectrometry (ICP-AES). The analysis was in duplicate.

5.2.3 Data Analysis

The Thermo ICAP 6300 instrument (ICP-AES) was used to analyze major 40 elements and reported the elements in levels of parts per million (ppm) at a detection limit of 0.01 ppm. The instrument was calibrated using the US EPA method 6020A. Analysis was

automatic, and data acquisition and processing was controlled by instrument software. The results were expressed as ppm and or ppb.

5.3 Results and discussion

5.3.1 Aluminum (Al)

During the start of the sampling period Aluminum was measured at 1.99 ppb at the discharge point and it was 2.49 ppb at the midsection of the wetland while it was 1.99 ppb at the outflow point (Figure 9). Aluminum was well within the target water quality range for irrigation water which should be ≤ 5 mg/l (DWAF, 1996a). The highest reduction of Aluminum was during the months of February and July with 99.44% and 97.01% reduction respectively. There is however, increase in Aluminum concentration by more than 100% in the wetland during April, May, June, August and September sampling period. There was no rainfall in the area during this period and this may have reduced the assimilative capacity of the wetland.

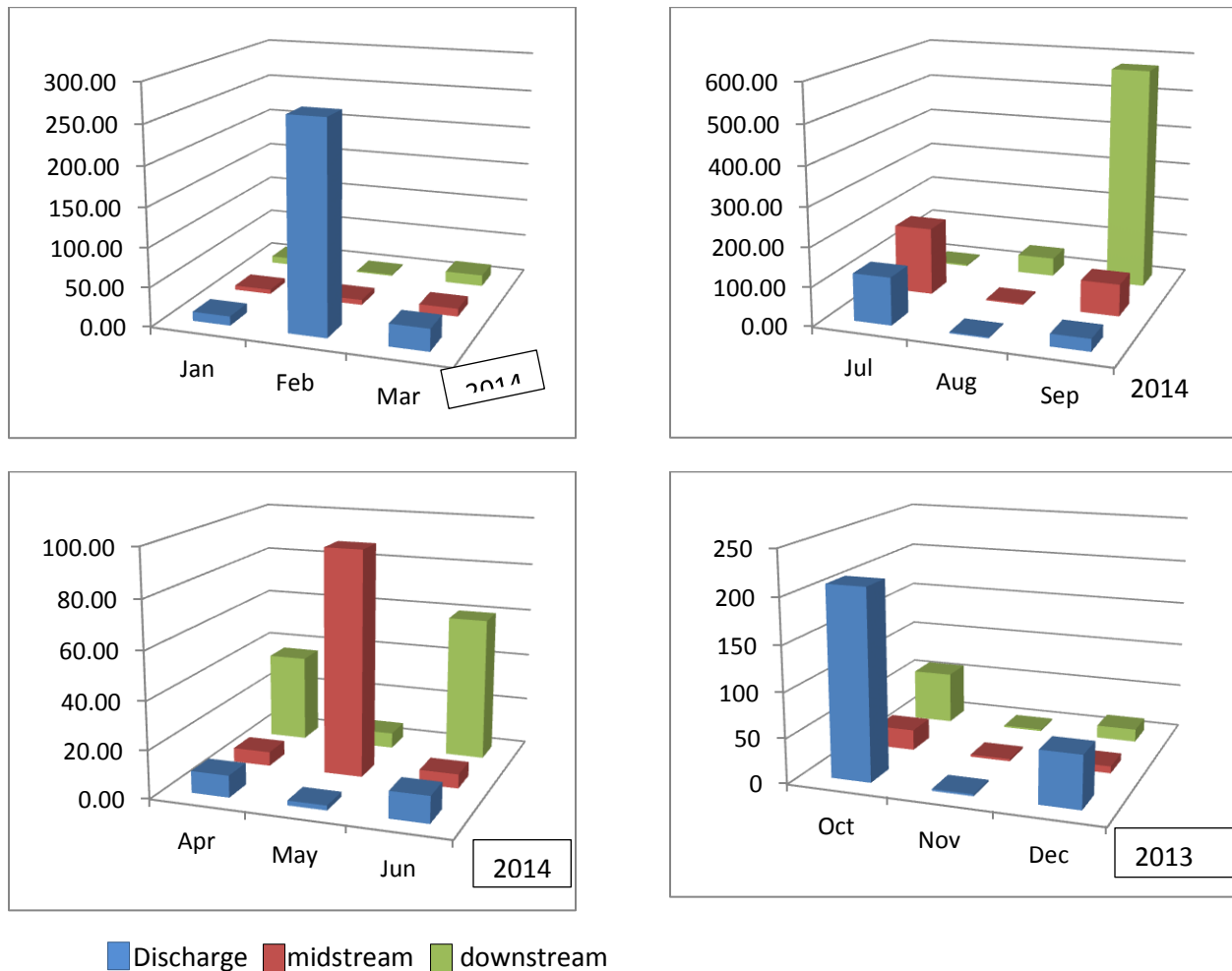


Figure 9: The variation in AI concentration (ppb) through the wetland

5.3.2 Titanium (Ti)

The wetland experienced the highest Titanium reduction of 89.99% during July and this followed the reduction by 89.89% and 71.43 % during February and December respectively (Figure 10). The reduction in Titanium was experienced during rainy months in the area. Titanium was also increased by more than 100% during dry seasons and the highest increase was during September when there was rainfall recorded in the area.

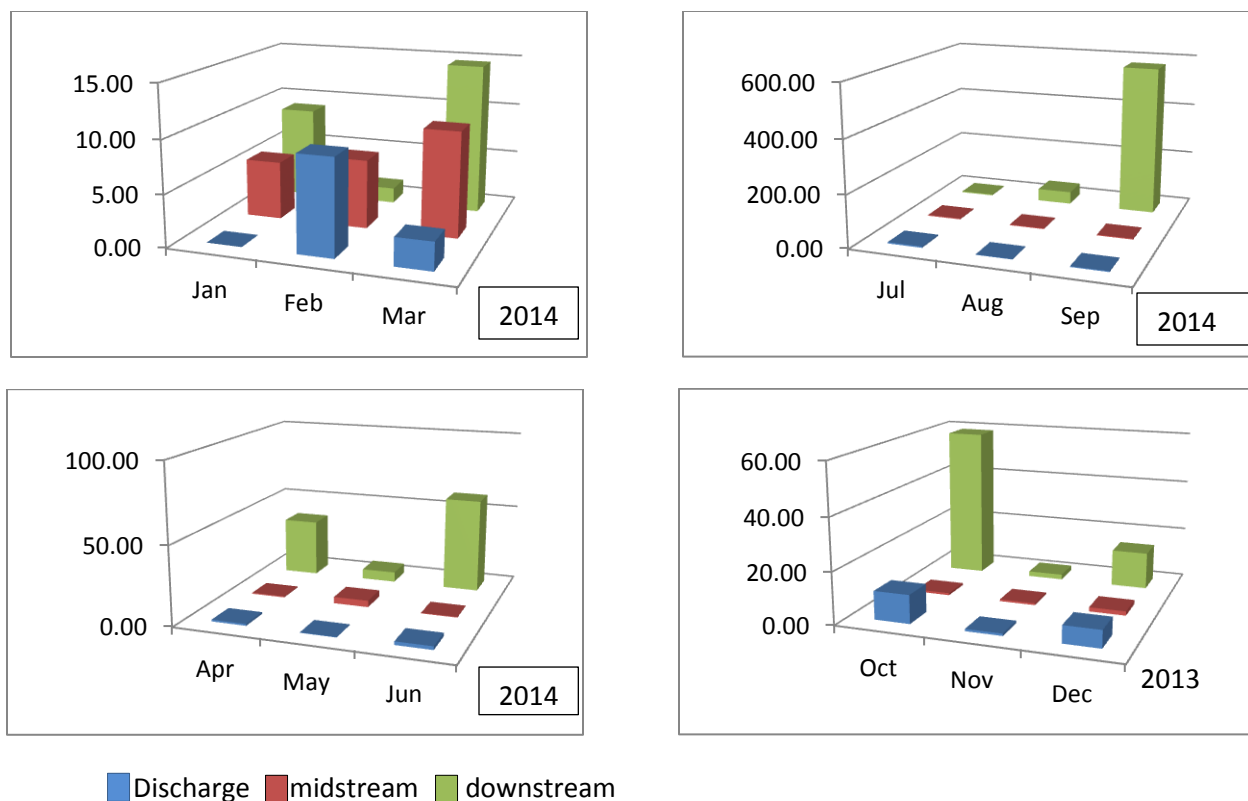


Figure 10: Variations in Ti concentrations (ppb) through the wetland

5.3.3. Vanadium (V)

Vanadium variations were recorded throughout the wetland with the highest value recorded at 56.63ppb during June at the downstream with the lowest value of 0.66ppb recorded at the midstream during March (Figure 11) and did conform to the target water quality range set at ≤ 0.1 ppm (DWAF, 1996a). The highest value was recorded during dry periods in the area and these were the periods when the wetland experienced mostly increased vanadium concentrations for half a year. Concentrations in vanadium were also reduced and the highest reductions were 89.54% during July. Although this was during dry seasons in the area, the metal absorption may have been the reason for this reduction. Between the discharge point and the midstream point, the wetland is dense and characterized by various plants and the introduction of vanadium was low at the discharge point.

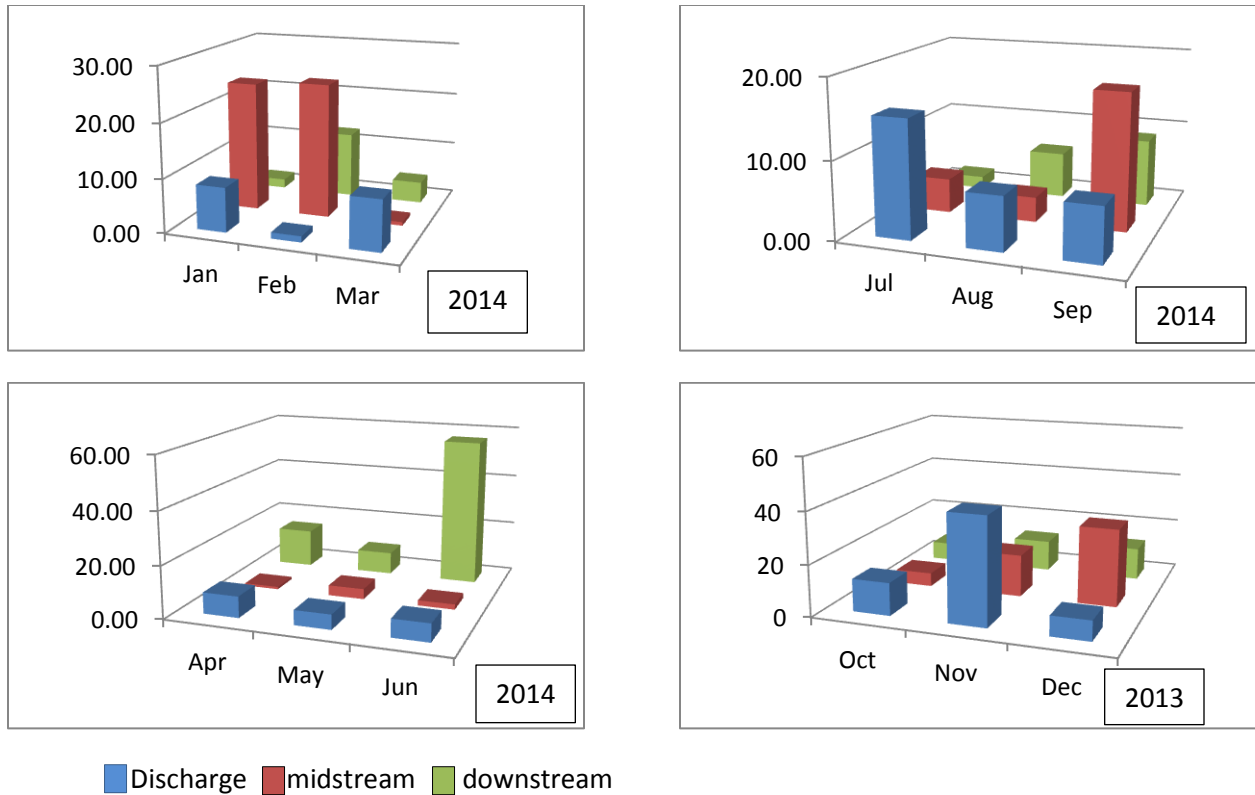


Figure 11: Variation in V concentration (ppb) through the wetland

5.3.4 Total Chromium (Cr)

Concentrations in Cr were mostly increased in the wetland having been increased for seven months in the twelve months sampling periods (Figure 12) and did conform to the target water quality range of ≤ 0.1 ppm (DWAf, 1996a). During December and January Cr concentrations were increasing and have increased by more than 100%. The highest reduction in Cr concentrations was 96.18% during July which was a non-rainy period. Dense vegetation between the discharge and midstream point may have resulted to high plant uptake the metals may have been the cause for the reduction in Cr.

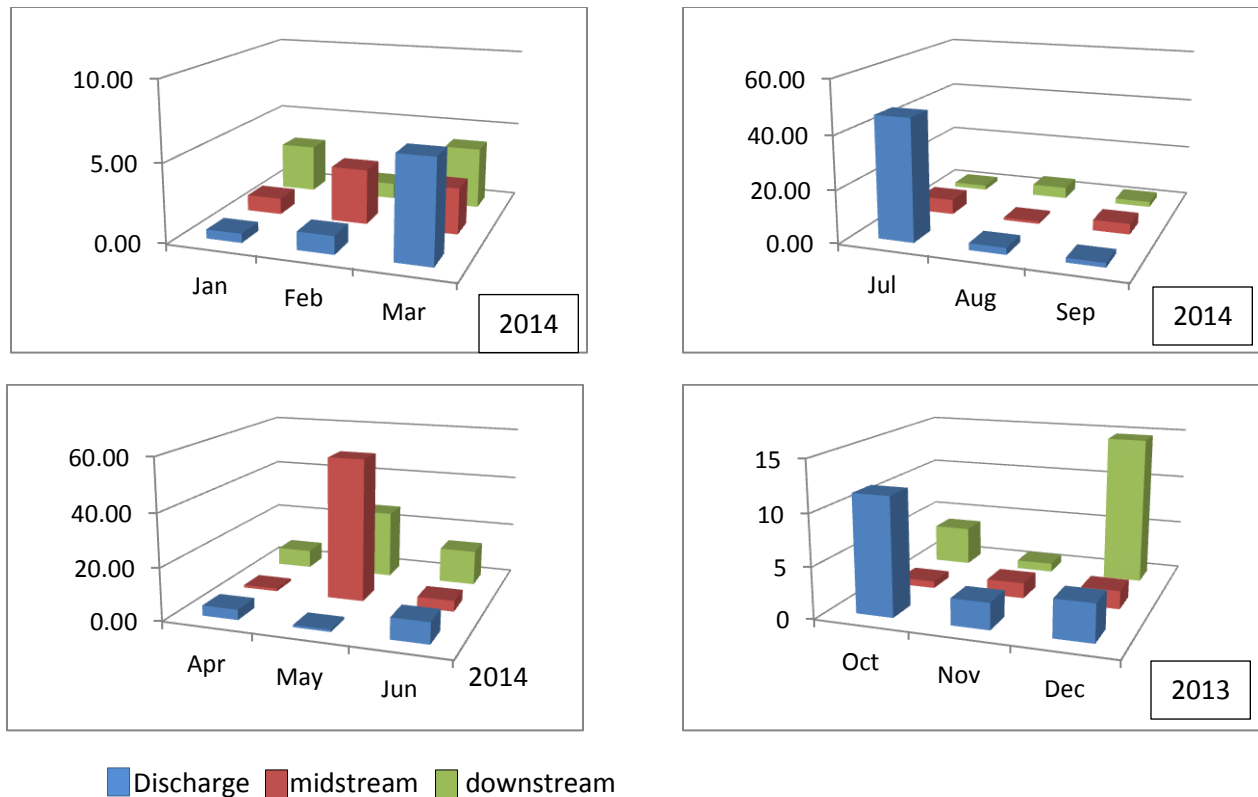


Figure 12: Variation in Total Chromium (ppb) concentration through the wetland

5.3.5 Manganese (Mn)

Manganese levels in the wetland varied considerably with the discharge point recording the highest value at 2271.48ppb during December 2013 while the midstream recorded the lowest value at 0.39ppb during August 2014 (Figure 13) and conformed to the target water quality range for irrigation set at $\leq 0.02\text{mg/l}$ (DWAf, 1996a). There were increases in the Mn concentration throughout the wetland for six months of the twelve months sampling period with November of 2013 having experienced the increased by more than 100%. January, April, May and October of 2014 also experienced Mn concentrations increasing by more than 100%. November 2013 recorded high rainfall in the area and runoffs from various parts of the localized catchment may have contributed to the increased concentrations during this month. However, during July, August and September of 2014 there were highest reductions of Mn through the wetland. During this period there was no rainfall recorded in the area so plant metal uptake may have been the source of metal reduction in the wetland.

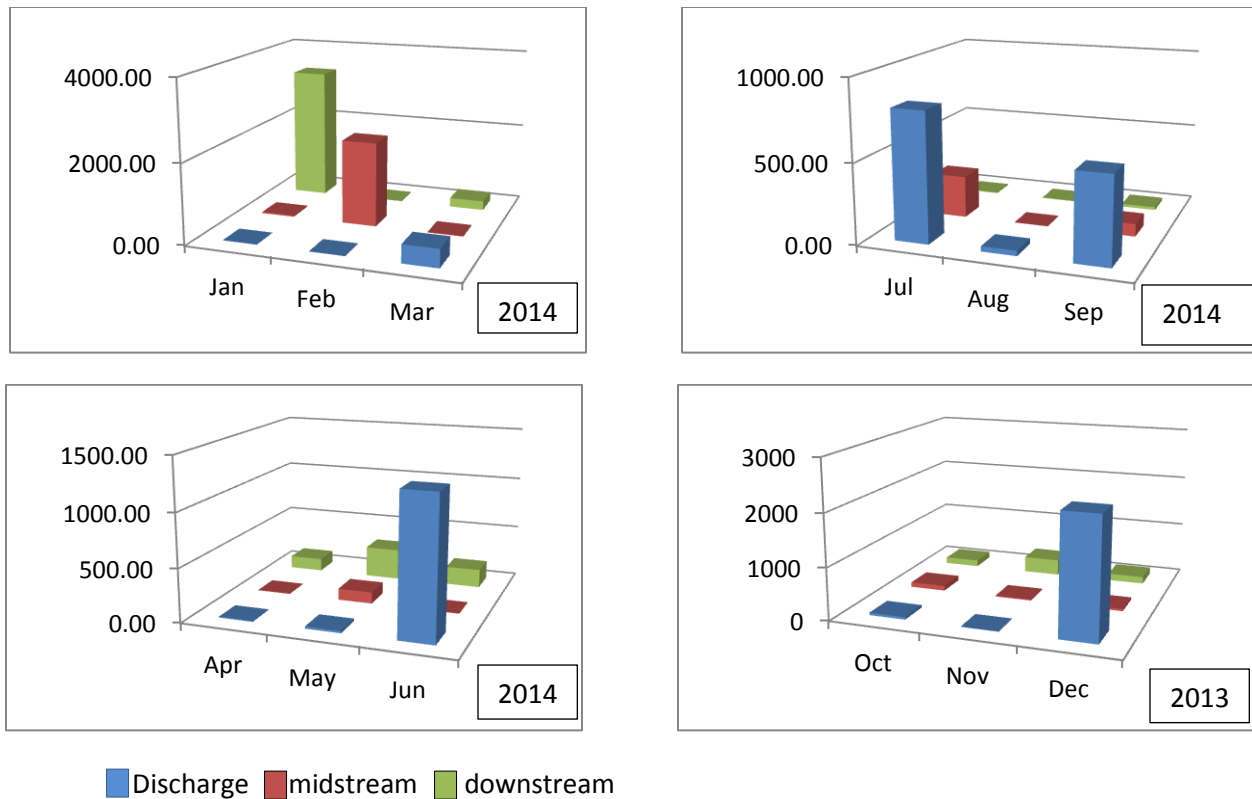


Figure 13: Variation in Manganese (ppb) concentration through the wetland

5.3.6 Iron (Fe)

There were mostly high concentrations of Fe in the wetland (Figure 14) and did not conform to the target water quality range for irrigation water set at ≤ 5 mg/l (DWA, 1996a). During rainfall seasons Fe may have been introduced in the midsections of the wetland and given the fact that wetland are characterized by very slow movement of water Fe may have been given longer residence time in the wetland. There was 96.48% reduction in Fe during December 2013. This significant reduction, however, was followed by increases of more than 100% during January, April, May and August of 2014. Another significant reduction of 99.58% occurred in July 2014 though it was followed by more than 100% increase during August 2014. Figure 14 below indicates the variations in Fe concentrations through the wetland.

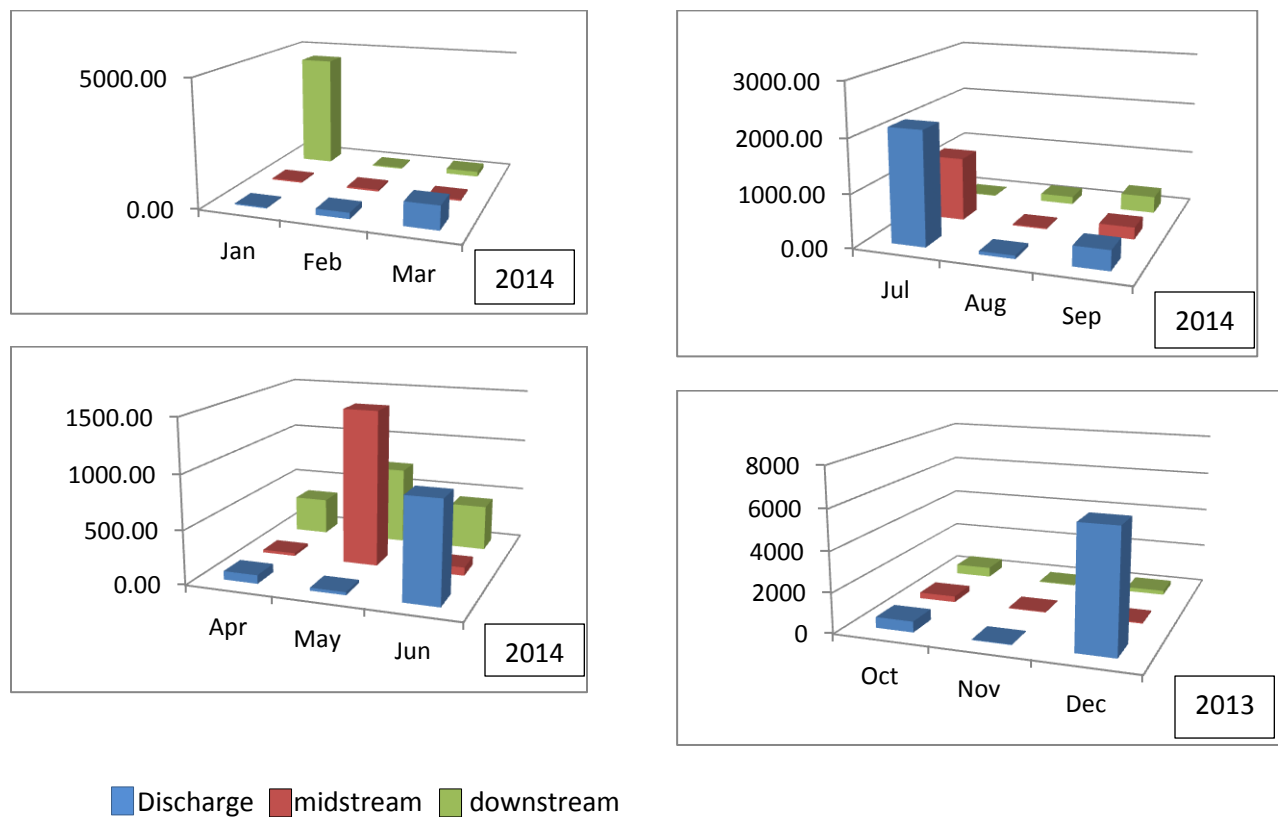


Figure 14: Variation in Iron (ppb) concentration through the wetland

5.3.7 Cobalt (Co)

Cobalt was mostly measured at low levels below the target water quality range of ≤ 0.05 ppm (DWAf, 1996a) through the sampling period (Figure 15). The highest was recorded at the 32.06 ppb in midstream while all the other measurements were always below 8 ppb throughout the sampling period. During November 2013 Co was increased by more than 100% in the wetland but immediately a reduction of 50.46% was noted during December 2013. There were also increases in the concentration of Co during January, February and March of 2014 with March recording the highest increase at 65.93%. These increases were also followed by significant reduction and the highest reduction recorded at 99.01% during July which was a non-rainy month. November and December 2013 as well as January, February and March of 2014 were rainy periods

and Co concentrations are increasing during this runoff season. Plant uptake may have been effective during dry periods when there was no runoff.

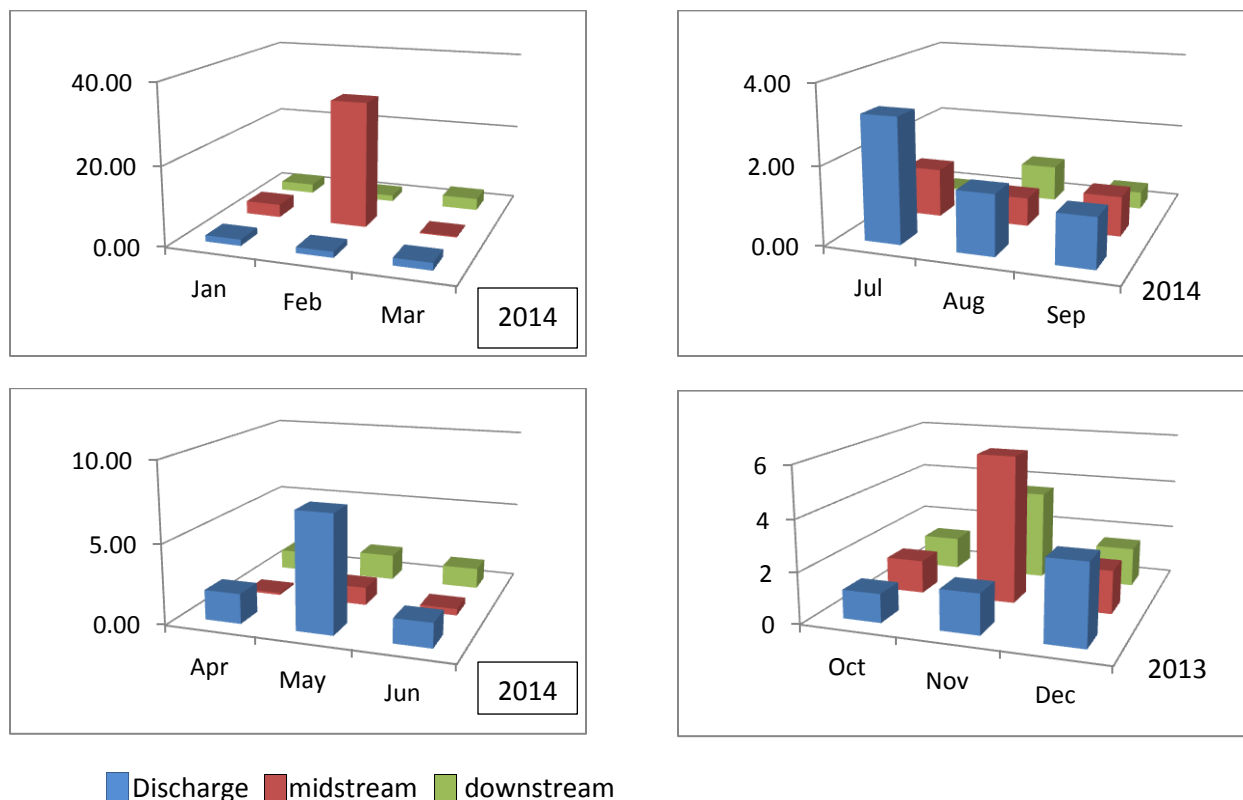


Figure 15: Variation in Cobalt (ppb) concentration through the wetland

5.3.8 Nickel Ni

Nickel was measured mostly in small amounts throughout the sampling period with the highest at 30.28 ppb at the discharge point recorded during July while downstream recorded the lowest at 0.47 ppb during the same month (Figure 16) and did conform to the target water quality range of ≤ 0.2 ppm (DAAF, 1996a). During the eight months of the sampling period Ni was increased and December 2013, February and April of 2014 recorded an increase of more than 100%. There was a insignificant reduction at 2.09% during January 2014. This was a rainy season in the area and runoff could have been responsible for the introduction of Ni in the wetland. The highest reduction in Ni concentration of 98.45% was recorded in July 2014 and another significant reduction was at 51% in October 2014. This was a dry period in the area and given the dense

vegetation in the wetland, plant uptake on metals may have contributed to the reduction in Ni. Figure 16 below indicates the variations in Ni concentrations through the wetland.

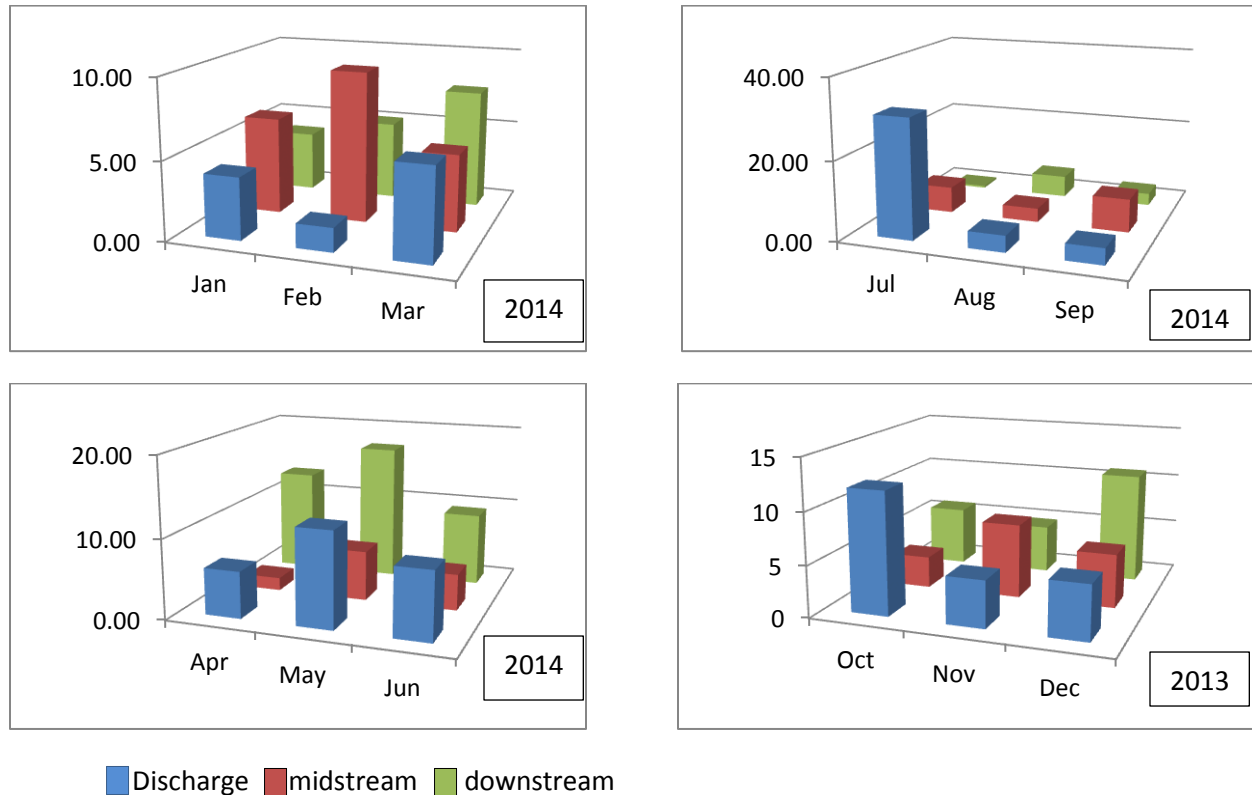


Figure 16: Variation in Nickel (ppb) concentration through the wetland

5.3.9 Copper (Cu)

Copper measurements reached the highest in July at the discharge point measuring 83.51 ppb while the lowest measurements were at midstream point in October at 1.8 ppm (Figure 17). Cu concentrations did conform to the target water quality range in irrigation set at ≤ 0.2 ppm (DWAf, 1996a). During the twelve month sampling period Cu reduction in the wetland occurred in seven months and the highest reduction was in July by 99.39%. There were, however, increases in Cu concentrations in the wetland for five months of the sampling period. In December 2013 there was an increase in Cu concentration by more than 100%. During this month the discharge point measured the lowest concentration of Cu but increased in the midsection and the downstream points. Runoff may have been the cause for the increase through erosional activities by

introducing more matters in to wetland. During dry season in July in the area there was high reduction in Cu concentration and this could have been due to high plant uptake of metals. Cu can be removed by between 69-99% in wetlands (Chen et al., 2009).

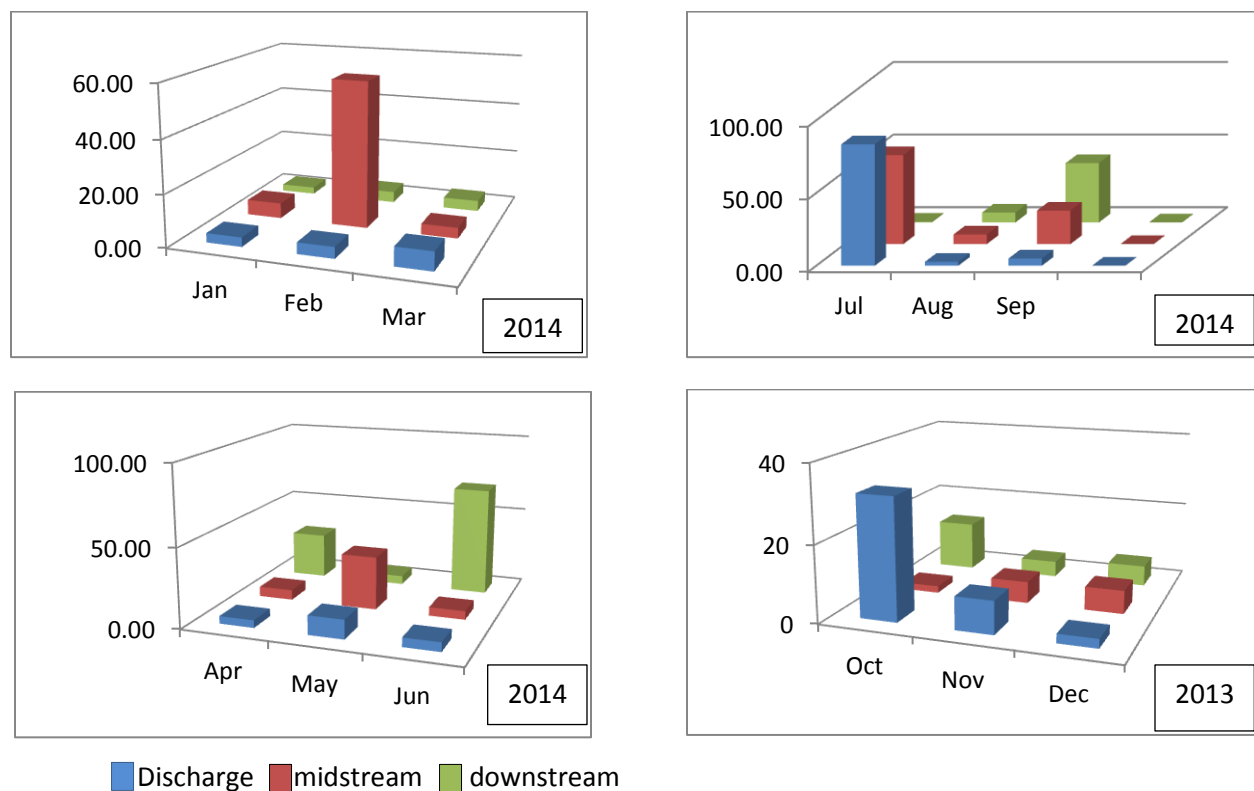


Figure 17: Variations in Copper (ppb) concentrations through the wetland

5.3.10 Zinc (Zn)

The discharge point had the highest introduction of Zn in the wetland in July at 113.4 ppb (Figure 18) and did conform to the target water quality range of 0 – 1 ppm for irrigation water (DWA, 1996a). However, in February during the rainy season the wetland midsection had increasing Zn concentration than at the discharge point. During April after the March rainfall the downstream point measured the highest concentration above both Discharge and Midstream point and at this point Zn concentrations were increased by more than 100% due to runoff transporting matter from the upstream to the downstream. Zn concentration remained increased by more than 100% in the May and June 2014. However, these increased concentrations were followed by the highest

reduction in July by 99.24%. July was one of the dry months in the area and by this time runoff matter could have completely settled and allow for plant uptake. Zn removal by wetland can be in the range of 54-99% (Chen et al., 2009).

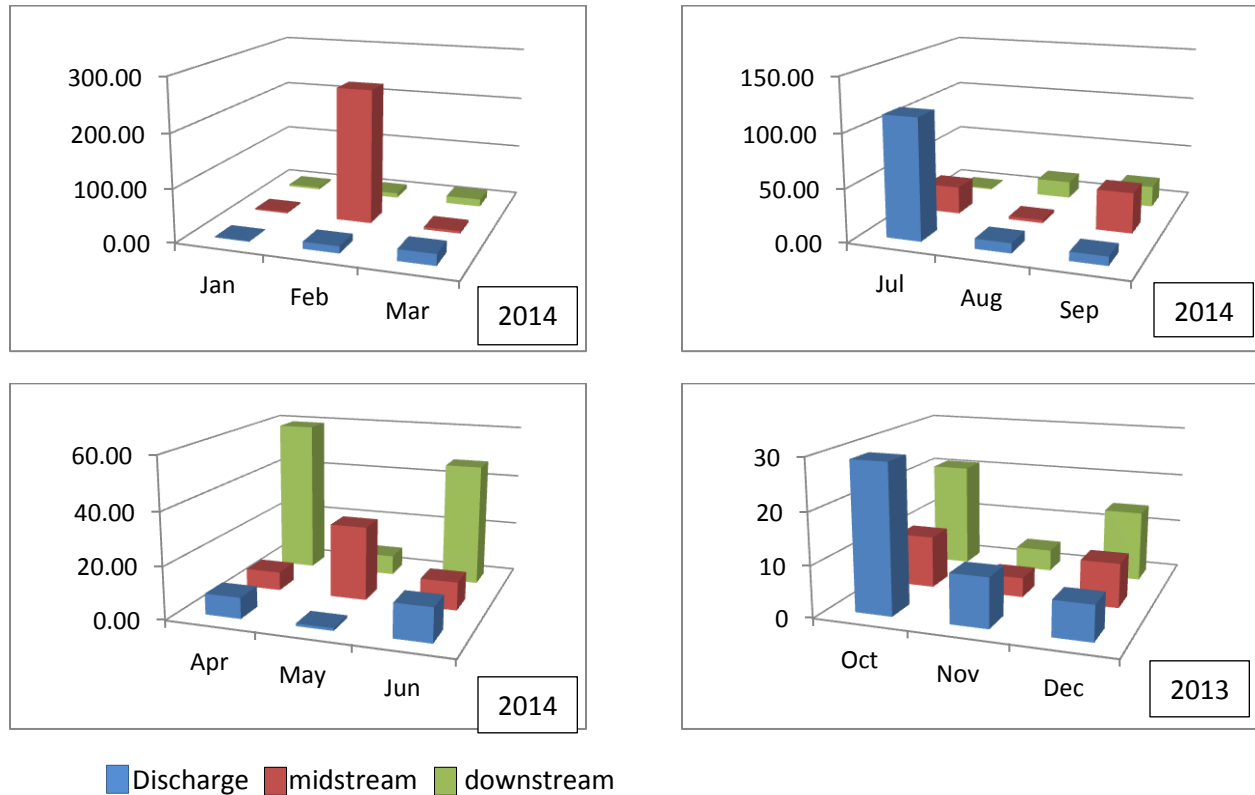


Figure 18: Variations in Zinc (ppb) concentrations through the wetland

5.3.11 Arsenic (As)

Arsenic measured very low levels and mostly less than 5 ppm in the wetland while its concentrations were reduced in nine months of the twelve months sampling seasons (Figure 19). The target water quality range for Arsenic in irrigation water is ≤ 0.1 mg/l (DWA, 1996a) and concentration conform to the target water quality range. Arsenic concentration was increased by 100% in the wetland during September and this occurred at the downstream section of the wetland. Arsenic is introduced to water resources through soil erosion and anthropogenic activities such as the application of fertilizers on irrigation lands (Tchounwou et al., 2012). Metal uptake by plants at the downstream section is expected to be less effective as compared to the midsections

which are very dense. Arsenic concentration was generally reduced throughout the wetland.

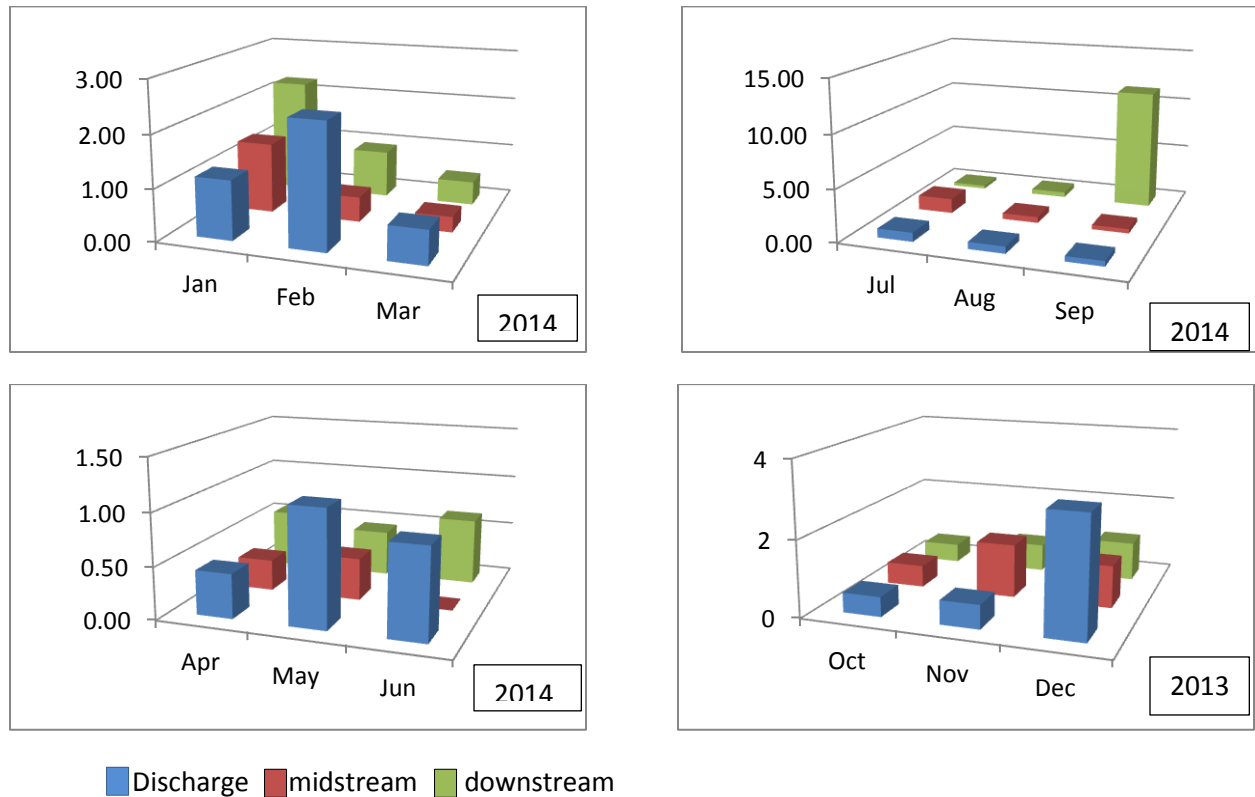


Figure 19: Variations in Arsenic (ppb) concentrations through the wetland

5.3.12 Molybdenum (Mo)

Although Molybdenum generally measured at low levels (Figure 20) in the wetland throughout the sampling period, it did not conform to the target water quality range for irrigation set as ≤ 0.01 mg/l (DWAf, 1996a) during February and July. However, in February the concentration of Mo was increased by more than 100%. At the discharge point it was measured at 0.23 ppb but the levels were much higher in the midsections of the wetland, measured at 106.42 ppb. This month was a rainy season in the area and it is expected that runoff may have contributed to the increasing levels in the midsections. The concentrations of Mo were later reduced by 97.7% during August and followed by minor but significant reductions in the preceding months.

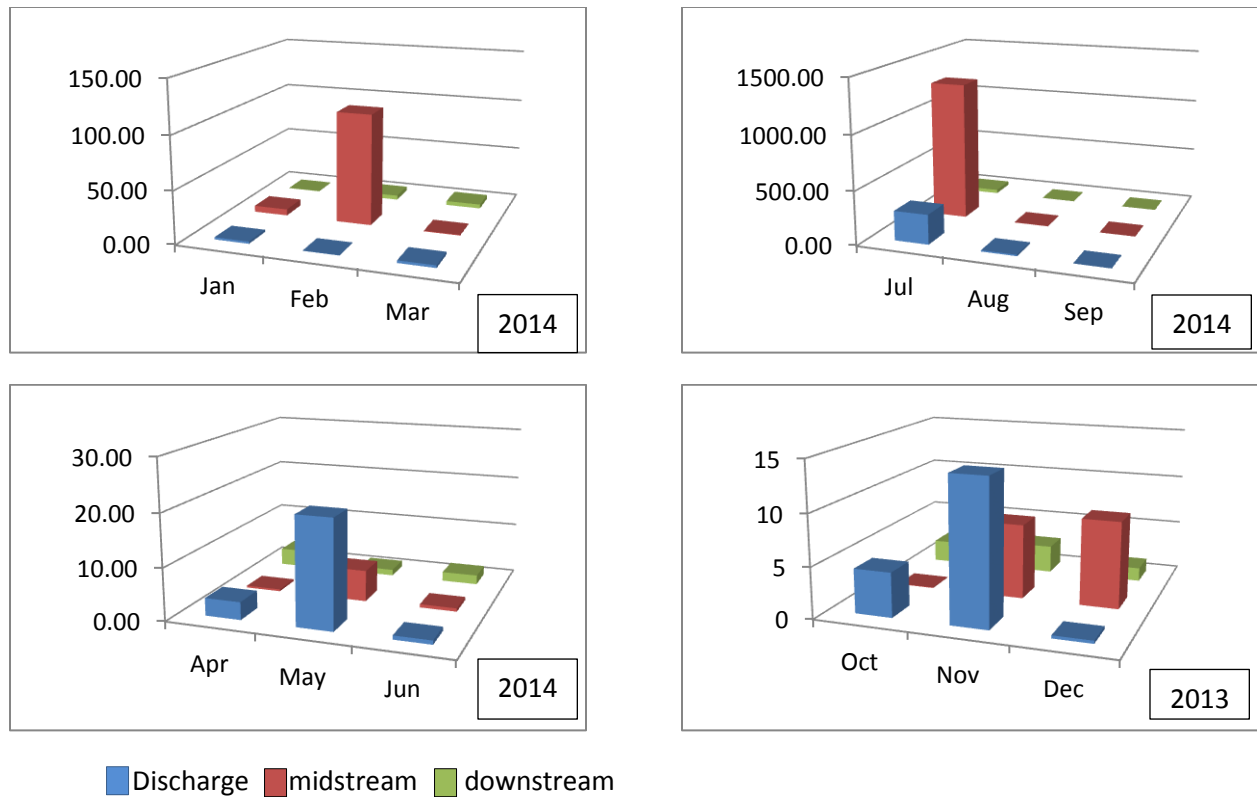


Figure 20: Variations in Molybdenum (ppb) concentrations through the wetland

5.3.13 Cadmium (Cd)

Cadmium measurements were in very low concentration in the wetland throughout the sampling period and always measured less than 0.3 ppb (Figure 21) and the levels conformed to the target water quality range for ≤ 10 ppm in irrigation (DWAF, 1996). Although at low concentrations, it was neither reduced nor increased. During March 2014, Cd was reduced by 88.1% in the wetland. However, this was followed by more than 100% increased concentrations during April 2014. March 2014 was a rainy season in the area and it is expected that the assimilative capacity of the wetland could have diluted the concentrations of Cd since it was always in very small concentrations. In April 2014 when runoff stopped it is expected that Cd may have settled down and dissolved in the wetland.

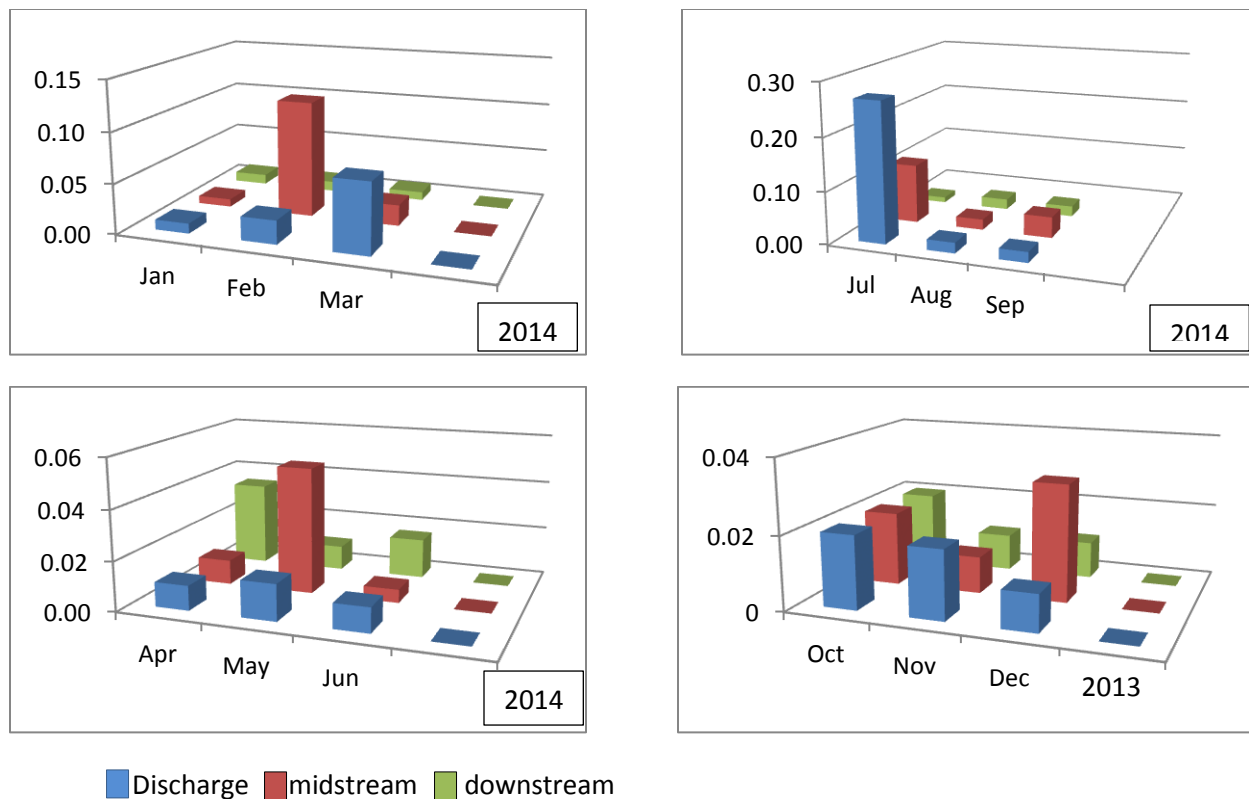


Figure 21: Variations in Cadmium (ppb) concentrations through the wetland

5.3.14 Tin (Sn)

Tin concentrations were increasing in the wetland in the first four months of the sampling period and the highest increase was measured at 82.62% in January 2014 (Figure 22). It is noted that in the following months there was a 50.36% reduction in Sn concentrations in March 2014. The First four months of the sampling period was a rainy season in the area and runoff may have been contributing to the increasing levels in the wetland. The significant reduction followed the end of rainfall and this could have allowed Sn to settle down and then allow for metal uptake by plants.

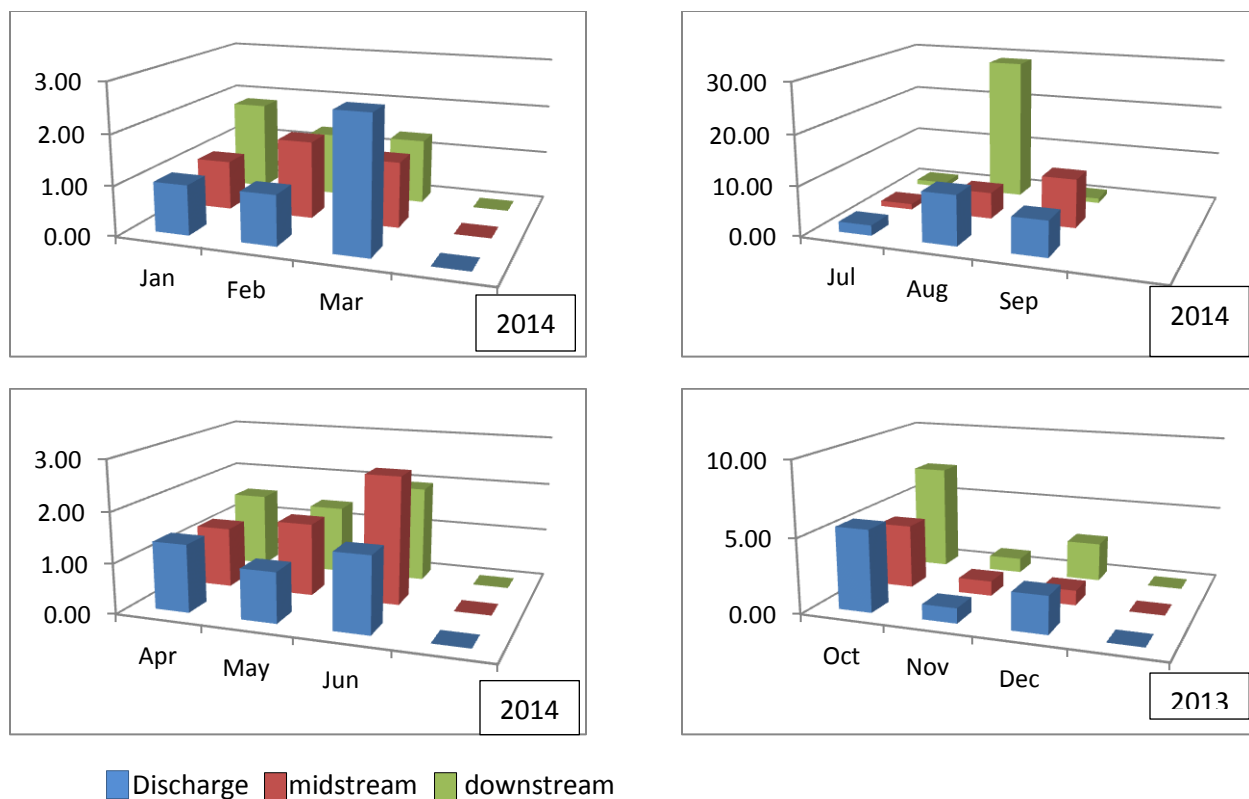


Figure 22: Variations in Sn (ppb) concentrations through the wetland

5.3.15 Antimony (Sb)

During the rainfall season in the area, Sb concentration was reduced throughout the wetland and the highest reduction was 87.31% during February 2014 (Figure 23). This significant reduction may have been facilitated by runoff which may have increased the assimilative capacity of the wetland. Also during the following months which were non-rainy periods, Sb concentration continue to be reduced in the wetland with the highest reduction measured at 94.1% and 97.8% in July and August 2014 respectively. After the rainy season flow through the wetland became slow again and allowed for the settlement of matter and further more allow for absorption by plants.

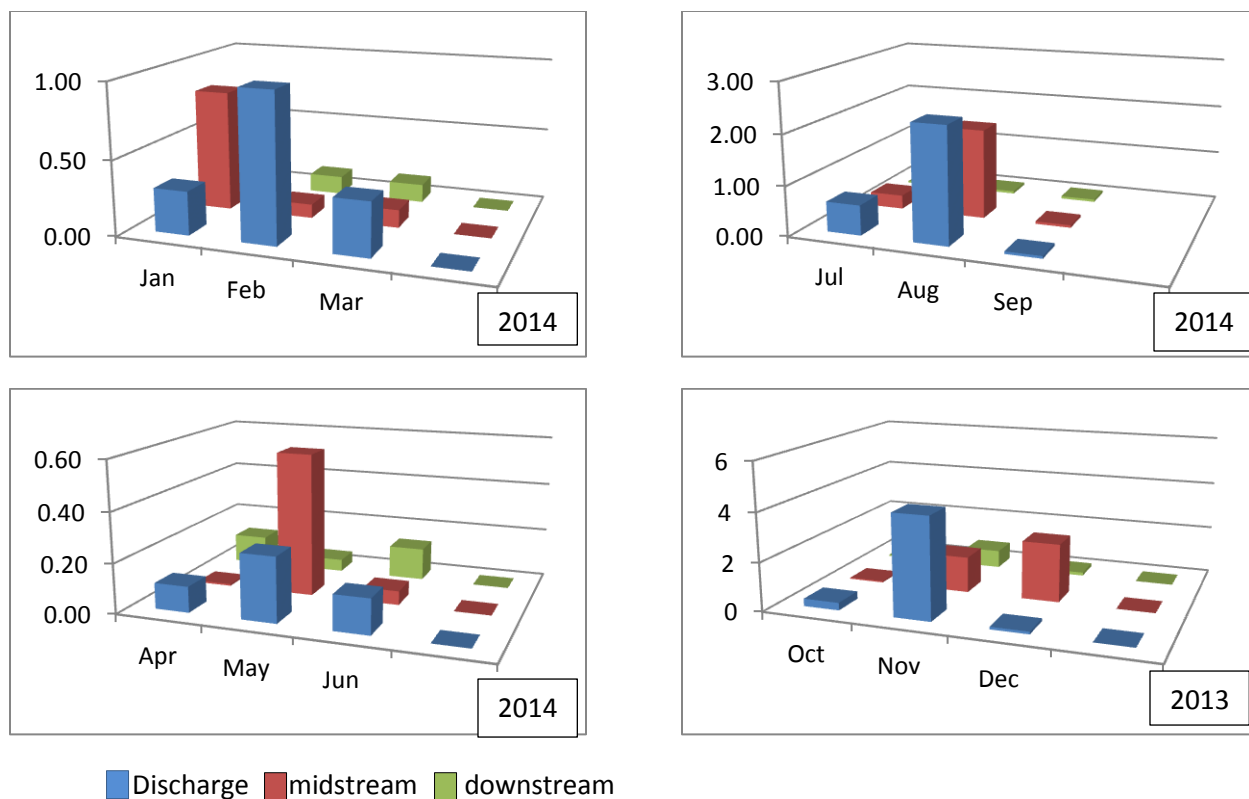


Figure 23: Variations in Sb (ppb) concentrations through the wetland

5.3.16 Mercury (Hg)

Although Mercury is a widespread environmental toxicant and pollutant (Tchounwou et al., 2012), its measurements were very low in the wetland throughout the sampling season with the highest level at 0.08 ppb measured at the discharge point in July 2014 while the lowest level was 0.0 ppb measured at the discharge point in September 2014 (Figure 24). Hg concentration was neither increased nor reduced in the beginning of the sampling period in October 2013 and in December 2013 there was an increase of Hg concentration in the wetland. This was a rainfall season in the area and the increase in Hg levels could have been the results of runoff since the levels are low at the discharge point but increasing at the downstream point. In July 2014 the Hg concentration increased by 86.15%. It is important to note that July 2014 was non-rainy month in the area and by this time runoff had stopped and allow for matter to dissolve in water while settling in the wetland. Mercury can be reduced by up to 98% by reeds and 99% by water hyacinth (Balazinski et al., 2001). When settled plant absorption may have

increased the reduction in Hg concentration and its levels were reduced by 87.5% in August 2014 followed by 100% reduction in September 2014.

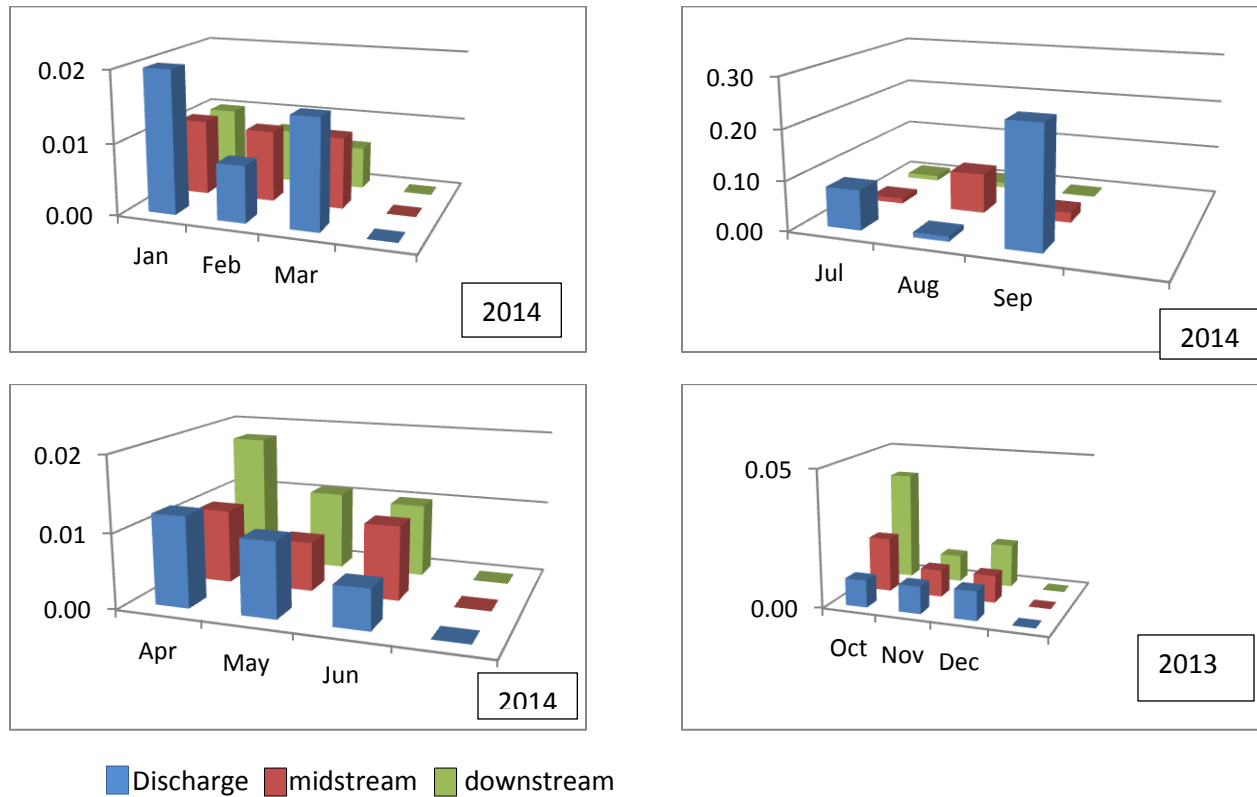


Figure 24: Variations in Hg (ppb) concentrations through the wetland

5.3.17 Lead (Pb)

Lead concentrations were generally low in the wetland with the highest measured at 5.77 ppm in the midsections of the wetland during May 2014 with the lowest measured at 0.05ppb during February 2014 (Figure 25) and did conform to the target water quality range set at ≤ 0.2 mg/l (DWA, 1996a). During the rainfall season Pb was increased in the wetland by more than 100% and again in April 2014 immediately after rainfall season. During rainy seasons it is expected that runoff could have eroded matter of different chemical composition and may have contributed to the increasing levels of Pb. During dry seasons when runoff was off, the wetland, through its slow water movement, may have allowed for the dissolving of matter and hence the increase in Pb concentrations. In the same time plant uptake may have started to play a role in the

wetland when sediments have settled down and allow reach by plants roots and there was a significant reduction in Pb concentration in the wetland at the end of the sampling period in October 2014. The efficiency of Pb removal from wetland can be between 95-99% and totally depend on its concentration and with little relation to its residence time (Chen et al., 2009).

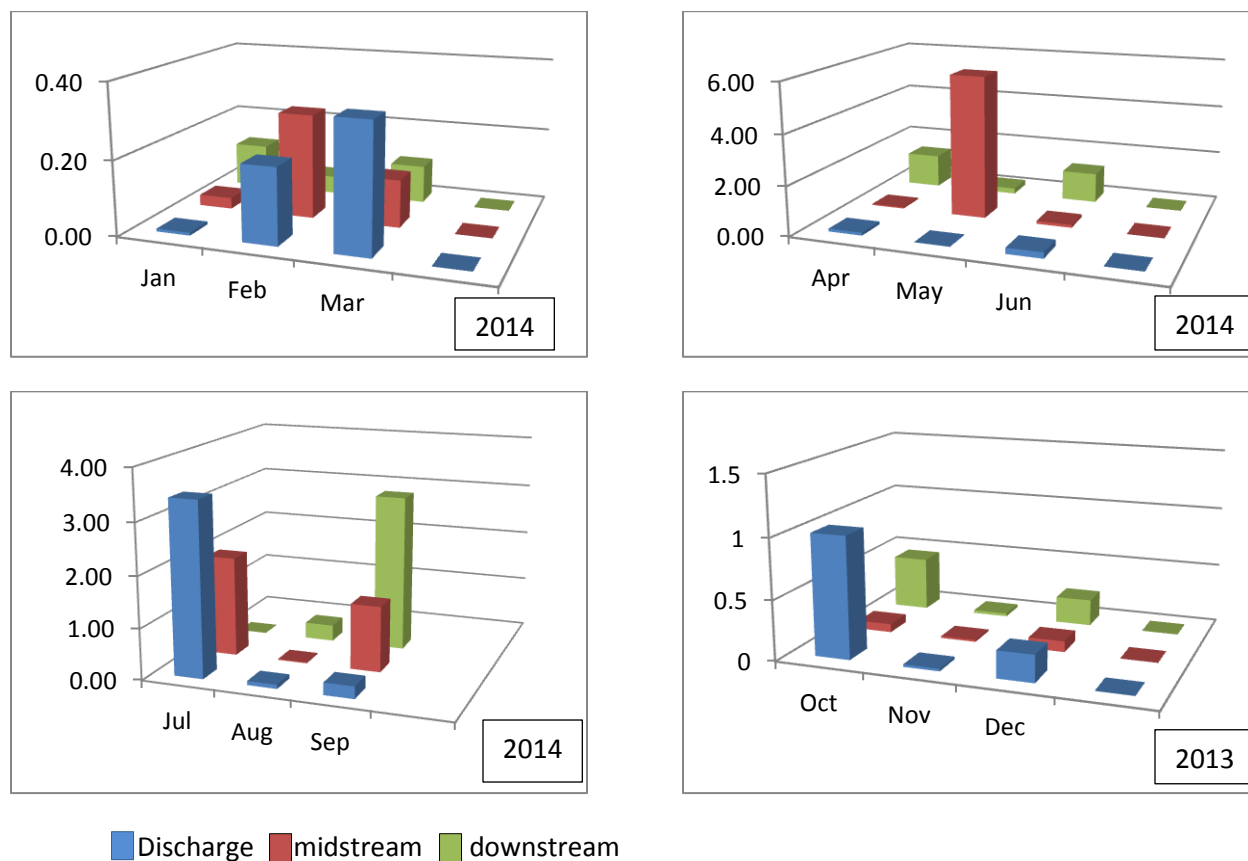


Figure 25: Variations in Lead (ppb) concentrations through the wetland

5.4 Conclusion

The theory that wetland environments are able to reduce pollution by absorbing pollutants can be said to be true with regard to the presence of heavy metals after passing through the wetland. Significant reductions on all the heavy metals were observed through the sampling points in the wetland. The slow flow of water through the wetland can be said to have a greater role in ensuring that the heavy metals have longer residence time in the wetland and provide time for the roots plants to absorb the

metals. Cadmium (Cd) was measured in very small amounts and was the only heavy metal which was neither reduced nor increased in the wetland. The heavy metals in the wetland did conform to the DWAF (1996) with the exception of iron and manganese which increased during the rainy season.

CHAPTER 6: THE GENERAL ANIONS OF WATER QUALITY THROUGHOUT THE WETLAND

6.1 Introduction

The variations of the different anions in water are discussed starting with discharge of effluent from Makhado township oxidation ponds which were the inflow into the wetland, through the middle section and outflow of the wetland. The anions analyzed are chloride, nitrite, bromide, nitrate, sulphates and phosphates.

6.2 Materials and methods

6.2.1 Water sampling

The water samples were collected also analysed for anions.

6.2.2 Ion chromatographic analysis

The water samples were filtered using a hypodermic syringe and a membrane filter 0.45 μ m sent were sent to Stellenbosch University. The water samples were analysed using Dionex Ion chromatography.

6.2.3 Data analysis

MS Excel 2010 was used to draw graphs and calculate average.

6.3 Results and discussion

6.3.1. Chloride

The highest value of chloride was recorded during September at 1707.1 ppm at the discharge point while the lowest reading was recorded at 22.62 ppm at the same point (Figure 26). The target water quality range for irrigation purposes is ≤ 100 ppm (DWAF, 1996a) above which crops start to accumulate the chloride contents to toxic levels which affect the quality of the crops (DWAF, 1996a). Mostly the chloride content did not conform to the DWAF limits except only during May 2014 at the discharge point where it was recorded at 22.62 ppm. The following graph indicates the variations of chloride contents through the wetland (Figure 26) with the downstream chloride level being mostly lower than the discharge point indicating the removal of chloride during its passage in the wetland.

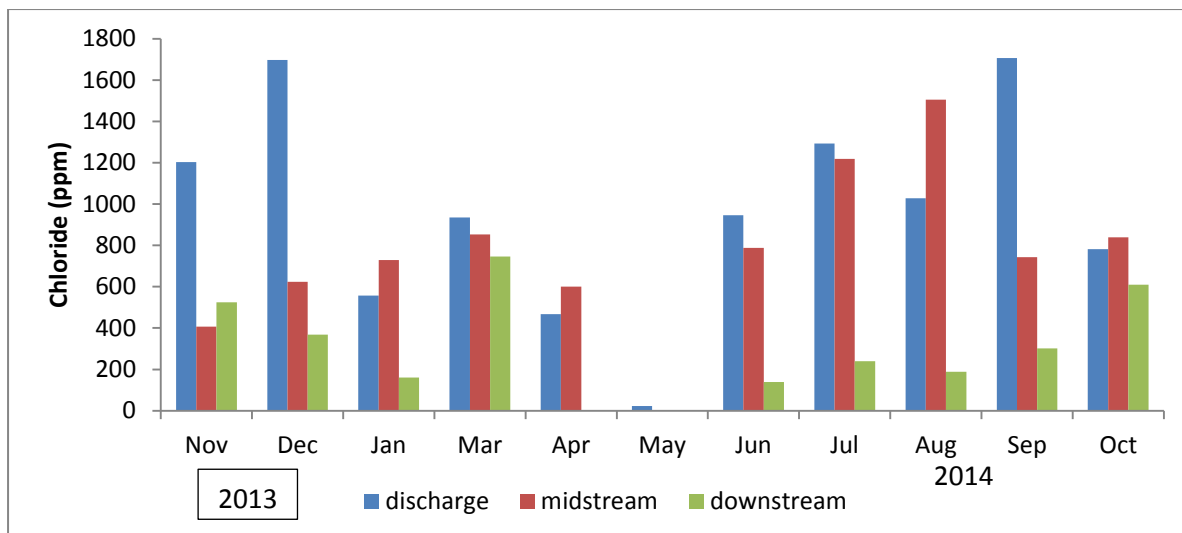


Figure 26: The variation in chloride content through the wetland

The downstream point recorded 0 ppm of the chloride contents during April 2014 and May 2014 while the midstream recorded 0 ppm only during May 2014.

6.3.2. Nitrite

The Nitrite concentrations recorded higher levels above the recommended target water quality range (Figure 27). The highest value was recorded at discharge point at 2134.14 ppm during September 2014 while the lowest value was recorded at 1.02 ppm at the downstream point during February 2014. The target water quality range for Nitrite is 0.5 ppm (DWAf, 1996a). The following graph shows the variation in concentration in Nitrite through the wetland during the sampling period (Figure 27).

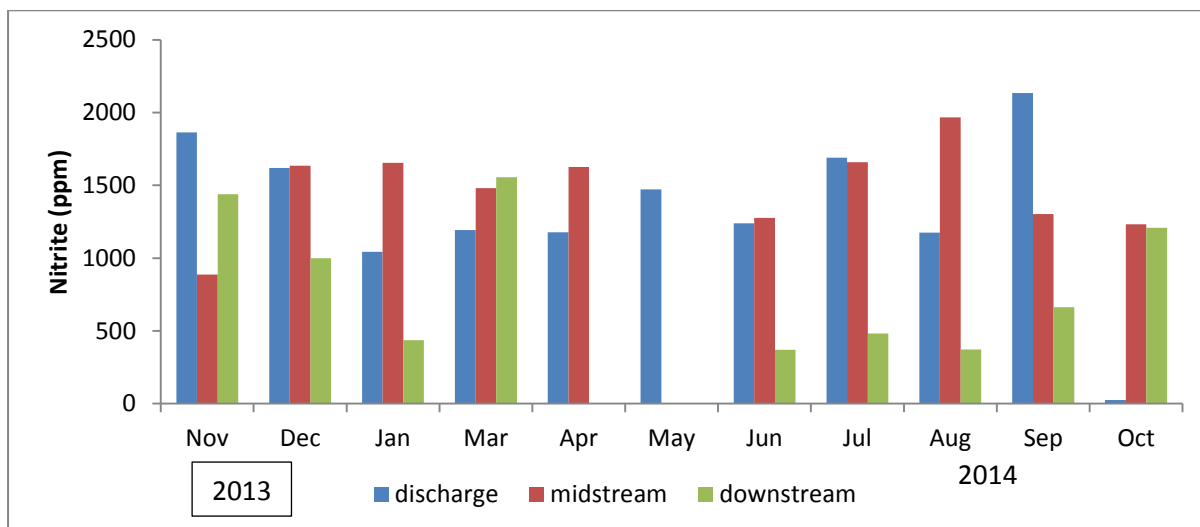


Figure 27: The variation in Nitrite concentrations through the wetland

Nitrite concentrations did not conform to the South African Water Guidelines on target water quality ranges for irrigation water.

6.3.3. Nitrate

High levels of Nitrate were recorded through the wetland with the highest values recorded at 8715.66 ppm recorded during May 2014 while the lowest reading was made at 167.73 ppm during September 2014 (Figure 28). During the sampling period Nitrate variations did not conform to the DWAF limits set at 0.5 ppm (DWAF, 1996a) on ten sampling events. But during other sampling runs, the nitrates levels were within the desired DWAF limits of nitrate concentrations. The following graph shows the variations in nitrate concentration through the wetland (Figure 28). The presence of nitrates in wetland may contribute to development of harmful algal blooms. Also the presence nutrients in the wetland waters may be exploited by subsistence farmers for use in the irrigation plots that are located close to the wetland.

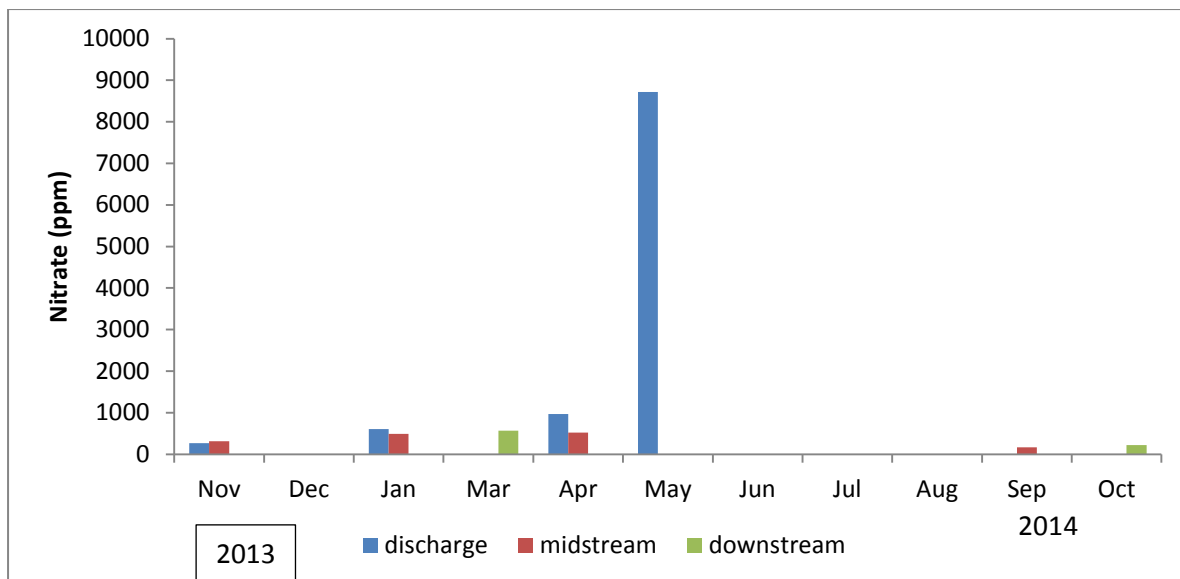


Figure 28: The variation in Nitrate concentrations through the wetland

6.3.4. Phosphate

Phosphate is salts containing phosphorus which is commonly applied in irrigation as fertilizers. It provides crops with the energy to grow and has therefore not been limited in irrigation water. The South African water quality guidelines on irrigation water do not provide for the target water quality range since it is a requirement for plant growth. The following graph shows the variations in phosphate through the wetland during the sampling period (Figure 29).

The highest value of phosphate was recorded during December at the midstream point at 996.27 ppm while the lowest was recorded at 34.29 ppm during October at the downstream point. The presence of phosphate in wetland may contribute to development of harmful algal blooms. Also the presence nutrients in the wetland waters may be exploited by subsistence farmers for use in the irrigation plots that are located close to the wetland.

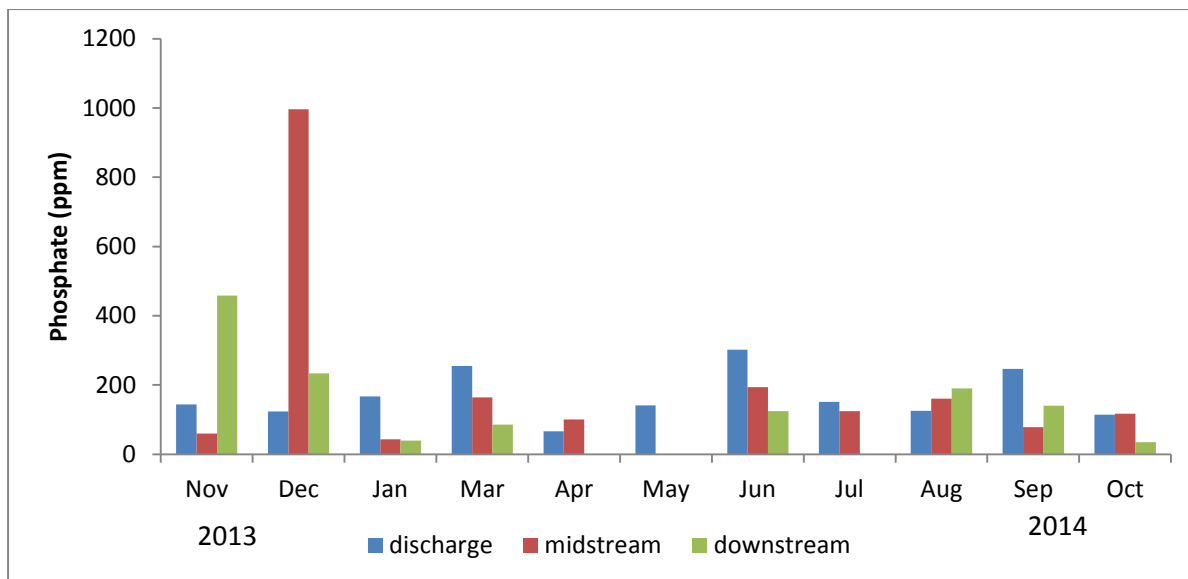


Figure 29: The variation in Phosphate concentrations through the wetland

6.3.5. Sulphate

Sulphate ion has fertility benefit in irrigation water and toxicity is rarely a problem except only in very high concentration where it may interrupt the uptake of other nutrients (Bauder et al., 2011). The highest value of sulphate was recorded at 315.08 ppm at the discharge point during May 2014 and the lowest value was recorded at 12.92 ppm at the downstream point during July 2014 (Figure 30).

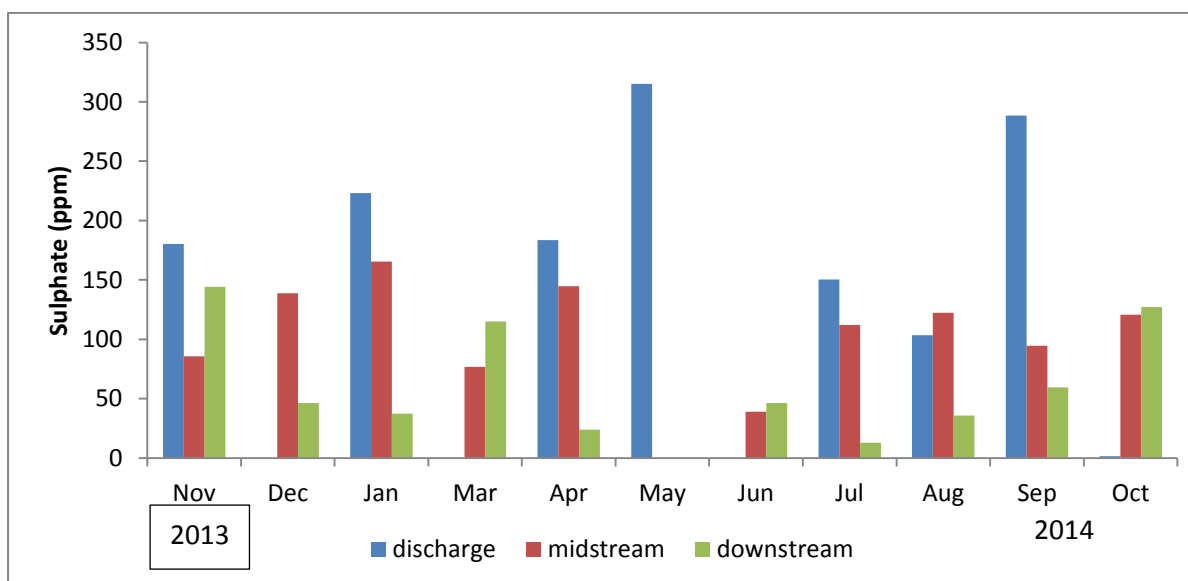


Figure 30: The variation of Sulphate concentrations through the wetland

6.3.6. Bromide

Bromide ion recorded 0 ppm in concentrations from November 2013 until July 2014 (Figure 31). From August 2014 it was recorded at 39.74 ppm and increased to 63.59 ppm during September 2014 and increased to 89.05 ppm at the midstream point while the discharge point and the downstream point continued to record 0 ppm (Figure 31). Bromide concentration in rain water is typically less than 0.01 mg/l and high concentrations are found in soils near sea water (Flury and Papritz, 1993) where its concentration may be well over 65 mg/L (Koti, 1971).

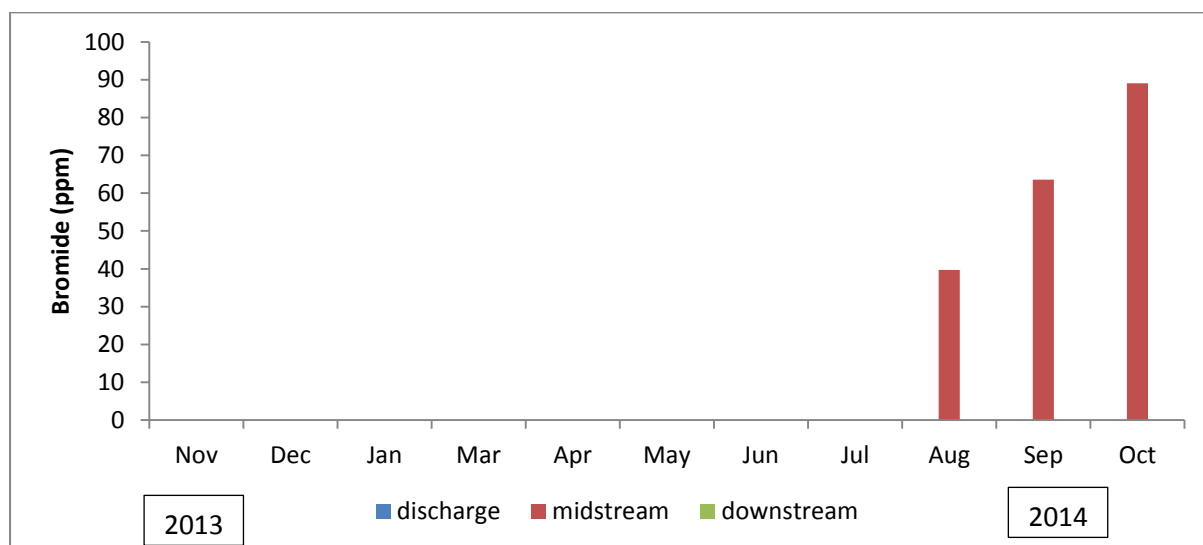


Figure 31: The variations in Bromide concentrations through the wetland

6.4 Conclusion

Chloride, Nitrite and Nitrate did not conform to the DWAF (1996) guidelines for irrigation water bringing forth risks on usage of such water for irrigation purposes. Phosphates and Sulphate which are used in irrigation as nutrients have been measured in significant levels throughout the wetland. The DWAF (1996) guidelines did not provide for target water quality range for both phosphate and sulphate. The study revealed that there are high levels of nutrients in the wetland thereby bringing forth risks of eutrophication. These characteristics have also made this wetland environment to be a favorable environment for the growth and development of cyanobacteria.

CHAPTER 7: TO ASSESS THE FARMER'S PERCEPTION ON WASTEWATER REUSE, SUSTAINABILITY, WATER QUALITY, HEALTH HAZARDS AND CROP YIELD

7.1 Introduction

Various farmers were sampled downstream the Makhado Oxidation ponds and the questionnaire was discussed with them. The sampling of farmers was based on random sampling and was also based on the availability of the farmer. All farmers interviewed were male farmers. Female farmers are not available on the study area except those that are found in cooperative but were represented by their male farmers.

7.2 Materials and methods

7.2.1 Questionnaire design

A questionnaire was developed to assess the farmers' perception on wastewater reuse, sustainability, water quality, health hazard and crop yield. A letter of consent was also presented to the concerned parties and consent was received.

Questionnaire was used to conduct interviews with farmers who were practicing irrigated agriculture along the wetland. The study was designed to establish the following: the perception of the farmers on wastewater reuse; the concerned water resource sustainability as well as the sustainability of irrigation along the wetland; how farmers think about water quality issues with regard to crop yield and health hazards and what management strategies do the farmers adopt in the use of water from the wetland during periods of low rainfall and drought.

7.2.2 Ethics consideration

The consent of the farmers requested first before the study was carried out. No identifiers were collected from the farmers.

7.2.3 Data Analysis

The data collected through the interviews and questionnaires was entered into the Microsoft excel version 2010 and was imported into and was analysed using the Statistical Package for Social Science (SPSS version 23).

7.3 Results and discussion

A questionnaire was developed and administered to the farmers downstream the Makhado oxidation ponds and their views are discussed below. All the interviewed farmers do not have formal training on agricultural issues. They grew up in families where irrigation was being practiced for subsistence purposes by their parents and learned the skills from young age. Although no formal education on agricultural issues, the majority of farmers have been educated as teachers with the majority having been trained during the former Venda government and graduated with diplomas in teaching. Only a percent of these farmers went to upgrade from diploma to Degree which was obtained from the University of Venda.

The majority of the irrigation farmers are male but female members are coming from a co-operative. The subsistence farmers derive most of their incomes from teaching and the farming contributes food supplies for the family. Some of them still depend on their teaching profession for income while others who are no longer working would buy vegetables and fruits and sell in order to earn a living. There are 4 female farmers in the Marengwe enterprise which is the only enterprise irrigating along the wetland. The impacts of drought have been felt by all in the study area with farmers not selling anything. Some farmers had to have their Eskom accounts suspended to due to non-payments resulting from lack of produce to sell. All the interviewed farmers share the same opinion that they are not making a living from irrigation.

7.3.1 Wastewater reuse

Wastewater reuse for irrigation purposes has been practiced for a long time has now been identified as an important source of water for irrigation due to the increasing scarcity of fresh water (Kilelu, 2004; Gumbo et al., 2010). The majority of the farmers interviewed agreed that if wastewater ponds are properly managed with effluent treated to meet the required standards for discharged in to the stream, then wastewater reuse is their desired options since freshwater is scarce in the area. There positive views by farmers in the study area regarding wastewater reuse since it is also loaded with nutrients and its suitability have been agreed up on by farmers.

7.3.2 Sustainability

Although in some parts of the world, the use of wastewater for irrigation has resulted all-year round cultivation (Kilelu, 2004; Gumbo et al., 2010), in the study area farmers remain seasonal irrigators due to lack of sufficient water for irrigation. Some farmers have resulted to using groundwater in the event that surface water becomes too low for abstractions. The boreholes are located close to the wetland. Farmers with boreholes have indicated that even their boreholes runs dry and they completely cease irrigation. So farmers in the study area remain seasonal irrigators even with the supplement of wastewater discharge in to the stream. Also due to the low rains, the Makhado oxidation ponds are receiving low inflows from the households and this in turn leads to low effluent discharge to the wetland.

7.3.3 Water quality

The use of low quality water for irrigation of crops has been noted around the world (Mayilla et al., 2015). Farmers in the area have acknowledged the presence of nutrients load in their water for irrigation and have expressed positive opinion since it reduces the need to apply fertilizers. They have indicated that they save money when it comes to purchasing fertilizers. This opinion is the same as that found by Mojid et al. (2010) and Gumbo et al. (2010) where farmers acknowledged fertilizer content and gave favorable opinion on the suitability of wastewater for irrigation purposes.

7.3.4 Health hazards

Health risks associated with the use the wastewater for irrigation is a point of concern for food production, especially with inadequately treated effluent which may result to microbial contamination and toxicity from heavy metals (Kilelu, 2004). Farmers in the area did not report any experience regarding health problems but Kilelu (2004) and Gumbo et al. (2010) indicates that microbial contamination is of serious concern in three broad categories and they are: consumers of the crops irrigated with inadequately treated wastewater, workers directly exposed to wastewater in the fields and population living near the fields irrigating with wastewater. It must be noted that irrigation downstream Makhado oxidation ponds is not by purely wastewater but it is by water from the stream receiving wastewater

discharge. So dilution is also expected which neutralizes the effluent from the wastewater ponds, hence health hazards in this case have not been reported yet.

7.3.5. Crop yield

The majority of the interviewed farmers in the study area reported that crop growth is good and this is expected due to the high level of nutrients in the waters originating from the wetland. The crops that the farmers were growing were: maize; tomatoes, spinach, cabbage and irrigating fruit trees such as oranges, mangoes and litchis. This is confirmed by the presence of nutrients in the irrigation waters (Figures 27 to 29). Also the presence of trace and essential metals in irrigation waters also contributes to the growth of the crops (Figures 9 to 20). Kilelu (2004) and Gumbo et al. (2010) indicated that there are nutrients and trace and essential metals in the wastewater that are beneficial and can contribute to sustainable irrigation. It is therefore not surprising that farmers in the area are not applying fertilizers on regular basis. Some farmers indicated that they apply fertilizers once throughout the crop season and they still grow well.

7.4 Conclusion

There is a positive opinion from the farmers regarding irrigation with wastewater since it is rich in nutrients. Farmers have acknowledged the presence of nutrients contents in wastewater and noted the advantageous use of such for irrigation. It has reduced the need for application of fertilizers and most famers have indicated that it saves them money on fertilizers. Proper management and compliance to different standards for the discharge of wastewater is of utmost importance since there is positive reliance to wastewater for irrigation. Health hazards were not reported in the study area.

CHAPTER 8: CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSION

8.1.1. The physical parameters of the general water quality

The DWA (1984) provided the target water quality range for the physical water quality parameters and the research revealed that some of the water quality parameters are out of the target water quality range for effluent discharge into a water resource. The EC and TDS parameters were found to be well outside the desired water quality range. The standards did not provide the target water quality range for turbidity. The research revealed that the wetland did not provide significant changes in pH, EC, TDS and water temperature through the wetland but significant changes occurred on the DO and turbidity.

Rai and Rajashekar (2014) provided target range on physical parameters that are suitable environments for the growth and development of Cyanobacteria and this study revealed that the above physical water quality parameters in the wetland are well within the range that are favorable environments for the growth and development of the cyanobacteria.

8.1.2. The heavy metal throughout the wetland

The theory that wetland environments are able to reduce pollution by absorbing pollutants can be said to be true with regard to the presence of heavy metals after passing through the wetland. Significant reductions on all the heavy metals were observed through the sampling points in the wetland. The slow flow of water through the wetland can be said to have a greater role in ensuring that the heavy metals have longer residence time in the wetland and provide time for the roots plants to absorb the metals. Cadmium (Cd) was measured in very small amounts and was the only heavy metal which was neither reduced nor increased in the wetland. The heavy metals in the wetland did conform to the DWAF (1996) with the exception of iron and manganese which increased during the rainy season.

8.1.3. The general anion characteristics through the wetland

Chloride, Nitrite and Nitrate did not conform to the DWAF (1996) guidelines for irrigation water bringing forth risks on usage of such water for irrigation purposes. Phosphates and Sulphate which are used in irrigation as nutrients have been

measured in significant levels throughout the wetland. The DWAF (1996) guidelines did not provide for target water quality range for both phosphate and sulphate. The study revealed that there are high levels of nutrients in the wetland thereby bringing forth risks of eutrophication. These characteristics have also made this wetland environment to be a favorable environment for the growth and development of cyanobacteria.

8.1.4. Farmers' perceptions on wastewater reuse

There is a positive opinion from the farmers regarding irrigation with wastewater since it is rich in nutrients. Farmers have acknowledged the presence of nutrients contents in wastewater and noted the advantageous use of such for irrigation. It has reduced the need for application of fertilizers and most farmers have indicated that it save them money on fertilizers. Proper management and compliance to different standards for the discharge of wastewater is of utmost importance since there is positive reliance to wastewater for irrigation.

8.2 RECOMMENDATIONS

Mainly, in dealing with the non-conformity of EC, DO and TDS, the Makhado waste water ponds need to comply with the general and special effluent standards set out by DWAF (1994).

The following strategies are recommended in order to counter the enriching of the wetland with phosphate and nitrate:

8.2.1. Controlled use of fertilizers

Farmers need to be educated on the need to apply fertilizers on the crops so as to understand when to apply fertilizers and the quantity needed. This will help control excessive fertilizers being eroded to the wetland.

8.2.2. Controlled use of agrochemicals

There needs to be an investigation to establish whether the origin of nitrate is from the applications of agrochemicals or decomposition of vegetation. This will help deal with the nitrate problem.

8.2.3. Set up water quality monitoring programme by relevant authorities

This programme will need to be established through the wetland with monitoring points established on the upstream of the wetland, points established at the discharge by the ponds, points established in the midsection of the wetland and also on the downstream of the wetland. This will help identify if the problem is being successfully dealt with. Further studies are recommended to research on the microbial contamination and toxicity levels of various metals and their potential effects on crops in the study area.

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Appendices

Appendix 1: climatic data

Comp#	Station Name		Latitude	Longitude	Altitude	
30739	MAKHADO: RABALI		-22.87038	30.08112	720	
Compno	Year		Month	Tmax	Tmin	Rain
30739	2013	January	1	30.38	20	372.87
30739	2013	February	2	30.7	19.83	1.27
30739	2013	March	3	28.89	18.57	35.31
30739	2013	April	4	27.56	13.9	14.99
30739	2013	May	5	26.39	9.86	0
30739	2013	June	6	25.71	7.45	0
30739	2013	July	7	23.67	8.45	0.76
30739	2013	August	8	26.41	10.71	0
30739	2013	September	9	30.65	13.86	0.25
30739	2013	October	10	28.8	15.55	6.35
30739	2013	November	11	31.87	18.66	126.24
30739	2013	December	12	29.9	19.31	51.82
30739	2014	January	1	30.21	20.14	262.89
30739	2014	February	2	29.41	19.29	80.26
30739	2014	March	3	29.53	18.67	87.38
30739	2014	April	4	27.97	14.11	0
30739	2014	May	5	27.48	9.81	0
30739	2014	June	6	25.96	6.79	0
30739	2014	July	7	24.67	7.23	0
30739	2014	August	8	27.03	9.72	0
30739	2014	September	9	29.89	13.51	0
30739	2014	October	10	30.18	15.69	1.02
30739	2014	November	11	30.46	18.28	7.11
30739	2014	December	12	30.21	19.75	22.35

ELEMENT	DESCRIPTION	UNIT	STATION TYPE
Tx	Average Maximum Temperature	°C	AWS
Tn	Average Minimum Temperature	°C	AWS
Rain	Average Total Rainfall [Calculated From Hourly Data]	mm	AWS

Appendix 2: Metals

Table 8. Aluminum measurements through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	209.93	1.99	58.30	11.79	265.94	28.24	9.14	1.99	11.13	122.09	2.96	31.68
midstream	23.06	2.49	7.81	5.65	6.64	10.13	5.98	94.35	5.98	174.41	3.34	82.65
downstream	58.69	1.99	14.45	8.97	1.49	14.62	36.71	6.48	60.13	3.65	48.42	574.1

Table 9. Titanium measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	10.99	0.86	6.71	0.00	9.19	2.67	1.12	0.25	2.23	4.80	1.34	2.99
midstream	0.83	0.71	1.65	5.65	6.64	10.13	0.57	4.16	0.35	2.99	2.99	2.99
downstream	58.69	1.99	14.45	8.97	1.49	14.62	36.71	6.48	60.13	3.65	48.42	574.1

Table 10. Vanadium measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	May	Jun	Jul	Aug	Sep
discharge	12.73	41.51	7.77	8.29	1.13	9.38	5.66	6.89	15.05	6.89	6.99
midstream	5.31	16.55	30.37	24.05	24.87	0.66	3.98	2.04	4.43	3.21	17.55
downstream	7.27	12.30	12.70	1.68	12.28	3.97	8.65	56.63	1.57	5.97	8.75

Table 11. Chromium measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	11.54	2.59	3.67	0.58	1.15	6.41	3.90	0.82	8.04	46.04	2.57	1.72
midstream	0.68	1.53	1.80	1.04	3.53	2.94	1.06	54.92	4.16	5.74	0.95	4.07
downstream	3.86	0.87	14.68	3.09	1.02	3.97	7.07	26.28	13.54	1.76	4.36	2.08

Table 12. Manganese measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	47.03	1.02	2271.48	8.15	6.38	456.41	7.68	20.83	1300.16	805.53	32.99	540.45
midstream	95.44	18.60	43.34	32.79	2119.21	12.06	3.56	108.01	4.23	263.35	0.39	78.19
downstream	125.9	308.59	134.22	3325.68	11.79	233.25	120.49	296.24	174.54	4.05	3.48	18.59

Table 13. Iron measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	541.65	25.34	6000.83	41.97	243.12	924.39	79.50	27.33	932.54	2135.57	62.18	372.24
midstream	302.86	33.73	50.32	52.88	70.32	58.95	26.71	1461.53	77.91	1206.13	21.44	226.81
downstream	503.47	28.55	211.20	4547.04	43.89	204.25	346.39	727.73	428.39	9.05	148.73	320.45

Table 14. Cobalt measurements(ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	1.13	1.59	3.15	1.61	1.48	1.85	1.87	7.29	1.52	3.18	1.54	1.26
midstream	1.33	5.85	1.72	3.33	32.06	0.26	0.13	1.12	0.41	1.25	0.73	1.02
downstream	1.3	3.59	1.56	2.38	1.56	3.07	1.27	1.66	1.32	0.03	0.93	0.45

Table 15. Nickel measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	May	Jun	Jul	Aug	Sep
discharge	11.88	4.55	5.26	3.96	1.52	5.82	12.03	8.60	30.28	4.20	4.13
midstream	3.08	7.23	5.22	6.20	9.59	4.92	6.31	4.58	6.62	3.51	8.44
downstream	5.82	4.71	10.80	3.87	5.05	7.60	17.28	9.22	0.47	5.50	3.08

Table 16. Copper measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	31.77	8.57	2.38	3.60	4.39	7.24	4.81	12.14	5.82	83.51	2.65	4.95
midstream	1.8	5.66	6.10	5.96	56.56	4.12	6.34	33.85	5.46	61.14	6.57	22.99
downstream	12.96	4.24	5.41	2.69	4.31	4.15	29.10	5.56	68.90	0.51	6.76	40.67

Table 17. Zinc measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	28.98	9.67	6.87	1.34	13.24	21.32	7.99	0.97	12.90	113.40	9.39	8.38
midstream	10.31	3.85	8.71	2.39	254.49	4.68	7.16	28.40	10.80	26.05	2.88	38.39
downstream	20.85	4.39	14.08	3.81	8.99	14.34	59.35	7.64	47.20	0.86	16.38	20.13

Table 18. Arsenic measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	0.52	0.62	3.10	1.14	2.38	0.65	0.43	1.11	0.87	0.86	0.67	0.5
midstream	0.58	1.41	1.11	1.37	0.48	0.30	0.30	0.41	0.3	1.41	0.57	0.42
downstream	0.5	0.73	1.03	2.25	0.92	0.47	0.56	0.44	0.64	0.30	0.47	11.4

Table 19. Molybdenum measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	4.37	14.03	0.29	2.05	0.23	2.42	3.38	20.52	0.76	276.09	12.59	0.58
midstream	0.06	7.38	8.53	6.04	106.42	0.60	0.37	6.01	0.64	1281.20	2.82	1.35
downstream	2.19	2.75	1.34	0.28	4.20	4.00	3.36	1.18	1.81	34.00	0.28	0.16

Table 20. Cadmium measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Discharge	0.02	0.02	0.01	0.01	0.02	0.07	0.01	0.01	0.01	0.27	0.02	0.02
midstream	0.02	0.01	0.03	0.01	0.12	0.02	0.01	0.05	0.01	0.11	0.02	0.04
downstream	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.02	0.01	0.02	0.02

Table 21. Tin measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	5.50	1.00	2.48	1.00	1.00	2.67	1.35	1.00	1.50	2.06	9.99	7.07
midstream	4.32	1.00	1.00	1.00	1.57	1.32	1.22	1.47	2.57	1.14	5.36	9.89
downstream	7.19	1.00	2.64	1.83	1.30	1.33	1.53	1.40	1.96	1.00	28.86	0.96

Table 22. Antimony measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	0.31	4.16	0.11	0.29	0.98	0.36	0.10	0.26	0.14	0.60	2.31	0.05
midstream	0.05	1.49	2.41	0.81	0.09	0.12	0.01	0.58	0.06	0.28	1.81	0.05
downstream	0.05	0.75	0.14	0.11	0.12	0.12	0.12	0.05	0.13	0.04	0.05	0.05

Table 23. Mercury measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.08	0.01	0.24
midstream	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.02
downstream	0.04	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.???

Table 24. Lead measurements (ppb) through the wetland

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	1.01	0.02	0.23	0.01	0.20	0.34	0.12	0.01	0.24	3.40	0.08	0.24
midstream	0.07	0.02	0.09	0.03	0.28	0.13	0.05	5.77	0.11	1.96	0.02	1.29
downstream	0.45	0.02	0.22	0.12	0.05	0.10	1.37	0.22	1.22	0.00	0.32	3.07

Appendix 3: Anions

Chloride

	Nov'13	Dec	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct, 14
discharge	1202.8	1697.4	556.76	935.71	467.45	22.62	945.94	1292.8	1028.4	1707.1	781.99
midstream	406.48	623.86	728.82	852.22	601.24	0	787.74	1219	1505.5	743.18	839.62
downstream	525.3	367.76	160.63	746.76	0	0	138.29	240.07	188.88	301.05	610.18

Nitrite

	Nov	Dec	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
discharge	1864	1620.1	1042.1	1193.3	1177.4	1472.5	1238.7	1689.5	1176.1	2134.1	25.15
midstream	887.26	1633.7	1655.5	1480.8	1625.2	0	1275.4	1659.4	1966.9	1302.4	1233
downstream	1439.4	999.73	436.46	1555	0	0	369.98	482.28	372.93	663.46	1208.5

Bromide

	Nov	Dec	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
discharge	0	0	0	0	0	0	0	0	0	0	0
midstream	0	0	0	0	0	0	0	0	39.74	63.59	89.05
downstream	0	0	0	0	0	0	0	0	0	0	0

Nitrate

	Nov	Dec	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
discharge	265.08	0	603.76	0	966.39	8715.7	0	0	0	0	0
midstream	312.37	0	488.94	0	517.28	0	0	0	0	167.73	0
downstream	0	0	0	566.7	0	0	0	0	0	0	221.38

Phosphate

	Nov	Dec	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
discharge	143.78	123.3	166.96	254.56	66.16	141.36	301.74	151.02	125.65	246.08	114.49
midstream	59.61	996.27	42.84	164.3	100.16	0	193.6	124.24	160.52	78.46	116.76
downstream	457.69	233.41	39.25	85.98	0	0	124.58	0	190.28	139.93	34.29

Sulphate

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
discharge	180.36	0	223.04	1.15	0	183.5	315.08	0	150.38	103.36	288.26
midstream	85.63	138.7	165.34	3.53	76.78	144.62	0	39.03	111.98	122.32	94.43
downstream	144.17	46.16	37.36	1.02	114.9	23.79	0	46.22	12.92	35.79	59.35

Appendix 4: questionnaire of farmers perceptions on wastewater reuse

LETTER OF INFORMED CONSENT

To whom it may concern

The purpose of this form is to inform you about this study, which is being carried out in your community, and to seek your consent to take part in it.

The project title is *TO ASSESS THE FARMER'S PERCEPTION ON WASTEWATER REUSE, SUSTAINABILITY, WATER QUALITY, and HEALTH HAZARDS AND CROP YIELD.* . This involves the asking you of questions about your daily use of water from the river for irrigation your crops/vegetables. Your assistance in answering the questions is requested.

Confidentiality and anonymity will be adhered to, all the time. The results of this study can be made available to you, should you ever wish to have them.

If this letter is clear to you, and you agree to take part, then write your name and sign below or just put your thumb print to indicate your informed consent.

Ihereby swear that I have heard/read and understood what this study is all about, and that whatever doubts I initially had, have been cleared. I understand that my participation is completely voluntary and that the results will be used purely for academic purposes and/or to improve disposal of used cooking oil in an environmental friendly manner. By appending my signature/thumb print, below I grant you my consent to take part in the study,

Signature of participant.....

Date.....

Researcher.....

Signature.....

FARMERS QUESTIONNAIRE

TO ASSESS THE FARMER'S PERCEPTION ON WASTEWATER REUSE, SUSTAINABILITY, WATER QUALITY, HEALTH HAZARDS AND CROP YIELD

A. Bio data

1. Gender

female		male	
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2. Age range (years)

15>25	25>30	30>35	35>40	40>45	+45	
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3. Education literacy

none	Primary school	Secondary school	College/polytechnic	university	
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4. Income per year 2015 (R000) from farming operations

10>25	25>30	30>35	35>40	40>45	+45	
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5. Income per year 2015 (R000) from non-farming operations

10>25	25>30	30>35	35>40	40>45	+45	
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6. Indicate sources of income (non-farming).....

B. USER DIRECTED QUESTIONS

1. Briefly describe your irrigation system

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2. How long (years) have you been irrigating on this land?

1>5	5>10	10>20	20>25	25>30	+30	
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3. Are you commercial or subsistence farmer?

Commercial		Subsistence	
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4. What crops are you irrigating

Ha	Crops	Seasons	Comments

5. Have you ever tried other crops?

Ha	Crops	Seasons	Comments

6. Do you crop rotation?

	Summer	Winter	Autumn	Spring
Crops				
Comments				

7. What methods of Irrigation do you apply?

Buckets		Drips		Flood		Other (Specify)	
----------------	--	--------------	--	--------------	--	------------------------	--

8. How much water do you use per day?

How many Buckets	For Drips & flood irrigation, how long do you run the pump?	Other (specify)

9. Do you apply fertilizers?

yes		no	
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10. How often do you irrigate?

daily		Weekly		Bi-weekly		Monthly		Bi-monthly	
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11. During your irrigation, do you see if your crops are growing well?

yes		no	
-----	--	----	--

12. If the answer is NO, what do you think is the problem?

13. If the answer is YES, what do you think is contributing to better growth

14. Any general problems you have with your crops

Problems	Managing the problems

B. RESOURCE DIRECTED QUESTIONS

15. Do you get enough irrigation water from this River?

yes		no	
-----	--	----	--

16. If the answer is NO, what do you think is the problem?

17. If the answer is YES, what do you think is the problem

18. How is the irrigation water quality

GOOD		BAD	
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19. If the answer is GOOD, why do you think so?

20. If the answer is BAD, why do you think so?

21. Do you prefer another source

yes		no	
-----	--	----	--

22. Have you tried groundwater

yes		no	
-----	--	----	--

23. Do you think you should use groundwater again

yes		no	
-----	--	----	--

24. Why

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25. Do you know that there are waste water ponds upstream, discharging in to this River

yes		no	
-----	--	----	--

26. Do you think this water is good for irrigation

yes		no	
-----	--	----	--

27. Do you sometimes smell bad odour from the water

yes		no	
-----	--	----	--

28. Do you think this River is polluted?

yes		no	
-----	--	----	--

29. What if is polluted? Would you continue irrigating

yes		no	
-----	--	----	--

30. How were you affected by water pollution over the years

yes		no	
-----	--	----	--

31. How did you deal with it?

32. How much do you trust water from this River

VERY WELL		Not SURE	
-----------	--	----------	--

33. Do you think if you can irrigate from this river for the next 25 years

yes		no	
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34. Do you think you can expand your field depending on this water

yes		no	
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35. Any general comments
