IMPACT OF ALEXANDRA TOWNSHIP ON THE WATER QUALITY OF THE JUKSKEI RIVER

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A research report submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the degree of Master of Science.

Johannesburg, October 2010

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for the Degree of Master of Science in Environmental Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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6th day of October 2010

ABSTRACT

Accommodation shortage in Alexandra Township, South Africa, has resulted in the establishment of informal settlements on any open land including Jukskei River banks. The closely built dwellings among several other factors have made refuse removal difficult and sanitation facilities inadequate, hence waste including human excreta is discharged on open lands or into the Jukskei. These wastes affect the water quality of the Jukskei River. This study, therefore, determined the changes in water quality as the Jukskei River flowed past Alexandra. Eleven physical, chemical and microbiological parameters were monitored between May and December 2009 at four sites in the Jukskei catchment using standard methods. Water entering Alexandra was only significantly high in turbidity (27.1 ± 4.5 NTU) while water exiting Alexandra contained significantly high pH (7.7 ± 0.1), nitrate (0.36 ± 0.07 mgN/l) and orthophosphate (0.41 ± 0.17 mgP/l). There was no statistical difference in *Escherichia coli* in the water upstream and downstream of Alexandra. The high nitrate-N, orthophosphate and *E. coli* downstream of Alexandra were likely to be associated with raw sewage, domestic and animal waste. Most measured parameters in water exiting Alexandra were within the acceptable ranges of aquatic ecosystems guidelines. Ammonium-N and electrical conductivity, however, fell into the bad categories of the aquatic and domestic guidelines respectively. *E. coli* concentrations were above the drinking water (0 cfu/ml) and recreational (<1.3 cfu/ml) guidelines. Turbidity and total suspended solids were significantly higher in the wet season than in the dry season while orthophosphate, suspended particulate organic matter, pH and electrical conductivity were higher in the dry season at all sites. The changing seasons had no significant influence on temperature, nitrate-N and dissolved oxygen at all the sites. The results suggest that some activities like poor waste disposal in Alexandra can reduce the water quality of the Jukskei River.

DEDICATION

To my father and mother,

my siblings, Tapiwa, Elliot and Wongayi.

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ABBREVIATIONS AND ACRONYMS

°C	degrees Celsius
ARP	Alexandra Renewal Project
cfu	colony forming units
COCCOS	Co-ordinating Committee for Community Open Space
CoJ	City of Johannesburg
DO	dissolved oxygen
DWAF	Department of Water Affairs and Forestry
DWEA	Department of Water and Environmental Affairs
EC	electrical conductivity
IWQGKRC	In-stream water quality guidelines for Klip River Catchment
km	kilometre(s)
km^2	square kilometre(s)
m	metre(s)
mg/l	milligrams per litre
ml	millilitre(s)
mm	millimetre(s)
mS/m	milliSiemens per meter
NTU	Nephelometric Turbidity Units
RJK	Royal Johannesburg and Kensington
SPOM	suspended particulate organic matter
TSS	total suspended solids
WHO	World Health Organisation
WRC	Water Research Commission
α	alpha
µg/l	micro grams per litre

1. INTRODUCTION

The water quality of the Jukskei River in the Gauteng Province of South Africa has been monitored since 1955 by organizations such as the DWAF, WRC and City of Johannesburg. Different water quality parameters have been measured at different times depending on the objectives of the various studies. Most studies indicate that the Jukskei is polluted to some degree (e.g. Campbell 1996; Huizenga and Harmse 2005; Van Veelen 2002). Huizenga and Harmse (2005) conducted a study to compare the water quality in the Jukskei River to the Klein Jukskei River which was used as a reference stream. The Klein Jukskei River emerges from the suburbs west of the Johannesburg whereas Jukskei River's source is in the east of Johannesburg. Both rivers flow in a northerly direction and their confluence is in the north of Johannesburg (Van Veelen 2002). Huizenga and Harmse (2005) observed that between 1979 and 2002 the Klein Jukskei River had relatively low phosphate (< 0.02 mg/l) and nitrate (< 3 mg/l) concentrations whereas phosphate concentrations for the Jukskei River were mainly above 0.5 mg/l and nitrate concentrations were above 3 mg/l (Table 1.1). In 1996, the average turbidity in the Jukskei River upstream of Alexandra Township was fivefold higher than that measured downstream of the township (Campbell 1996). High nutrient concentrations in the Jukskei River have been blamed for the eutrophication of the Hartbeespoort Dam as the Jukskei is a tributary of the dam. Water quality problems of the Jukskei, especially high bacterial load, are related to urbanization (Van Veelen 2002). In 2003, the concentration of *Escherichia coli* in the Jukskei was 300 000 cfu/ ml, more than four orders of magnitude higher than the recommended 1 to 2 cfu/ ml (DWAF 2003). Surface water quality problems are not unique to Jukskei River, in fact most South African rivers that flow through informal settlements experience similar problems (Van Niekerk 2000).

Table 1.1: Water quality history in the Jukskei River downstream of Alexandra Township

Years	Parameters					
	Phosphate (mg/l)	Nitrate (mg/l)	Ammonium (mg/l)	Electrical conductivity (mS/m)	pH	Turbidity (NTU)
1994	0.80	5.00	22.50	89.00	8.25	25.00
1995	1.00	7.80	22.00	81.00	8.60	18.00
1996	0.75	7.80	30.00	90.00	8.25	6.00
1997	0.45	7.80	25.00	85.00	8.90	19.00
1998	0.50	5.80	16.30	75.00	8.70	20.00
1999	1.00	3.70	10.00	63.00	8.50	21.00
2006	<0.5	2.48	0.61	52.25	8.05	4.65
2007	<0.5	3.25	0.75	43.75	7.83	4.60
2008	0.55	2.78	1.07	38.93	7.58	10.73

Adapted from Campbell (1996), Van Veelen (2002) and City of Johannesburg (2009)

There are 22 primary drainage regions in South Africa, the largest of which is the Orange with an annual discharge of 90.7 cubic meters per second (Chakhela 1981). Most major rivers like the Orange, Crocodile and Oliphants flow through or supply urban areas with water (Ashton and Haasbroek 2002). They are an important source of water to rural communities, agriculture, mining, domestic use in towns, wildlife, recreational activities and they also create habitats for a diverse range of aquatic animals (Davies and Day 1998). In addition to these services, rivers especially urban rivers, also affect the psychological well-being of people. In a study conducted by Maas *et al.* (2006) in Netherlands, it was observed that urban natural capital such as rivers and parks reduces the stress associated with urban environments and generates emotional and psychological benefits for people. Furthermore, urban rivers enhance air quality by releasing moisture and removing dust and pollutants from the atmosphere (Maas *et al.* 2006).

Most of the rivers that flow through urban areas are under pressure partly due to the large and dense human populations that depend on the products and services that these rivers provide (Ashton and Haasbroek 2002). In 1950, 43.1 % of South Africa's population lived in urban areas, in 2005, it increased to 57.9 % and it is anticipated that by 2015 it will be 62.7 %

(United Nations Database 2005). The rate of population increase is higher than the number of formal houses available for people to live in which makes accommodation a problem in the country's urban areas. This has resulted in informal settlements developing to meet the demand for accommodation. According to the Department of Housing, in 1989 Gauteng contained 412 000 formal houses in the province's townships, with 422 000 shacks in their backyards and 635 000 shacks on vacant land. In 2008, 30 % of all urban housing in South Africa was classified as "shacks" (Population Reference Bureau, 2008). Additionally, of the 11.89 % of South Africa's population that resides in shacks, 19.94 % of these people are in Gauteng (Statistics South Africa 2007). Informal settlements lie outside of the formal planning process and usually lack or have low levels of basic services such as water and sanitation (Abbott 2002). Overcrowding makes the removal of wastes (garbage collection) difficult and residents end up creating their own waste dumps. Informal settlements are frequently formed in the vicinity of rivers and streams, which serve as water supplies (Hranova *et al.* 2006). For example, the Klip River is a source of water for Gauteng Province but informal settlements near Kagiso, Durban Roodepoort Deep and western Soweto are diffuse sources of pollution to the Klip River (DWAF 1999). In addition, the informal settlements in the township of Alexandra are potential diffuse source polluters of the Jukskei River which is a tributary to the Crocodile River. The Crocodile River flows to the eutrophic Hartbeespoort Dam which provides drinking water to the city of Pretoria (Campbell 1996).

1.2 Background of Alexandra Township

Alexandra Township, located 13 km North East of Central Johannesburg, South Africa (Figure 1.1), was established as a "Native Township" in 1912 (Vogel 1996). The Jukskei River flows through the township and informal settlements occur mainly on the western side of the river (Figure 1.1).

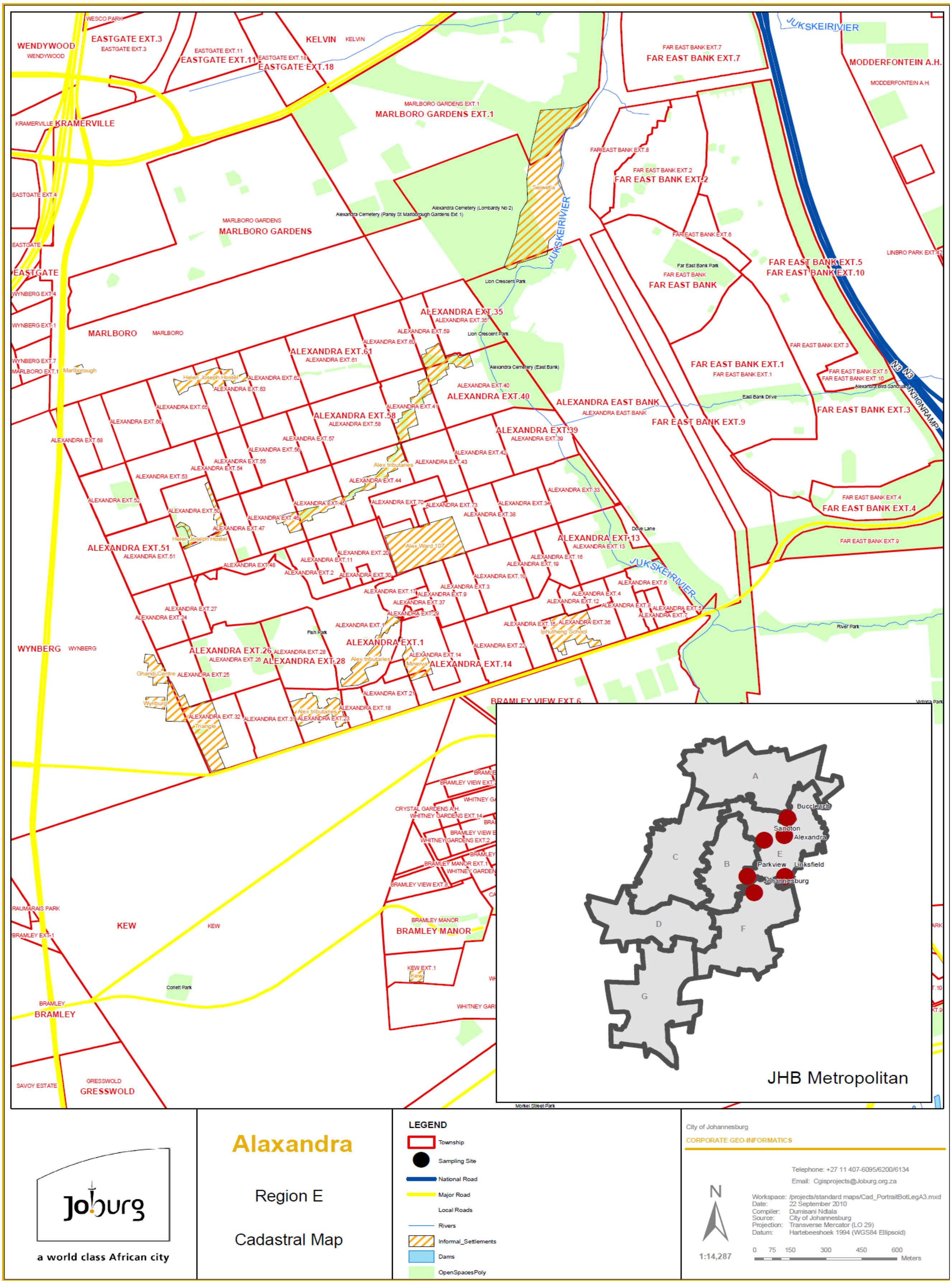

Figure 1.1: Map showing Alexandra Township and its location relative to Johannesburg

The 800 hectare township saw a large population influx between 1945 and 1948 (de Jager 1990). During that period, Alexandra was not serviced with any form of basic infrastructure (de Jager 1990). Population continued to increase in the township and in 1963, in an effort to upgrade Alexandra, the government legislated that a limit of 35 000 people were to be housed in single dwelling units (de Jager 1990). As a result, between 1964 and 1973, 56 000 people were forcibly moved to Soweto and about 15 000 to Tembisa (de Jager 1990; Morris 2000). Nevertheless, Alexandra's population continually increased.

Between the years 1987 and 1990 an "Urban Renewal Plan" was implemented. Full engineering services, including a water reticulation system, water-borne sewage, electrical reticulation and on-stand ablution facilities were provided to all dwelling units in Alexandra (Campbell 1996). The improvements, however, attracted more people.

Alexandra's population increased from approximately 30 000 in the mid 1920s to an estimated range of 470 000 to 750 000 in 2001 (Wilson 2002). This was partly due to depleted economies and wars in neighboring countries which resulted in influx of immigrants into Johannesburg (de Wet *et al.* 2001). Furthermore, with the abolition of the influx legislation in 1986, many people moved from rural to urban areas to seek employment. Alexandra became a destination, and mass immigration resulted in informal settlements putting a heavy demand on the township's infrastructure. Faced with this situation, President Thabo Mbeki, in 2001 launched the Alexandra Renewal Project (ARP) which aimed to replace informal settlements with formal government housing (ARP 2001). By May 2008, 1 400 free houses had been built in the Extension 7 area of Alexandra (ARP 2008), but accommodation is still limited and sanitation standards are still low in Alexandra. People dwelling on the banks of the Jukskei discard sewage and litter directly into the river. Overflowing chemical toilets, oil, kitchen waste and detergents are potential sources of pollution to the Jukskei River.

1.3 Problem Statement

The rate of increase of the population in Alexandra has outpaced the availability of formal accommodation. Thus informal houses (shacks) have been constructed on any open space including the banks of the Jukskei River (Figure 1.2). Of the estimated 20 000 shacks in Alexandra, 7 000 are located in backyards. Alexandra's infrastructure was designed for a population of about 70 000 (World Bank 2001) but the significant, unplanned population in Alexandra Township has overloaded the infrastructure such that water pressures are low and sewers frequently overflow (Dudula 2008). This problem is especially pronounced in Old Alexandra where sanitation facilities like water provision and sewer coverage are inadequate (de Wet *et al.* 2001). Furthermore maintenance is difficult because overcrowding in the area prevents waste removal and repair of damaged sewer pipes (World Bank 2001). Hence, litter and waste (raw sewage, wash water, kitchen waste and other domestic wastewater) is either dumped on free land or straight into the Jukskei River.

Figure 1.2 Dwellings on the bank of Jukskei River and litter that is dumped straight into the river.

In the informal areas of the Township, stagnant pools frequently occur alongside refuse such that during the wet season, refuse is easily washed into the Jukskei River (Figure A1). Agriculture and construction of shacks on Jukskei's River banks lead to bank erosion (Figure A2, Appendix and Figure 1.2), and in the rainy season this eroded matter is washed down the river. Dwellers of Jukskei's banks are at the risk of losing their property or even their lives when the river banks overflow during the rainy season.

Pollution of the Jukskei River is frequently discussed in light of the negative impacts that it has on the health of informal settlers in Alexandra. But less attention is paid to the alternative perspective; the possible contribution of pollution that the informal population of Alexandra Township might have on the ecology of the Jukskei River. After flowing through Alexandra, Jukskei River flows west of Pretoria to join the Crocodile River, and eventually into the Hartbeespoort Dam. This dam supplies water to the city of Pretoria and is highly eutrophied (Dudula 2008). The Jukskei is an example of a water quality deterioration problem that is becoming more frequent in informal and residential development areas of South Africa.

In this study, I attempted to quantify the possible effect that informal developments (especially those on Jukskei River banks) in Alexandra Township have on the physico-chemical and microbiological water quality of the Jukskei River. Water quality parameters were examined at three sites high in the catchment of the Jukskei and one site downstream of Alexandra over a period of nine months. The parameters examined were: temperature, pH, electrical conductivity (EC), turbidity, total suspended solids (TSS), suspended particulate organic matter (SPOM), dissolved oxygen (DO), ammonium, nitrate, orthophosphate and *Escherichia coli (E. coli).*

1.4 Aim and Objectives

The aim of this research was to quantify changes in water quality that Alexandra Township might have on the water quality of the Jukskei River and to characterize seasonal changes in water quality. The specific objectives of the research were:

1. To determine the changes in the physical, chemical and microbial water quality of the Jukskei River as it passes through Alexandra Township.
2. To describe the changes in physical-chemical and microbial water quality of the Jukskei River from high in the catchment (Zoo Lake on Braamfontein Spruit) to the sampling point lowest in the catchment (Buccleuch).
3. To quantify seasonal patterns in the physical, chemical and microbial water quality of the Jukskei River.
4. To compare the physical-chemical and bacteriological parameters in the river reach that passes through Alexandra with the South African and international water quality guidelines.

2. WATER QUALITY

Water quality includes the microbiological, physical, chemical and radiological properties of water (WRC 1998). Many of these properties are controlled or influenced by substances which are either dissolved or suspended in water (Palmer *et al.* 2004). Water quality affects the biota that live in a river and it also affects the suitability of the water in the river for uses such as drinking, agriculture or recreation (Skoroszewski 1999). A river is polluted when it is either directly or indirectly altered due to human activity resulting in the modification of ecological systems to an extent that harm occurs to the resident aquatic life or to humans (Lloyd 1992; Ellis 2005).

Pollution can come from point or diffuse sources. Point or "end of pipe" sources are associated with man-made discharges from industrial activities, municipal wastewater collection and treatment systems and other activities (Hranova 2006). Diffuse or non-point sources are associated mainly with land drainage and surface runoff, which enters a water body by dispersed and poorly defined ways. Diffuse pollution in urban areas is associated mainly with polluted urban runoff (drainage) contaminated with materials washed off of streets, roads, roofs, open spaces etc. (Hranova 2006). According to DWEA (2009) urbanisation in South Africa is associated with increased non-point pollution of rivers.

Organic wastes produced by humans are not very different in composition to natural products of leachates of plant and animal origin from land surfaces (Lamb 1985). The main distinction between the two inputs is the much higher concentration of pollutants discharged by humans living in high density settlements. Dilution here is insufficient to reduce these concentrations to natural levels, the quality of the receiving water declines and its capacity to support various uses is impaired (Tchobanoglous and Schroeder 1985). Anthropogenic alteration of the biological and chemical functions in a river can result in increased primary production, algal blooms and reduced habitat availability. Furthermore, anthropogenic influences on water systems can cause ecosystem destruction, which results in species and population extinction (Malmqvist and Rundle 2002).

2.1 Physical Water Quality Variables

2.1.1 Temperature

Climate, structural features and anthropogenic activities of a river catchment area influence its thermal conditions (Palmer *et al.* 2004). Increases in water temperature normally result in decreased oxygen solubility and may also increase the toxicity of certain chemicals, both of which may result in increased stress in many aquatic organisms (Palmer *et al.* 2004). Aquatic organisms like some fishes require specific temperature for spawning and the development of eggs and young (Petts 1984).

2.1.2 Turbidity, total suspended solids and suspended particulate organic matter

Turbidity and total suspended solids (TSS) are important physical water quality parameters where turbidity is a measure of water clarity. TSS refers to the suspended materials in a water column comprising an inorganic fraction (silts and clays) and an organic fraction SPOM, which includes algae, zooplankton, bacteria, and detritus (McAlister and Ormsbee 2005). Small particles suspended in water scatter and absorb light, giving the water a murky or turbid appearance (Lamb 1985). High concentrations of TSS reduce water clarity and decrease light available to support photosynthesis. TSS in high concentrations has also been shown to alter predator-prey relationships – e.g. turbid water might make it difficult for fish to see their prey (Lamb 1895). Increases in turbidity often result from release of domestic sewage, industrial discharge (including mining, pulp and paper manufacturing) and physical perturbations such as road use, road and bridge construction (Palmer *et al.* 2004).

2.2 Chemical water quality variables

2.2.1 pH

The concentration of hydrogen (H^+) and hydroxyl ions (OH^-) in water give a measure of pH (Palmer *et al.* 2004). Most fresh waters are almost neutral, pH of 6-8 (Davies and Day 1998). The type of rocks and minerals in a catchment usually determines the pH of a river (Lamb 1985). pH is a critical determinant of many biological functions; pH that is too high or too low may damage an organism by interfering with its metabolic processes (Lamb 1985). Human-induced acidification of rivers is normally the result of industrial effluents, mine drainage and acid precipitation.

2.2.2 Dissolved oxygen (DO)

Dissolved oxygen is of fundamental importance in maintaining aquatic life and is therefore one of the most widely used water quality variables (Tchobanoglous and Schroeder 1985). DO is the amount of gaseous oxygen dissolved in water, which enters surface waters through reaeration. Oxygen is also released into water as a product of photosynthesis (Selman 2007). Factors causing a decrease in DO (hypoxic conditions) in rivers include elevated temperature and salinity, respiration of aquatic organisms, decomposition of organic materials by microorganisms and chemical breakdown of pollutants (Palmer *et al.* 2004). Dissolved oxygen concentrations in water should range from 70 to 120 % saturation (Selman 2007). Hypoxic systems, having DO concentrations below 30 %, have detrimental effects on some aquatic organisms depending on a species sensitivity and stage of development (eggs, larvae or adult) (DWAF 1996a).

2.2.3 Electrical conductivity (EC)

Another important chemical water quality parameter is EC, the ability of water to conduct electrical current (Palmer *et al.* 2004). EC increases as the concentration of ions (most importantly, calcium, magnesium and bicarbonate) increases (Tchobanoglous and Schroeder 1985).

2.2.4 Nitrate, ammonium and phosphate

Nitrogen (as nitrate or ammonium) and phosphorous (orthophosphate) are essential nutrients for the growth of aquatic plants and animals (Lamb 1985). For this reason, these compounds are nutrients or biostimulants when discharged as wastewater to rivers (Tchobanoglous and Schroeder 1985). On entering rivers, phosphorous is dissolved in the water column as PO_4^{3-}or adsorbed onto soil and other particles (Lamb 1985). High concentrations of phosphorous occur in waters that receive sewage, leaching or runoff from cultivated land (Palmer *et al.* 2004) and also detergents. In South Africa, phosphorous is seldom present in high concentrations in unimpacted surface waters because it is actively taken up by plants and thus under natural conditions concentrations between 10 and 50 µg/l are commonly found (DWAF 1996a).

Nitrogen enters rivers via sewage, municipal and industrial wastewater and runoff from fertilized agricultural fields (Lamb 1985). Sewage waste is high in nitrogen in the form of urea and upon entering water bodies; the urea is converted into ammonium (NH_4^+). NH_4^+ is then converted to nitrite (NO_2^-) through the assimilation of the bacteria *Nitrosomonas*. *Nitrobacter* bacteria convert NO_2^- to nitrate (NO_3^-) and this nitrification process consumes oxygen thereby decreasing the concentration of dissolved oxygen in the water (Brisbin and Runka 1995). Nitrate-N and ammonium-N are essential plant nutrients (Skoroszewski 1999). In well oxygenated waters (80 – 120 % DO), ammonium-N concentrations will be below 0.1 mg/l N (DWAF 1996a). NH_4^+-N + NO_3^--N concentrations less than 0.5 mg/l N are considered to be sufficiently low that they can limit eutrophication (DWAF 1996a).

Nitrogen and phosphate can stimulate the growth of algae which provide food for higher organisms (invertebrates and fish). However an excess of nitrogen or phosphorous can result in the over-production of plankton. When the plankton die and decompose, they consume oxygen in the water leaving other oxygen-dependent organisms stressed (Palmer *et al.* 2004).

2.3 Microbiology

Total coliform bacteria concentration is normally used as an indicator of the microbiological quality of water (Keller 1960). These bacteria are a collection of relatively harmless microorganisms that live in the intestines of both warm- and cold-blooded animals (Lamb 1985). A specific subgroup of this collection is the fecal coliform bacteria, the most common member being *Escherichia coli (E. coli*) (Tchobanoglous and Schroeder 1985). The difference between *E. coli* and other coliforms is that *E. coli* is found exclusively in the faeces of warm-blooded animals while other coliforms are naturally found in vegetation, soil, water and faeces. *E. coli* in water bodies indicates recent contamination by sewage or animal waste and it also indicates the presence of disease-causing bacteria, viruses and protozoa (Health Canada 2006). For these reasons, *E. coli* is considered to be the species of coliform bacteria that is the best indicator of human fecal pollution and the possible presence of pathogens (Keller 1960). Pathogenic organisms in water can be transferred to humans through water consumption (Diesch, 1970). For example potential diseases that can be transferred to humans from cattle waste containing pathogens are salmonellosis, anthrax, tuberculosis, tetanus, colibacilosus etc (Azevedo and Stout 1978).

The presence of *E. coli,* especially when above 100-200 counts per 100 ml, is an indicator of a potential health risk for individuals exposed to this water (DWAF 1996c). According to Dallas and Day (2004), it is possible that South African rivers that pass through or those close to informal settlements with no waterborne sanitation and meagre water supplies are severely contaminated by faecal pathogens.

2.4 Seasonal Variation in water quality

Surface water quality generally changes with seasons (McAlister and Ormsbee 2005). Seasonal variations have been reported in water quality parameters such as EC, TSS, pH, temperature, oxygen and nutrients (Nelson *et al.* 1996). For example, in a study conducted on the Long Indian River in Florida, ammonium, nitrite and phosphate concentrations were significantly higher in the wet season than in the dry season (Doering 1996). Seasonal variations in precipitation, surface runoff and ground water flow have a strong effect on the concentration of pollutants in river water (Vega *et al.* 1998). In South Africa, Highveld cold dry seasons (May to October) lead to decreased water temperature. TSS, EC and turbidity tend to be lower during winter periods as there is less rainfall and runoff from a river's catchment (Clarke 1993). During the wet season (November to April), increased discharge, high turbulence and increased aeration in rivers result in high DO concentrations. Rivers also tend to be more turbid during the rainy season due to increased eroding power (Koning and Roos 1999).

3. METHODS

3.1 Study Area

The Jukskei River is one of the ten river catchments in Metropolitan Johannesburg (COCCOS 1986) and forms part of the catchment of the Limpopo River which flows into the Indian Ocean. The river catchment is 800 km^2 (Campbell 1996) and its source is situated upstream of Bruma Lake at the foot of the Witwatersrand area. It flows north through the Bezuidenhout Valley whereby the river is covered by storm water culverts. It then flows through several residential areas including the 2.5 km reach through Alexandra. The Jukskei flows in a northerly direction where it joins the Crocodile River which then flows into the Hartbeespoort Dam. Three major tributaries that join the Jukskei before it joins the Crocodile River are the Braamfontein Spruit, Klein Jukskei Spruit and the Modderfontein Spruit. The Jukskei catchment is located in the Johannesburg Granite Dome and is composed of granitoid gneisses and migmatites (Anhaeusser 1999 as cited by Dudula 2008).

The Jukskei catchment has a warm and moderate climate. It lies within the summer rainfall region of South Africa, which is characterised by afternoon thunderstorms. Mean annual air temperatures range from 10.1 °C in June to 20.1 °C in January. Average daily maxima range from 16 °C (winter) to 25.6 °C (summer). The average annual rainfall is 713 mm. The wettest month is January with an average monthly rainfall of 125 mm. The driest month is July with an average monthly rainfall of 4 mm (Weather Bureau 1997).

3.2 Sampling Sites and Data Collection

3.2.1 Sampling sites

Sampling was conducted monthly from May to December 2009. This period is representative of the dry season (May to October) and the wet season (November to December). Sampling sites were selected on the basis of safety, accessibility and representativeness of the study area. Water was sampled at Zoo Lake (PRE1), Royal Johannesburg and Kensington Golf Club (PRE2 and PRE3), and Buccleuch Drive (POST) (Figure 3.1). The sites were named according to their location from Alexandra, therefore the furthest site relative to Alexandra high in the catchment is PRE1 and the site low in the catchment is POST. These sites lie between latitudes 26°3S and latitude 26°9S, and between longitudes 28°1E and 28°6E (Table 3.1).

Table 3.1: Geographic locations of sampling sites in the study

Sampling site	Area sampled	GPS co-ordinates
PRE1	Zoo Lake, Parkview	26°9'35"E 28°1'48"S
PRE2	Royal Johannesburg and Kensington Golf Club, Linksfield North	26°9'26"E 28°6'7S
PRE3	Royal Johannesburg and Kensington Golf Club, Linksfield North	26°9'4"E 28°6'28"S
POST	Buccleuch Drive, Buccleuch	26°3'29"E 28°6'13"S

- PRE1 – the sampling site is along the Braamfontein Spruit which is a tributary to the Jukskei River. The site is uppermost in the catchment in the study area and is approximately 500 m downstream from Johannesburg Zoo. The Braamfontein Spruit is not in the Alexandra catchment as its confluence with the Jukskei River is downstream of the township. Therefore, PRE1 site represents areas high in the Jukskei catchment.
- Royal Johannesburg and Kensington Golf Club (RJKGC) – two sampling sites were selected within the golf course, both lower in the catchment than PRE1 but higher in the catchment than Alexandra Township. These two sites are on the Sandringham Stream which is also a tributary to the Jukskei.

As part of the maintenance system at RJKGC, the turf at the course is fertilized in March and September every year (Malcolm Bromley, Course Manager[i]). Golf courses can contribute substantially to pollution of rivers passing through them, due to frequent fertilizer application and irrigation which washes excess nutrients into runoff thereby increasing nutrient loads in the rivers (Wilkes University Center for Environmental Quality 1999). Therefore, water quality was measured at a point where the river enters the golf course (PRE2) and at about 700 m downstream of PRE2. This second downstream site (PRE3) was used to determine whether the golf course changes the chemical quality of Jukskei water before it enters Alexandra

- POST – this site is approximately 1.5 km downstream of Alexandra Township. At this site, the river would have collected runoff and debris from the Township and therefore comparison of this to the golf course samples would reflect the degree of impact Alexandra has on the river.

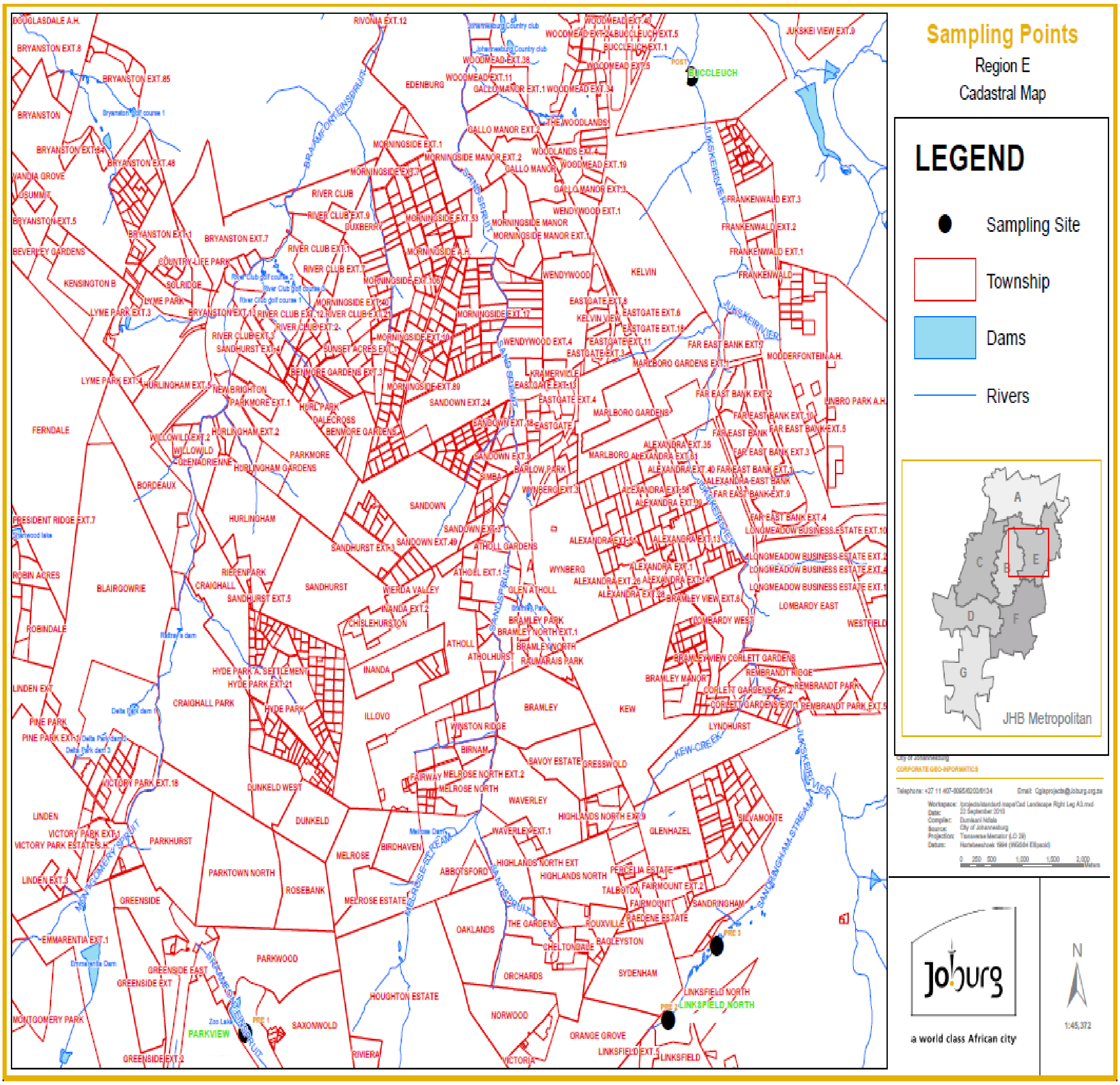

Figure 3.1: Sampling points for the study

3.2.2 Sample collection

Two grab samples of water were collected from each site on each date. One litre acid-washed opaque plastic bottles (Figure A3) were used (Clesceri *et al.* 1998). Samples for microbial analysis were collected in sterile whirl pack bags (Figure A4). Samples were collected from mid-stream (Figure 3.2), to avoid the scouring effects near the river banks (WRC 1998). After collection, samples were stored in a cooler box on ice and in the dark to maintain a low temperature and limit photosynthesis of phytoplankton and microbes during transport to the laboratories (Clesceri *et al.* 1998).

Figure 3.2: Water collection at midstream of the PRE3 sampling site

3.3 Field and Laboratory Analysis of Water Samples

Electrical conductivity, dissolved oxygen, pH and temperature were measured immediately after sample collection at every site because these properties of water can change quickly (Tchobanoglous and Schroeder 1985). The following instruments were used: HANNA H19210N ATC pH Meter, HANNA H19143 Auto Cal Dissolved Oxygen Meter and HANNA H199300 Conductivity Meter (Figure A5). Temperature was measured using the DO and EC meters.

All the other physical and chemical variables were measured in laboratories at the University of the Witwatersrand. Turbidity was measured from unfiltered water samples using an electronic laboratory nephelometer. TSS and SPOM were measured based on the standard methods from Dallas *et al*. (1994).

Samples for ammonium, nitrate and phosphate analysis were filtered using a Whatman glass fibre filter paper and frozen. These were all analysed at once after sampling was complete using standard methods adapted from Clesceri *et al* (1998). *E. coli* was determined at the M and L Laboratory Services in Johannesburg.

3.4 Statistical Analysis

The parametric one-way analysis of variance (ANOVA) was used for the detection of differences in water quality among the four sites since nine samples were collected per parameter at each site throughout the sampling period. Statistica software version 6 (2001) was used. The level of significance (α) was 0.05 and the P values obtained were referred to as model Ps in the results section. A model P less than 0.05 indicates that at least two of the sites differ in parameters from each other. To determine where differences lie between specific sites, the Tukey Studentized Range was used ($\alpha = 0.05$). Tukey's test was used because it is least conservative, that is, chances of missing where the real differences lie are small. Tukey's test is more powerful when testing for variance in small numbers of groups and is appropriate in this case where only four sites were tested for differences in variables (Maxwell and Delaney 2003). The Kruskal Wallis test was used to detect differences in *E. coli* concentrations among the sites as the sample size was small since *E. coli* was enumerated for four months only.

The Wilcoxon Mann-Whitney test for two independent samples (Statistica) was used in determining whether parameters varied with changing seasons (wet and dry). The

Wilcoxon Mann-Whitney test was used as the data were from two different populations (Conover 1971) that is, from the dry and the wet seasons. The significance levels that were considered in this analysis were $\alpha = 0.05$ and 0.10.

Microsoft Office Excel software (2007) was used to produce time series graphs.

4. RESULTS

4.1 Water Quality at the Four Sampling Sites

4.1.1 Turbidity

Turbidity varied from 5.6 to 50 NTU and differed significantly by site (model *P* < 0.05) (Figure 4.1). These differences were observed between the PRE2 site (at the upper end of the Royal Johannesburg and Kensington golf club) and the POST site (downstream of Alexandra) where turbidity at PRE2 site was significantly higher than at the POST site (*P* < 0.03). Turbidity at the PRE2 site was approximately two times higher relative to the site downstream of Alexandra and this pattern was fairly consistent throughout the sampling period (Figure 4.2). It is surprising that the mean turbidity was much lower downstream of Alexandra Township (Figure 4.1) where a lot of waste from the township is dumped into the Jukskei River. Seasonal influences on turbidity were only observed at PRE2 and PRE3 sites (at the golf club), where values recorded in November and December (wet season) were highest and this coincided with the onset of the rains (*P* < 0.05) (Figure 4.2).

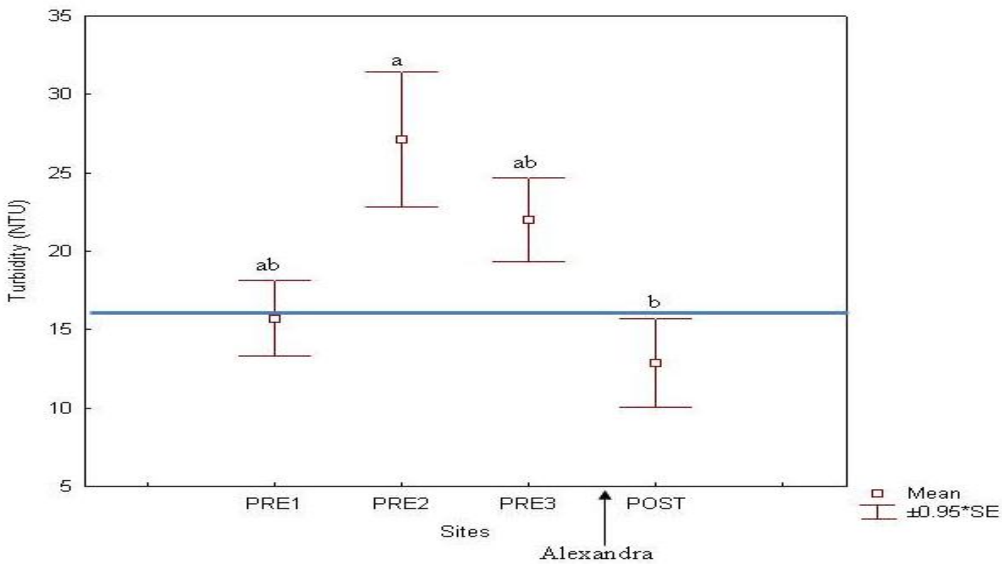

Figure 4.1: Mean site turbidity values for the nine months of sampling (*n* = 9). Model *P* < 0.05. ±SE (standard error). Groups a and b are significantly different at *P* < 0.05; ab and a, and ab and b are not significantly different. The blue line represents the upper limit for the ideal turbidity of 7-16 NTU for aquatic ecosystems in the Jukskei catchment (Van Veelen 2002).

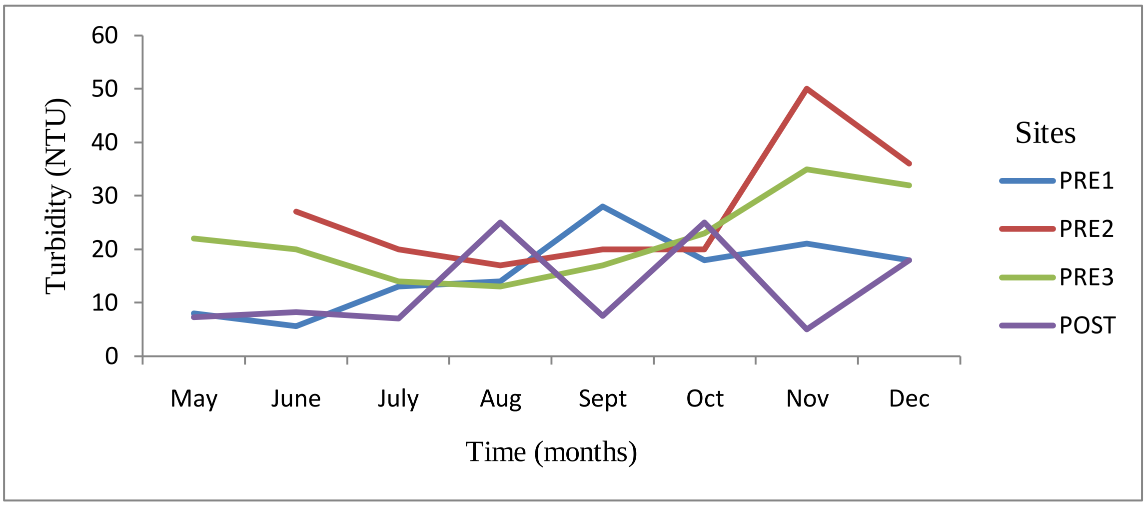

Figure 4.2: Monthly site turbidity time series. PRE1: dry season mean (DS) – 14.43 ± 3.26 NTU, wet season mean (WS) – 19.50 ± 1.50 NTU; PRE2: DS – 20.80 ± 1.66** NTU, WS – 43.00 ± 7.00 NTU; PRE3: DS – 18.17 ± 1.70** NTU, WS – 33.50 ± 1.50 NTU; POST: DS – 13.33 ± 3.69 NTU, WS – 11.50 ± 6.50 NTU. **Significant at 5% significance level.

4.1.2 Total suspended solids (TSS)

The TSS concentrations varied from 6.65 to 103.98 mg/l and were not significantly different among sites ($P > 0.05$) (Figure 4.3). Dry season (May to October) TSS concentrations at the PRE3 site (just before the water enters Alexandra Township) were significantly lower than the wet season concentrations ($P < 0.05$) (Figure 4.4). There were no significant seasonal variations at the other three sites (Figure 4.4).

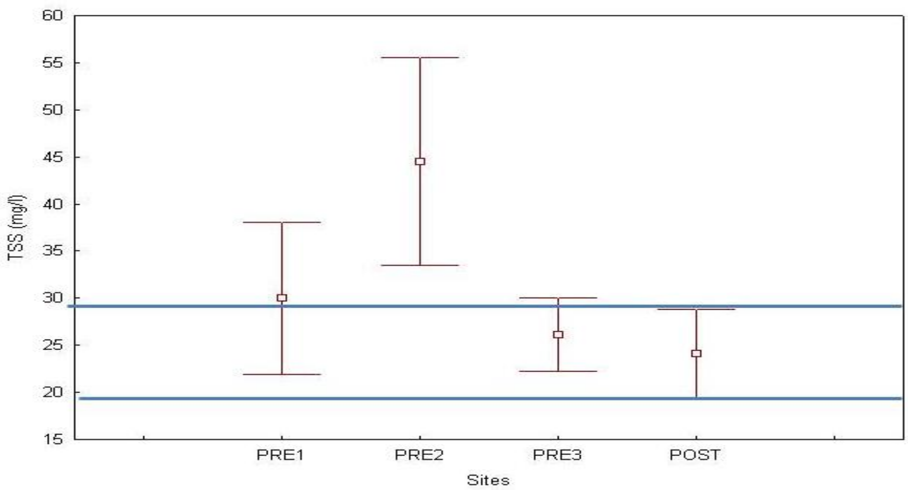

Figure 4.3: Mean site total suspended solids values for the nine months of sampling (n = 9). Model $P > 0.05$.The blue line represents the acceptable range of TSS of aquatic environments in the Klip River catchment of 20-30 mg/l (In-stream water quality guidelines for the Klip River catchment (IWQGKRC) 2003).

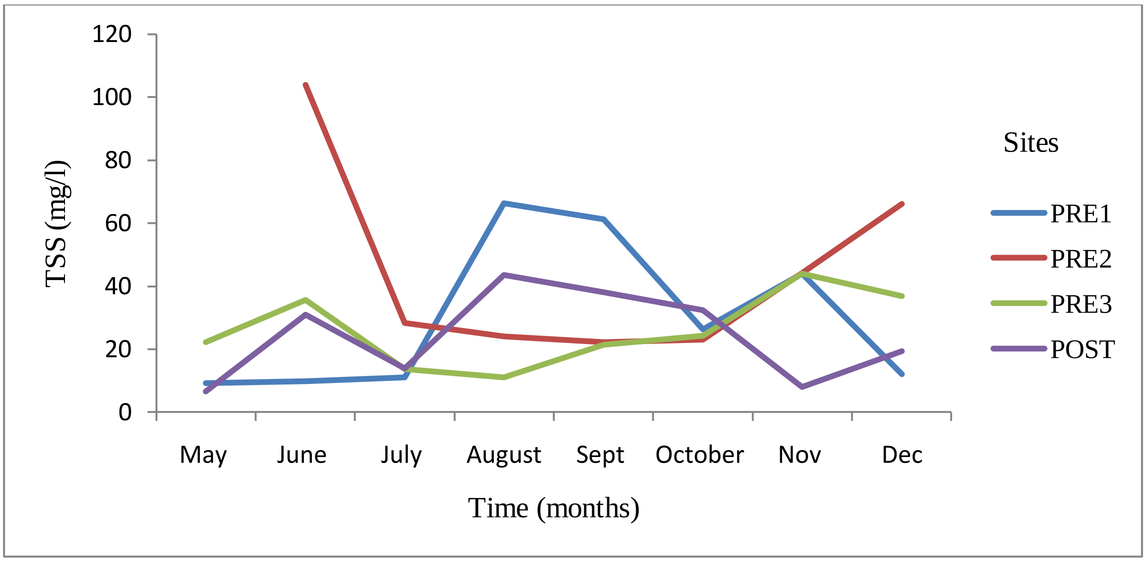

Figure 4.4: Monthly site total suspended solids time series. PRE1: DS – 30.69 ± 10.81 mg/l, WS – 27.99 ± 15.89 mg/l; PRE2: DS – 40.22 ± 15.98 mg/l, WS – 55.22 ± 15.50 mg/l; PRE3: DS – 21.41 ± 1.70** mg/l, WS – 40.49 ± 3.55 mg/l; POST: DS – 27.56 ± 5.85 mg/l, WS – 13.74 ± 5.68 mg/l. **Significant at 5% significance level.

4.1.3 Suspended particulate organic matter (SPOM)

The mean suspended solids were comprised of 57 to 63 % organic matter (4.56-88.28 mg/l) at the four sampling sites. Suspended organic matter content was fairly consistent at all sites throughout the sampling period except for the high concentrations measured at PRE2 in June (Figure 4.5). Thus there were no significant differences in organic content in the water entering and exiting Alexandra ($P > 0.05$) (Figure 4.6). Water exiting Alexandra (at POST site) contained significantly lower concentrations of organic matter content in November and December than during the dry season months ($P < 0.10$) (Figure 4.5). Seasonal variations in SPOM were not observed at the other three sampling sites (Figure 4.5).

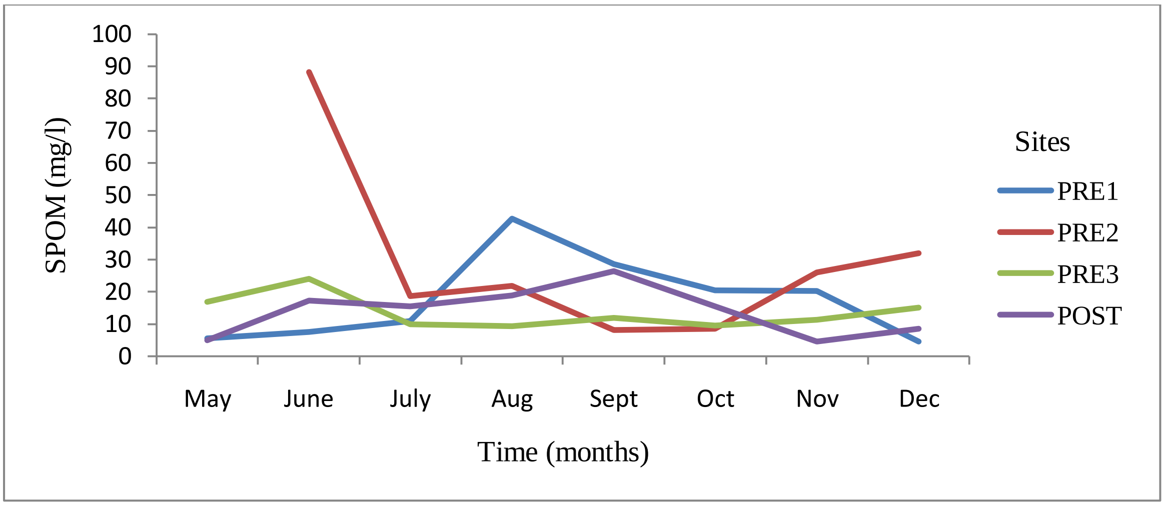

Figure 4.5: Monthly site suspended particulate organic matter time series. PRE1: DS – 70.63 ± 7.34** mg/l, WS – 41.90 ± 4.20 mg/l; PRE2: DS – 63.54 ± 11.87 mg/l, WS – 53.65 ± 5.25 mg/l; PRE3: DS – 65.73 ± 6.47*mg/l, WS – 33.35 ± 7.75 mg/l; POST: DS – 67.00 ± 10.17 mg/l, WS – 50.70 ± 6.90 mg/l. **Significant at 5% significance level. *Significant at 10% significance level.

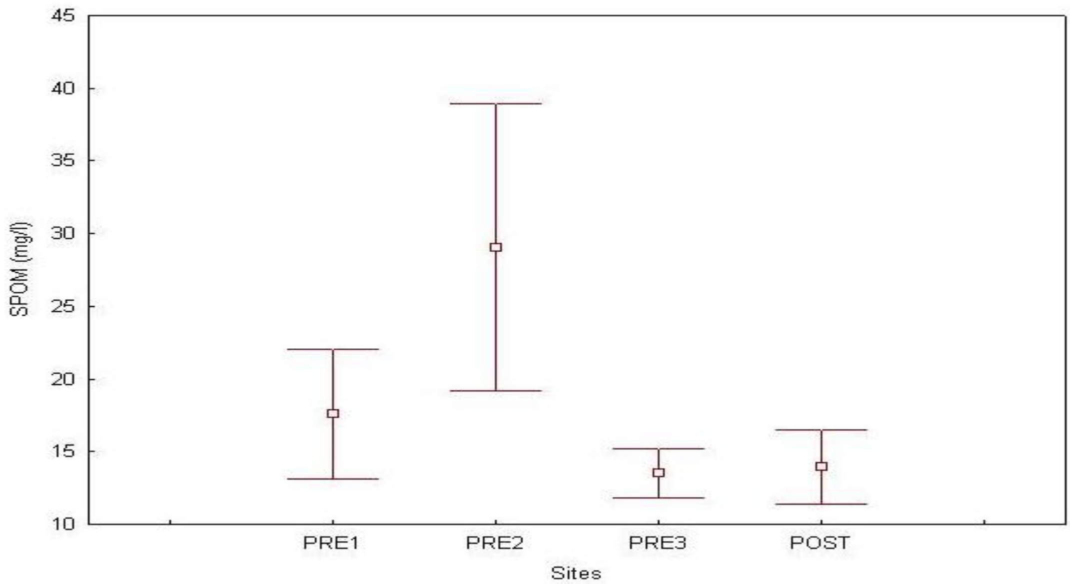

Figure 4.6: Mean site suspended particulate organic matter mg/l for nine months of sampling (n = 9). Model $P > 0.05$.

4.1.4 Temperature

Water temperature ranged from 8.3 to 27.9 °C and was not significantly different among the four sampling sites ($P > 0.05$) (Figure 4.7) although temperature was measured at different times of day. There were also no significant seasonal temperature variations at all the sites ($P > 0.10$) (Figure 4.7).

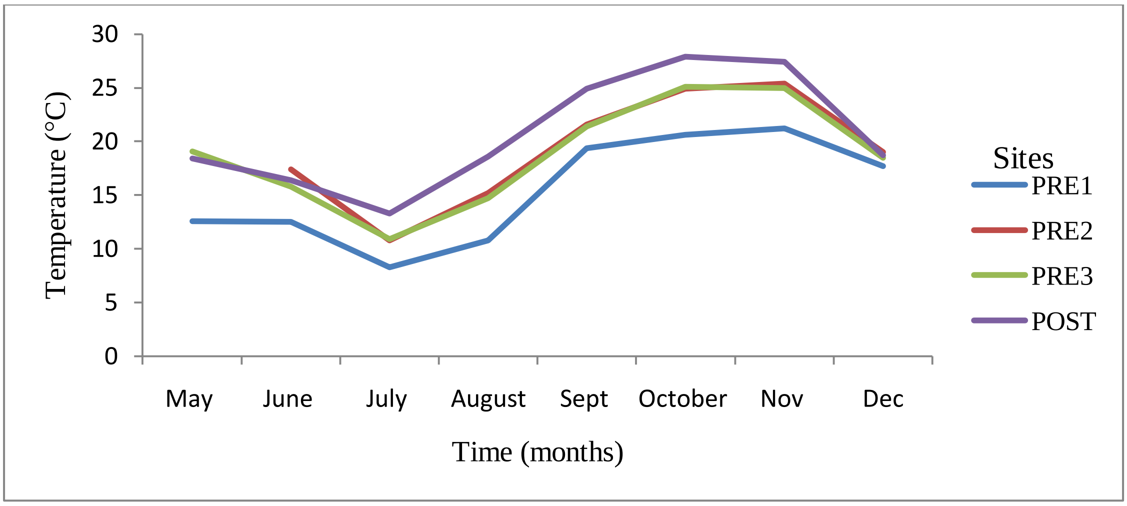

Figure 4.7: Monthly site temperature time series. PRE1: DS – 14.0 ± 2.0 °C, WS – 19.5 ± 1.8 °C; PRE2: DS – 18.0 ± 2.5 °C, WS – 22.2 ± 3.2 °C; PRE3: DS – 17.8 ± 2.1 °C, WS – 21.8 ± 3.3 °C; POST: DS – 19.9 ± 2.2 °C, WS – 23.1 ± 4.4 °C.

4.1.5 pH, electrical conductivity (EC) and dissolved oxygen (DO)

Replicate samples from August for pH, EC and DO at the PRE3 and POST sites were collected from the streams at one minute intervals. This was done to detect variations in readings over short time periods and to determine how consistent instruments were. The parameters for the five replicates at both sites were fairly constant (Table 4.1).

Table 4.1: The concentrations for the replicates sampled in August 2009

Site	Replicate	Parameters		
		pH	Electrical conductivity (mS/m)	Dissolved oxygen (% saturation)
PRE3	1	8.4	410	66
	2	8.5	421	62
	3	8.6	421	61
	4	8.6	422	63
	5	8.4	421	70
POST	1	8.9	497	74
	2	9.0	513	74
	3	8.9	514	77
	4	8.9	515	77
	5	8.9	519	65

Variations in pH among the sites were observed (model $P < 0.05$). The mean pH of the water exiting Alexandra (8.3 ± 0.1) was significantly higher than that at the PRE1 site (highest site in the Jukskei catchment, mean = 7.7 ± 0.1; $P < 0.05$) (Figure 4.8). There were no other significant differences observed between the sites (Figure 4.8). The pH values for water sampled in November and December at the PRE1 and PRE2 sites were significantly lower than pH for the dry season months ($P < 0.10$) (Figure 4.9). There were no other seasonal variations observed at the other two sites (Figure 4.9).

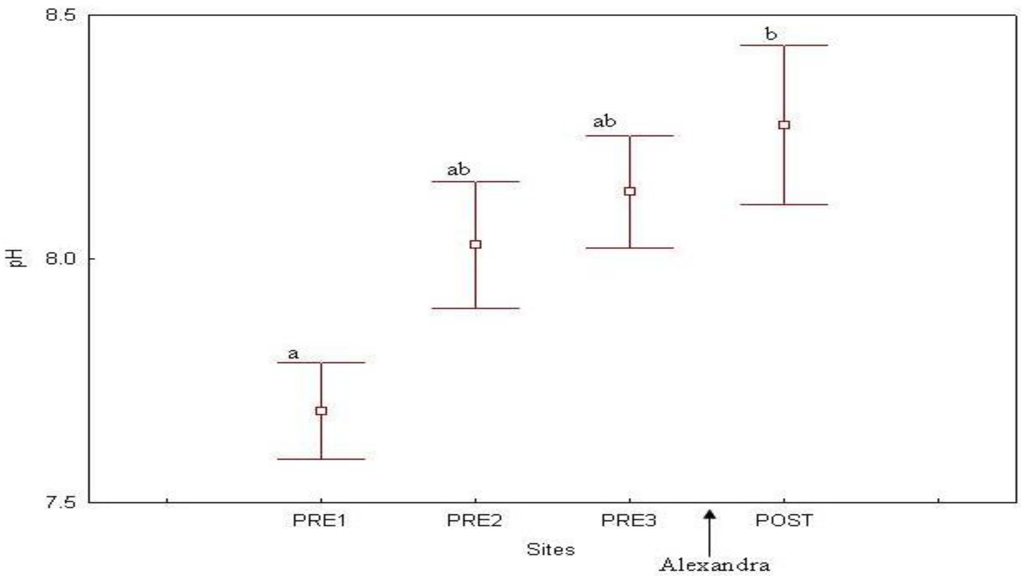

Figure 4.8: Mean site pH for nine months of sampling ($n = 9$). Model $P < 0.05$. Groups a and b are different.

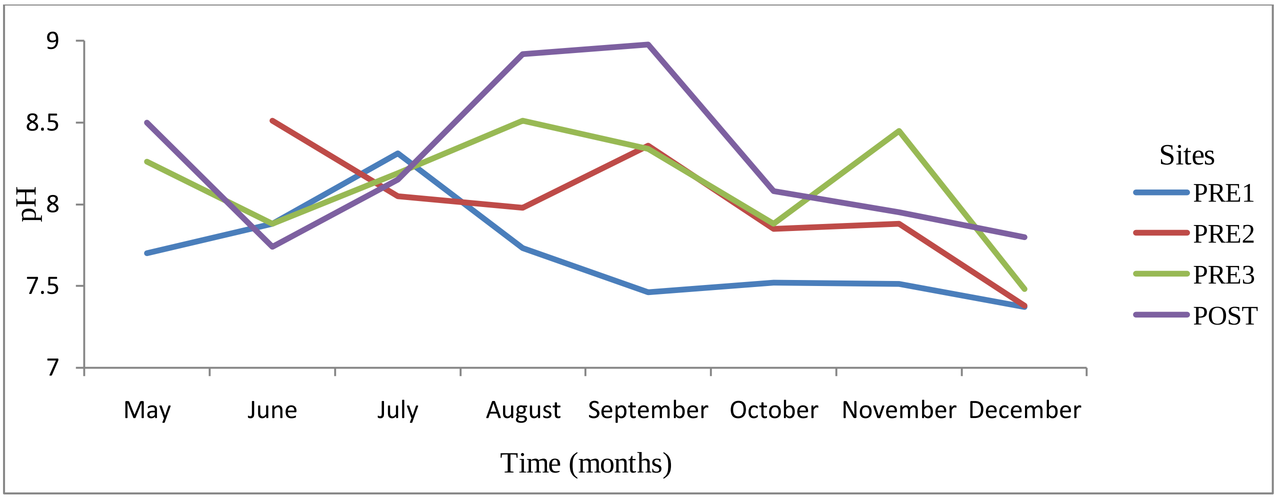

Figure 4.9: Monthly site pH time series. PRE1: DS – 7.77 ± 0.12*, WS – 7.45 ± 0.05; PRE2: DS – 8.18 ± 0.12*, WS – 7.65 ± 0.25; PRE3: DS – 8.18 ± 0.10, WS – 8.00 ± 0.50; POST: DS – 8.40 ± 0.17, WS – 7.90 ± 0.10. *Significant at 10% significance level.

Electrical conductivity was within a range of 100 units among all the sites between July and December (Figure 4.10) and therefore no significant variations in EC were observed among the sites (*P* > 0.05) (Figure 4.11). The dry season EC (May to October) was significantly higher than the wet season EC at all sites (*P* <0.10) (Figure 4.10).

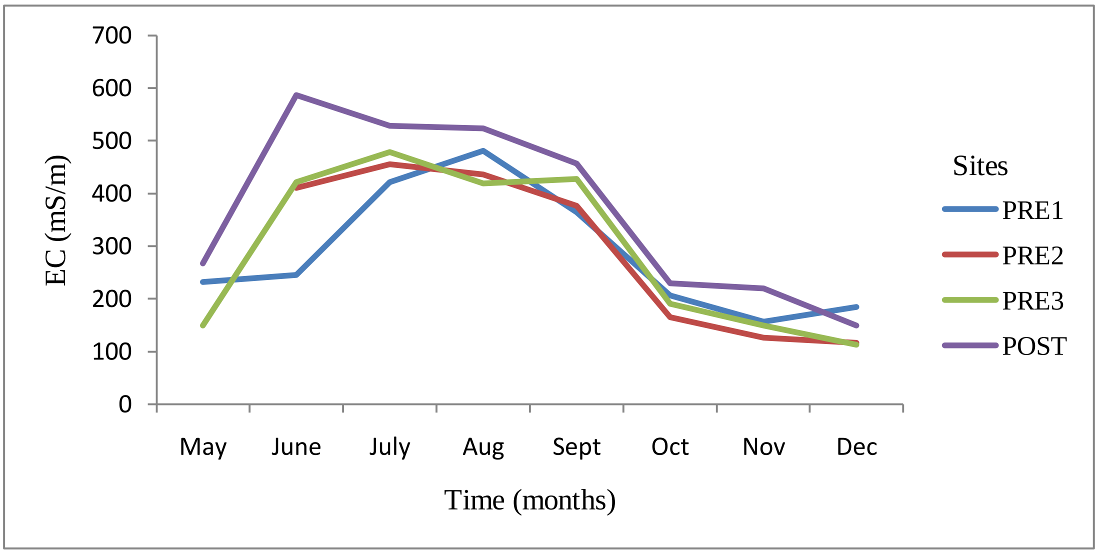

Figure 4.10: Monthly site electrical conductivity time series. PRE1: DS – 325 ± 46** mS/m, WS – 171 ± 14 mS/m; PRE2: DS – 369 ± 53* mS/m, WS – 121 ± 5 mS/m; PRE3: DS – 348 ± 57* mS/m, WS – 131 ± 19 mS/m; POST: DS – 432 ± 61** mS/m, WS – 185 ± 35 mS/m. **Significant at 5 % significance level. *Significant at 10 % significance level.

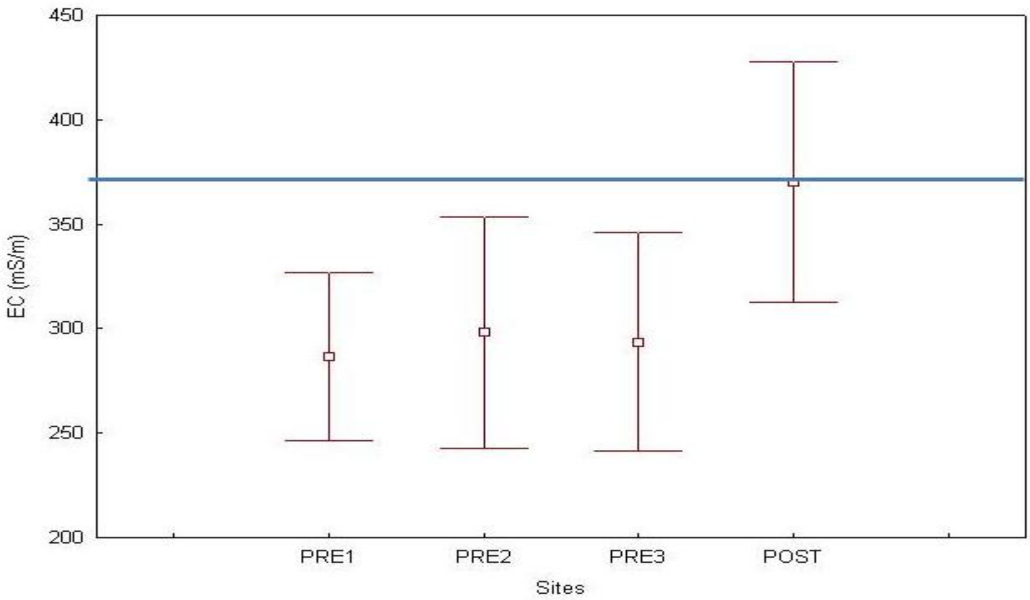

Figure 4.11: Mean site electrical conductivity for nine months of sampling (n = 9). Model $P > 0.05$. Blue line indicates the maximum tolerable limit for electrical conductivity in water for domestic use (DWAF 1996b).

Significant differences existed among sites for both % saturation DO (19 – 73 %; model $P < 0.01$) and DO concentration (2.08 – 8.12 mg/l; model $P < 0.03$) (Figures 4.12 and 4.13). The PRE1 site had the lowest DO saturation than the three downstream sites (PRE2, PRE3 and POST, $P < 0.04$) (Figure 4.12). The DO concentrations at the PRE1 site were, however, only lower than concentrations at the PRE3 and POST sites ($P < 0.04$) (Figure 4.13). These trends were consistent throughout the sampling period (Figures 4.14 and 4.15). There were no significant seasonal variations at all sites ($P > 0.10$) (Figures 4.14 and 4.15).

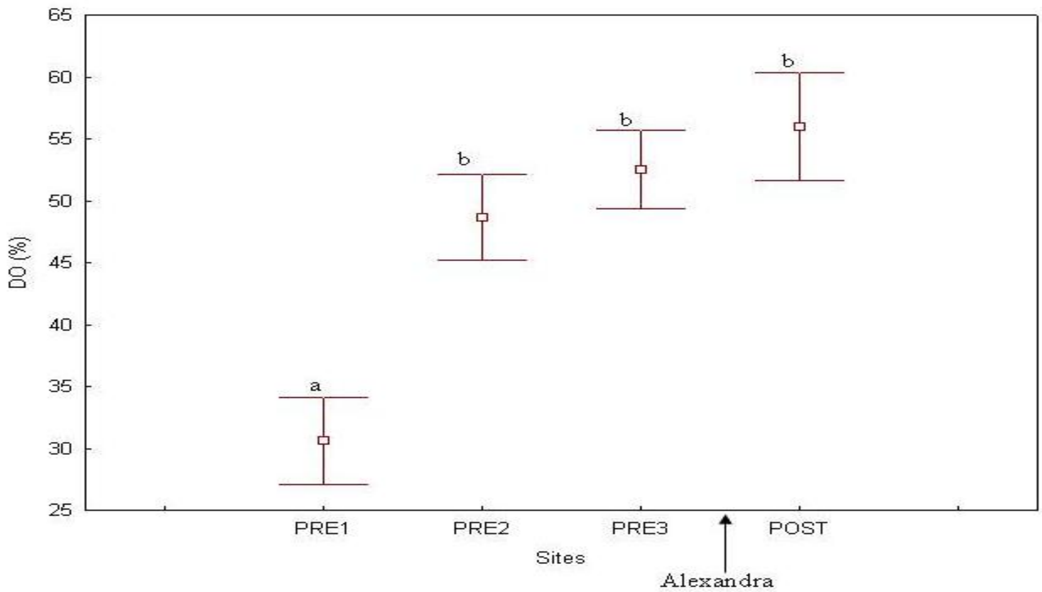

Figure 4.12: Mean site % dissolved oxygen saturation for nine months of sampling (n = 9). Model P <0.01. Groups a and b are different.

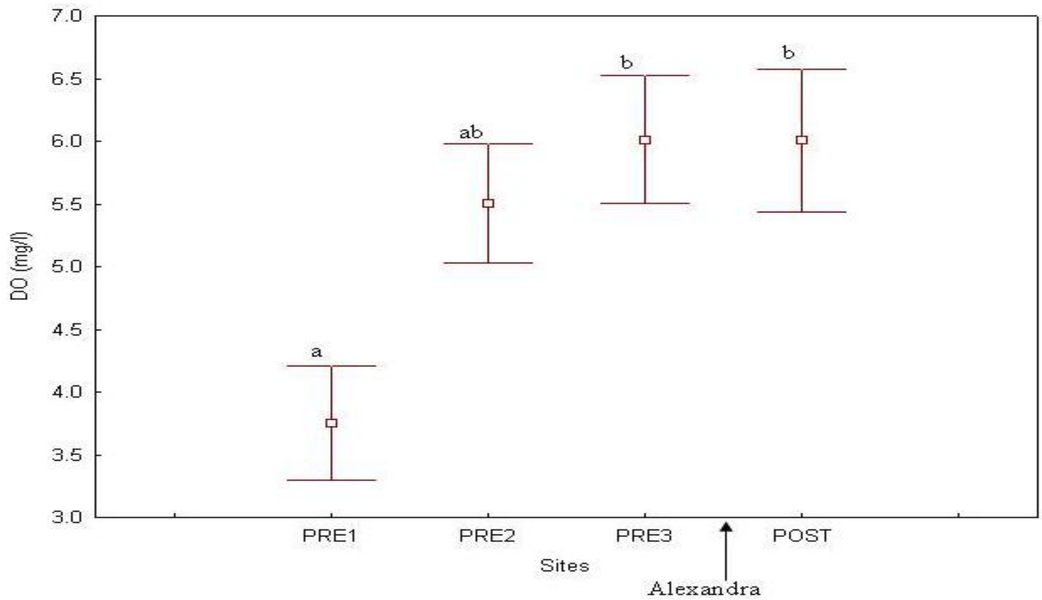

Figure 4.13: Mean site dissolved oxygen concentration (mg/l) for nine months of sampling (n = 9). Model P < 0.03. Groups a and b are different.

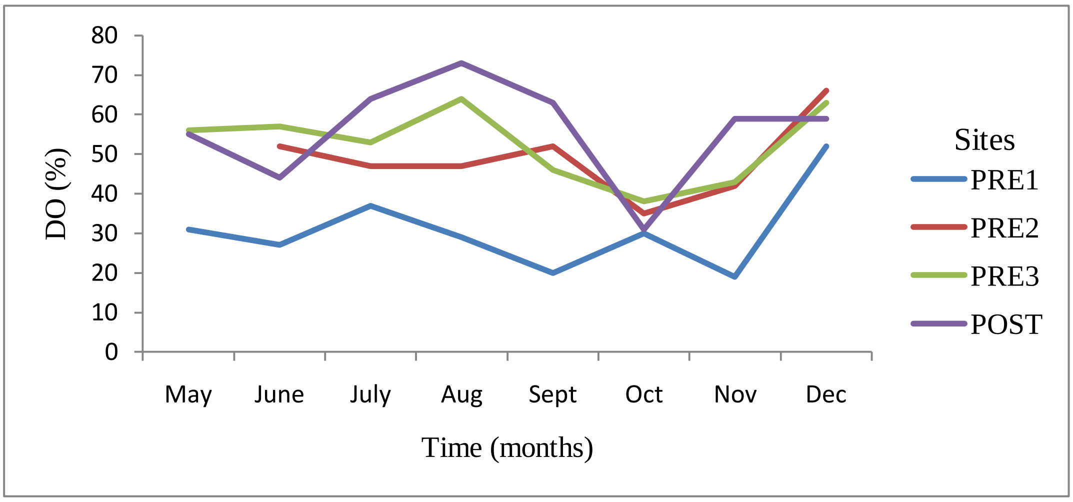

Figure 4.14: Monthly site % dissolved oxygen saturation time series. PRE1: DS – 29.00 ± 2.27 %, WS – 35.50 ± 16.50 %; PRE2: DS – 46.60 ± 3.11 %, WS – 54.00 ± 12.00 %; PRE3: DS – 52.30 ± 3.73 %, WS – 53.00 ± 10.00 %; POST: DS – 55.00 ± 6.23 %, WS – 59.00%.

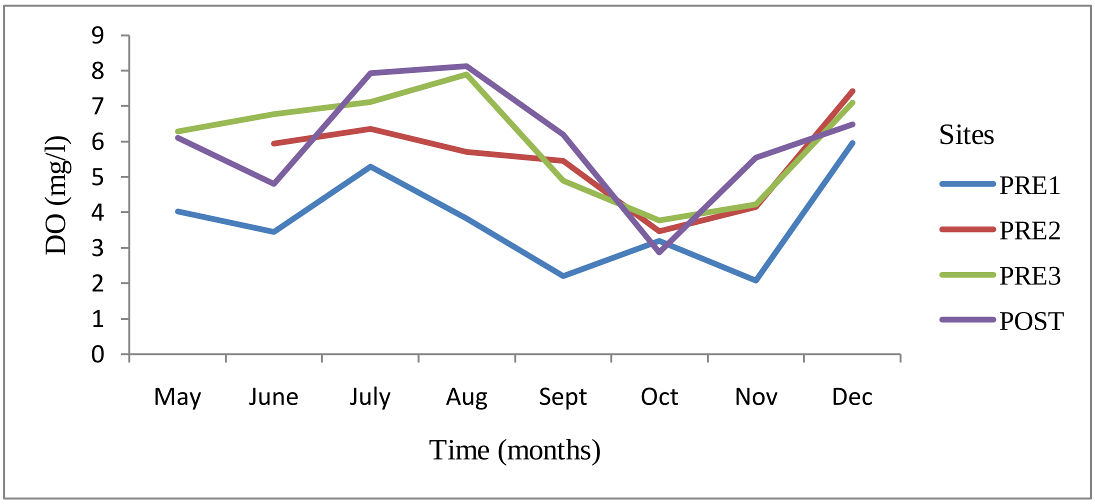

Figure 4.15: Monthly site dissolved oxygen concentration (mg/l) time series. PRE1: DS – 3.38 ± 0.35 mg/l, WS – 3.79 ± 1.82 mg/l; PRE2: DS – 5.11 ± 0.47 mg/l, WS – 5.48 ± 1.52 mg/l; PRE3: DS – 5.80 ± 0.60 mg/l, WS – 5.36 ± 1.32 mg/l; POST: DS – 5.69 ± 0.79 mg/l, WS – 5.72 ± 0.37 mg/l.

4.1.6 Nitrate-N (NO_3^- - N)

Nitrate-N concentrations ranged from < 0.05 to 2.2 mg NO_3^- - N /l among the sites and significant differences were observed (P < 0.01) (Figure 4.16). Nitrate-N concentrations were at least double (1.4 - 2.2 mg NO_3^- - N /l) in water exiting Alexandra than concentrations measured in the water upstream of the township (P < 0.01) (Figures 4.16 and 4.17). The lowest NO_3^- - N concentrations were measured in the water at the golf club (PRE1 and PRE2 sites) and these were also significantly lower than concentrations in the water at the PRE1 site ($P < 0.03$). This pattern was consistent throughout the sampling period (Figures 4.16 and 4.17). There were no significant differences in NO_3^- - N between the golf club sites ($P > 0.05$) (Figure 4.16). The changing seasons had no influence on the NO_3^- - N concentrations at all the sites (Figure 4.17).

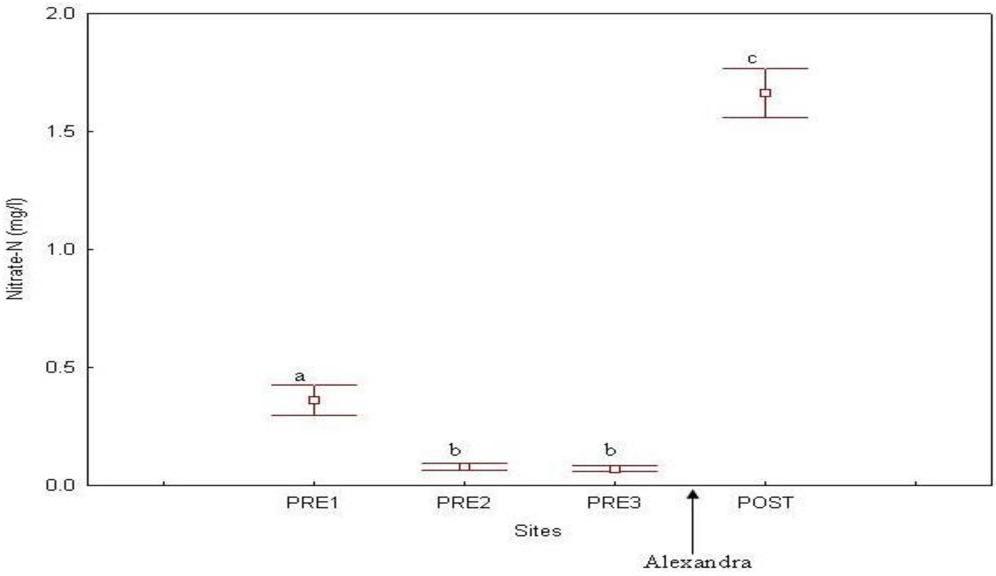

Figure 4.16: Mean site nitrate-N concentration for nine months of sampling (n = 9). Model $P < 0.01$. Groups a, b and c are different. Groups a and b are different.

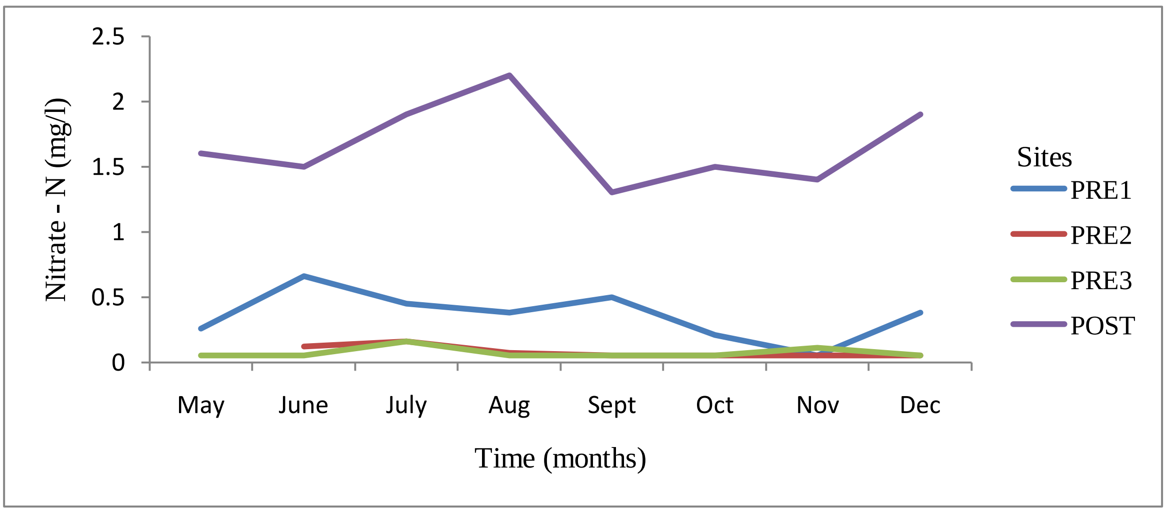

Figure 4.17: Monthly site nitrate-N concentration time series. PRE1: DS – 0.41 ± 0.07 mg NO_3^- - N /l, WS – 0.22 ± 0.17 mg NO_3^- - N /l; PRE2: DS – 0.09 ± 0.02 mg NO_3^- - N /l, WS – 0.05 mg NO_3^- - N /l; PRE3: DS – 0.07 ± 0.02 mg NO_3^- - N /l, WS – 0.08 ± 0.03 mg NO_3^- - N /l; POST: DS – 1.67 ± 0.13 mg NO_3^- - N /l, WS – 1.65 ± 0.25 mg NO_3^- - N /l.

4.1.7 Ammonium-N (NH_4^+ - N)

Differences in NH_4^+ - N were observed high in the catchment before the water entered Alexandra. Here, NH_4^+ - N concentrations at the PRE1 site were higher (mean: 5.17 ± 2.13 mg NH_4^+ - N /l) than concentrations at the golf club sites (mean: 0.09 ± 0.04 mg NH_4^+ - N /l) and this pattern was consistent throughout the sampling period ($P < 0.03$) (Figures 4.18 and 4.19). There were no significant differences in nitrate concentrations between the PRE1 and POST sites (Figure 4.18). The onset of the wet season resulted in NH_4^+ - N concentrations becoming significantly lower than those recorded for the dry season only in the water exiting Alexandra Township ($P > 0.10$) (Figure 4.19).

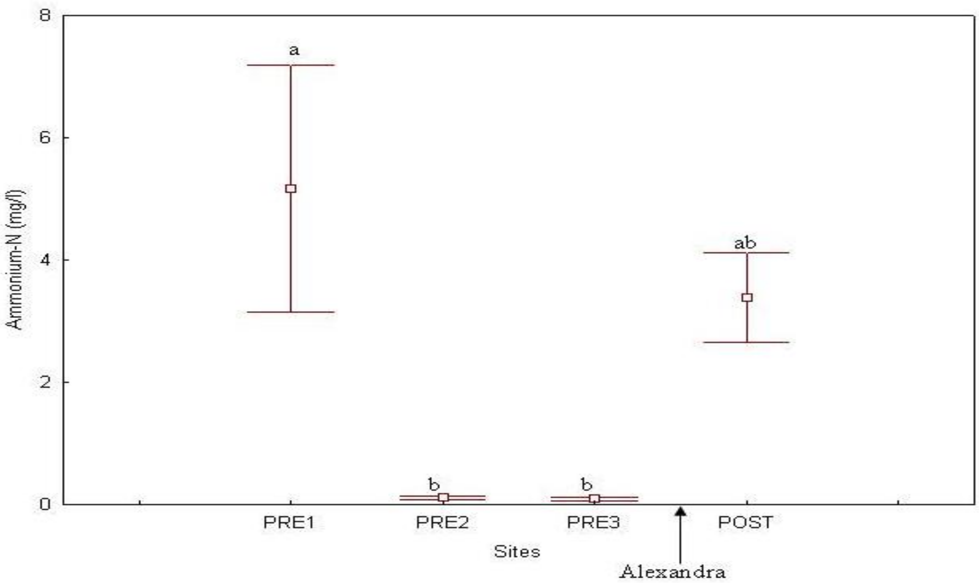

Figure 4.18: Mean site ammonium-N concentrations for nine months of sampling (n = 9). Model $P <$ 0.01. Groups a and b are different.

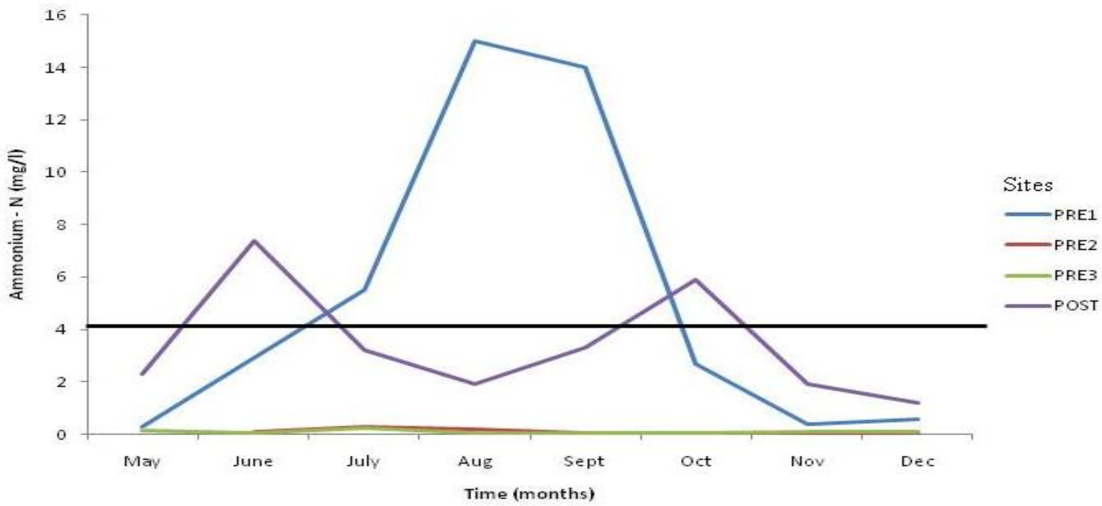

Figure 4.19: Monthly site ammonium-N concentrations time series. PRE1: DS – 6.73 ± 2.55 mg NH_4^+ - N /l, WS – 0.49 ± 0.09 mg NH_4^+ - N /l; PRE2: DS – 0.14 ± 0.05 mg NH_4^+ - N /l, WS – 0.05 mg NH_4^+ - N /l; PRE3: DS – 0.10 ± 0.03 mg NH_4^+ - N /l, WS – 0.08 ± 0.01 mg NH_4^+ - N /l; POST: DS – 4.00 ± 0.89* m NH_4^+ - N g/l, WS – 1.55 ± 0.35 mg NH_4^+ - N /l. *Significant at 10 % significance level. The black line depicts the maximum tolerable limit of ammonium concentrations for aquatic ecosystems in the Klip River catchment (IWQGKRC 2003).

4.1.8 Orthophosphate (P)

The orthophosphate concentrations among the four sampling sites differed significantly and ranged from less than 0.05 to 0.83 mgP/l (model $P < 0.01$) (Figures 4.20 and 4.21). The differences were only observed between the golf club sites (PRE2 and PRE3) and the PRE1 and POST sites (Figure 4.20). The mean orthophosphate concentrations at the PRE1 and POST sites (0.41 ± 0.17 mgP/l and 0.46 ± 0.07 mgP/l respectively) were higher than the concentrations at the PRE2 and PRE3 sites (0.05 mgP/l at both sites) ($P < 0.03$). It is important here to note that orthophosphate concentrations increased the Jukskei River flowed past Alexandra Township (Figure 4.20). The wet season orthophosphate concentrations at the PRE1 and POST sites were significantly lower than the dry season concentrations ($P < 0.05$) (Figure 4.21). No significant seasonal variations were observed at the golf club sites (Figure 4.21).

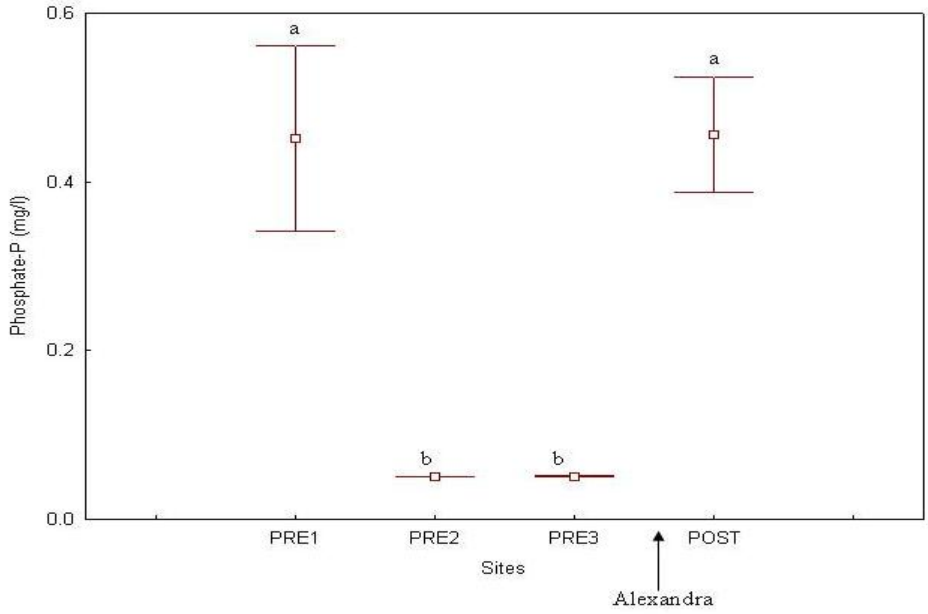

Figure 4.20: Mean site phosphate-P for nine months of sampling (n = 9). Model P < 0.01. Groups a and b are different.

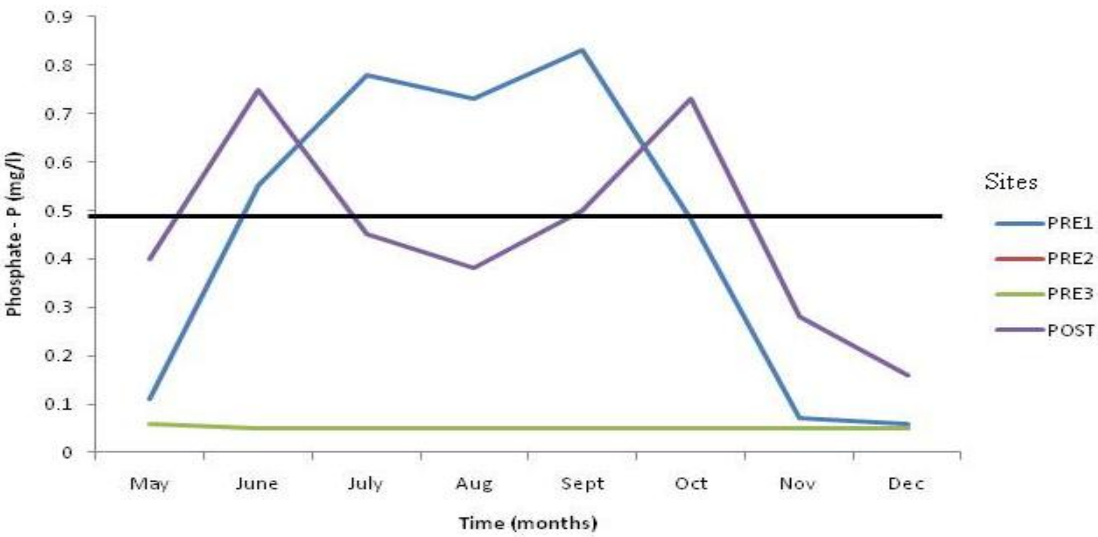

Figure 4.21: Monthly site phosphate-P time series. PRE1: DS – 0.58 ± 0.11** mgP/l, WS – 0.07 ± 0.01 mgP/l; PRE2: DS – 0.05 mgP/l, WS – 0.05 mgP/l; PRE3: DS – 0.05 mgP/l, WS – 0.05 mgP/l; POST: DS – 0.54 ± 0.07 mgP/l, WS – 0.22 ± 0.06 mgP/l. **Significant at 5 % significant level. The black line represents the upper limit for the acceptable range for phosphate in the Jukskei River catchment (City of Johannesburg, 2009).

4.1.9 *E. coli*

E. coli counts downstream of Alexandra were at least two orders of magnitude higher than those measured at the other three upstream sites. Despite these high counts, there were no statistical significant differences in the *E. coli* concentrations in the water both upstream and downstream of Alexandra even after the data were logarithmically transformed (Figure 4.22).

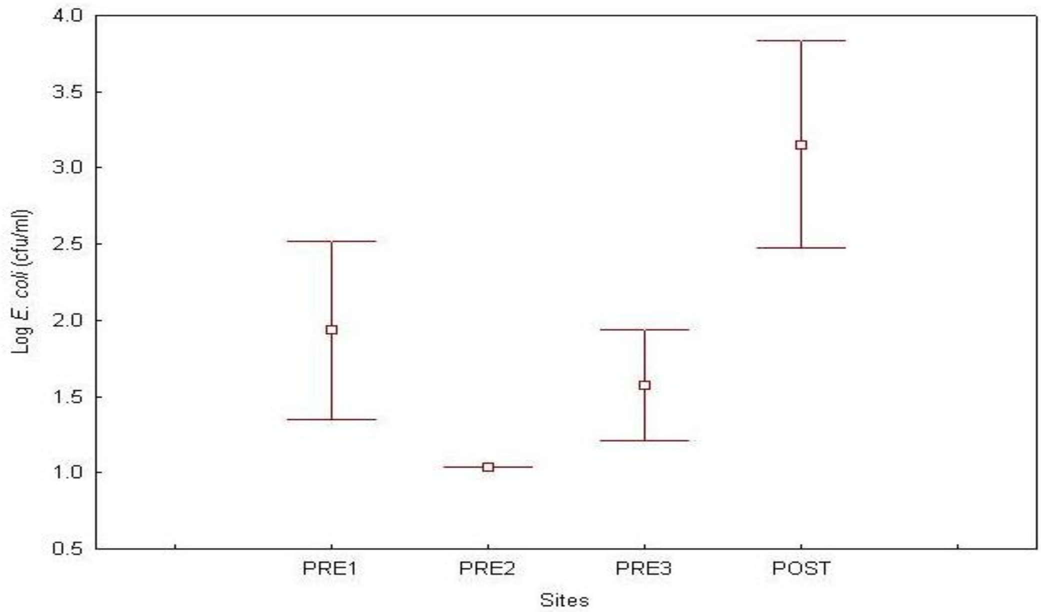

Figure 4.22: Mean site *E. coli* counts for four months of sampling (n = 4). Model $P > 0.05$.

5. DISCUSSION

5.1 Water Quality Changes upstream and Downstream of Alexandra Township

The Zoo Lake site (PRE1) on the Braamfontein Spruit is not in the same catchment as the golf course sampling sites as the confluence of the Spruit and Jukskei River is more than 5 km downstream of Alexandra. The site, however, is representative of high catchment areas in the Jukskei catchment.

5.1.1 Physical quality

Release of domestic sewage into rivers can increase turbidity levels and TSS concentrations in a river (Boulton and Brock 1999). It was strange, however, that despite the release of raw sewage into the Jukskei River from Alexandra Township, turbidity levels downstream of the township were lower than those recorded in the water entering the township. The PRE1 site receives water that is treated 100 % from Johannesburg Zoo, however, turbidity levels at the site were slightly higher than the ones measured downstream of Alexandra.

Turbidity normally increases in the rainy season for most South African rivers (Chutter 1969) and this might be one of the reasons for the increased turbidity levels in the wet season at the RJK golf course sites. Anthropogenic activities like road and bridge construction can result in increased levels of turbidity (Ogbeibu and Victor 1989). This could have caused the high turbidity and TSS levels at the golf club sites in the wet season since bridge maintenance was taking place there (Figure 5.1). The turbidity levels for most of the sampling period at all sampling sites were below the maximum tolerable limit of 35 NTU for the Jukskei catchment (Van Veelen 2002) except the wet season levels (36-50 NTU) at the PRE2 site which were above the tolerable limit. The mean and wet season TSS concentrations at the PRE2 site were above the Klip River catchment acceptable range of 20 to 30 mg/l (IWQGKRC 2003). High turbidity levels reduce light penetration leading to a decrease in the rate of photosynthesis and therefore primary production in a river (Dallas and Day 2004).

Figure 5.1: Maintenance work at PRE3 site

Cattle grazing and domestic sewage are among the major human sources of SPOM (Hellawell 1986). Organic matter from these sources requires oxygen for decomposition and often depletes oxygen upon entering surface waters thereby decreasing DO concentrations in that system. Other effects of high SPOM levels are an increase in turbidity levels, TSS and nitrate concentrations, and possible bacterial contamination (Dallas and Day 2004). High SPOM levels at the PRE2 site could have resulted in the high TSS and turbidity levels recorded at the site.

The temperature recorded at all the sampling sites during the sampling period was within the range for aquatic ecosystems in the Jukskei catchment of 11.9 to 29.9 °C (Van Veelen 2002).

5.1.2 Chemical quality

Changes in pH influence the availability and toxicity of important plant nutrients such as phosphate and ammonium. For example, pH values > 8.0 cause ammonium ions to be converted to toxic unionized ammonia (DWAF 1996a; Horne and Goldman 1995). Most southern African surface waters are neutral or alkaline (pH 7.0 to 8.0) (Skelton 2001). The pH for all the sampling sites in the study were alkaline (7.4-9.0) for the whole sampling period and most were within the Jukskei catchment aquatic ecosystems "ideal range" of 6.5 to 8.5 (CoJ 2009). Campbell (1996) also measured pH of 7.0 – 8.0 in the Jukskei River. The significantly high dry season mean pH at PRE1 and PRE2 could have been a result of low flow although flow rate was not measured in this study. Skoroszeweski (1999) observed that pH was significantly higher in the dry season when there was low flow than during the wet season on the main rivers of the Lesotho Highlands Water Project. During the wet season, decaying matter from the ground is washed down by rain into rivers. Decomposing matter produces carbonic acid which can lower the pH in a river (Hem 1985). This could have been the reason for the significantly lower pH in the wet season at the PRE1 and PRE2 sites. The seasonality in pH at these two sites could also have been due to rain. Rainfall that is not affected by pollution has pH varying from 4.3 to 6.0 (Mphepya *et al*. 2004) and it lowers pH upon entering rivers (Hem 1985).

The mean EC levels in water upstream of Alexandra (Figure 4.4) was within the "tolerable" category of the DWAF domestic use water quality guidelines of 150 to 370 mS/m (DWAF 1996b) while the mean EC levels downstream of the township were in the "bad" category (>370 mS/m) of the domestic guidelines. High EC levels in a water body indicate high ion concentrations. According to DWAF (1996b), EC >370 mS/m gives water an extreme salty taste. Consumption of water containing high EC can have adverse effects on patients with heart problems as well as high blood pressure (DWAF 1998). High EC can also impact on the biochemical reaction system, blood circulation and the nerve conduction system of the human body (Virkutye and Sillanpaa 2006).

It was expected that DO concentrations would be lowest at PRE1 and highest at the POST site. This is because samples were first collected at the PRE1 site in the morning and last at the POST site in the afternoon. Dissolved oxygen concentrations in rivers vary throughout the day due to photosynthesis and respiration processes of aquatic biota. There is minimum DO concentrations at night and near dawn, maximum concentrations normally occur by mid afternoon (DWAF 1996a). Decaying debris at the PRE1 site (Figure 5.2) could have also caused the low DO concentrations measured at the site. The presence of oxidizable organic matter can lead to reduction in the concentration of DO in surface waters due to oxygen depletion by aerobic decomposition of organic waste by microorganisms (Dallas and Day 2004).

The DO concentrations at all the sites were below DWAF's aquatic ecosystems target water quality range of 80 to 120 %. Concentrations of DO less than 100 % of saturation indicate that DO has been depleted from the theoretical equilibrium concentration (DWAF 1996a) and can be indicative of contamination of water by solid waste (Mvungi *et al.* 2003) although this can occur naturally. Continuous exposures of less than 80 % saturation of DO can be harmful leading to conditions such as physiological and behavioural stress of aquatic organisms (DWAF 1996a). Insufficient oxygen may result in tissue damage, bleeding, and extreme loss of blood from, the gills, liver, kidneys and spleen of exposed fish (Drewett and Abel 1983).

Figure 5.2: Debris and algae at the PRE1 site

Water entering Alexandra Township had nitrate-N and ammonium-N concentrations of <0.20 mg N/l throughout the sampling period, even in September when foliar fertilisers were applied to the turf at the RJK golf club. Foliar fertilizers are more efficiently taken up by plants than those applied to soils (Ling and Silberbush 2002) and thus theoretically small concentrations are washed down to water bodies. Natural levels of ammonium in surface water are usually less than 0.20 mg/l (WHO 1993), which makes the water at PRE2 and PRE3 ideal for aquatic ecosystems.

Water exiting Alexandra contained nitrate-N and ammonium-N concentrations of >1.50 mg nitrate-N/l and >3.00 mg ammonium-N/l. These high concentrations could have resulted from raw sewage and animal waste which were washed down or dumped into the Jukskei from the township as sewage contains high concentrations of ammonium (DWAF 1996a). Animal waste probably from Johannesburg Zoo and at Zoo Lake could have caused the high ammonium-N concentrations in the water at the PRE1 site. It is most important to note that ammonium concentrations at the PRE1 site peaked in August while one of the lowest concentrations at the POST site were recorded in that month (Figure 4.19). The peak at the PRE1 site might have resulted from an overflow from a burst sewer pipe near the site.

The high nitrate-N and ammonium-N concentrations downstream of Alexandra could also have been attributable to the application of commercial fertilizers to the crops cultivated in the township. Ammonium in rivers is converted to nitrate under aerobic conditions (Brisbin and Runka 1995). The fertilisers contain highly soluble ammonium salts (DWAF 1996a). These fertilizers could have been washed or leached into Jukskei River thereby contributing to the high ammonium and nitrate concentrations in the water exiting Alexandra.

The high ammonium-N concentrations recorded at the PRE1 and POST sites (0.28-15.00 mgN/l and 1.20-7.40 mgN/l respectively) were too high for many fresh water organisms as concentrations ranging from 0.53 to 22.8 mg/l are toxic (McAlister and Ormsbee 2005). Nitrate concentrations at all the sites were below the maximum limit for the acceptable concentrations for the Jukskei catchment of <6 mgN/l (CoJ 2009).

Water exiting Alexandra contained higher orthophosphate concentrations than water entering it. High concentrations of phosphate are likely to occur in waters that receive raw or treated sewage (Dallas and Day 2004). This might have been the case at the PRE1 and POST sites as orthophosphate concentrations at these sites were higher than the ones at the golf course sites (Figure 4.21). The wet season concentrations of orthophosphate at the POST and PRE1 sites (0.06 to 0.28 mgP/l) indicate P enrichment as this condition occurs when phosphate concentrations in a river exceed 0.025 mg/l in the summer season (DWAF 1996a). Concentrations for PRE2 and PRE3 were within the “ideal” category (<0.2 mg/l) for aquatic ecosystems of the Jukskei catchment while those for the PRE1 and POST sites fell in the "bad" category of >4.00 mgP/l (CoJ 2009) for most of the sampling period (see Figure 4.21).

High nutrient concentrations at the PRE1 site were probably due to Zoo effluent and decomposing matter at the site (Figure 5.2) which results in the depletion of oxygen in water and may explain the low DO concentrations at the site. Phosphorous and nitrogen concentrations higher than threshold values can cause proliferation of primary producers and eutrophication thereby decreasing DO concentrations and increasing pH in a water body (Dodds and Welch 2000). This may inhibit the growth and survival of macroinvertebrates and fish (Dallas and Day 2004). About six fish species have been identified in the Jukskei River, yet under natural conditions seventeen indigenous species are expected to occur in the river (Van Veelen 2002). The high nutrient concentrations in the water exiting Alexandra could be contributing to the death or migration of macroinvertebrates to healthier sections of the river. In general, the water exiting Alexandra has poor quality with regards to nutrients such as nitrate-N and orthophosphate whose concentrations were too high for average surface water.

5.1.3 Microbial quality

E. coli concentrations varied substantially between sites and over the seasons from 1 to 100 000 cfu/ml. *E. coli* concentrations at all the sites were above WHO (2008) drinking water guidelines (0 cfu/ml) and DWAF (1996c) ideal recreation guidelines (<1.3 cfu/ml). The *E. coli* concentrations found downstream of Alexandra (at the POST site) could have resulted from raw sewage entering Jukskei from the township and possibly animal waste was entering the river as there are a number of backyard poultry projects in the township.

High nutrient and *E. coli* concentrations are associated with improper human and animal excreta and other domestic waste disposal which results in waste entering rivers (Mvungi *et al.* 2003; Dallas and Day 2004). Despite the provision of 1 200 chemical toilets, 600 septic tanks and 72 000 individual property connections to the sewage system in

Alexandra (Makungo 2006), nutrient and *E. coli* concentrations downstream of the township still remain high (31-100 000 cfu/ml). In an interview study conducted by Makungo (2006), residents do not use facilities like chemical toilets during the night as it risky for them due to the high crime rate in the area. Therefore they resort to using bucket latrines which they empty in the Jukskei River or in the drainage system. Apart from this, the chemical toilets supplied to the informal settlements are costly to service and some of these end up overflowing (Makungo 2006).

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Temperature, pH, nitrate-N and orthophosphate were significantly higher in river water exiting Alexandra than in the water entering the township. *E. coli* concentrations at all the sites were not statistically different. The significantly high parameters measured in the water downstream of Alexandra could be a result of improper waste disposal in the township particularly in the informal settlements. This is a clear indication that the activities carried out in the informal settlements have detrimental significant impacts on the river's water quality. It was surprising though that turbidity levels, TSS and SPOM concentrations in the water entering Alexandra were at least twice higher than those measured downstream of the township considering the poor waste disposal methods in Alexandra. The high turbidity and TSS in water upstream of Alexandra could be attributable to natural factors e.g. the streams up in the catchment could be abundant in benthic feeders which cause resuspension of sediments due to frequent stir up. Natural causes for the high SPOM concentrations upstream of Alexandra could be due to decomposed matter from the large amounts of low surface area litter that are washed down into the streams.

Seasonal effects were observed in some parameters at some sampling sites; turbidity levels and TSS concentrations were significantly higher in the wet season than in the dry season at some sites. Orthophosphate and SPOM concentrations and pH were significantly higher in the dry season at some sites while EC levels were significantly higher in the dry season at all sites. The changing seasons had no influence on temperature, nitrate and DO concentrations at all sites.

Most measured parameters downstream of Alexandra were in the acceptable ranges for aquatic ecosystems except for EC levels and ammonium-N concentrations which fell in the bad categories of the national and international domestic and aquatic guidelines. Dissolved oxygen concentrations at all sites, however, were too low for aquatic life of between 80 and 120 % (DWAF 1996a). The mean *E. coli* concentrations at all the sites were above DWAF'S (1996c) target water quality range of 0 – 1.3 cfu/ml; they were also higher than the standard guidelines for drinking water of 0 cfu/ml (WHO 2008).

6.2 Recommendations

Pollution levels in the Jukskei River downstream of Alexandra were not as high as expected, and are less detrimental to the water quality of the Jukskei River according to the guidelines except for *E. coli*, nitrogen (as ammonium and nitrate) and orthophosphate. It is not known, however, to what extent activities like continual improper waste disposal in the township will impact on the water quality of the Jukskei River since population in the township is five times more than its infrastructure can support. It is also worrying that the chemical toilets provided in the township are not used as most people reside far from them.

Implementation of sewage sanitation services in the informal areas of Alexandra is difficult. This is because the shacks are built so close together such that there is hardly space to place or build other structures. Main sewer lines are far (at least 1.5 km) from the informal settlements such that it would be costly to lay sewer pipes and connect them to the informal houses. One of the informal settlements is right on one of the banks of Jukskei River, thus even if it were possible to provide sanitation services there; it would attract more people there and pollution problems would continue in the Jukskei River. Additionally, it is risky for people to live there as this area is prone to flooding during the rainy season. Any other options for remedying the pollution problem like decentralising waste treatment to Alexandra might be impossible to implement, e.g. a duckweed biological treatment system might require at least 100 ha of land (one-eighth of land in Alexandra) to efficiently treat sewage from the township. Therefore, the most economical option that the informal settlement dwellers might have is to be relocated to other areas where there are sanitation services and people can built their dwellings around the sanitation facilities while they await decent accommodation from the government.

The PRE1 site (Zoo Lake) had high nutrient and *E. coli* concentrations. This shows that not only townships in Johannesburg experience water quality problems; these are also systematic in relatively wealthy parts of the city.

7. APPENDIX

Figure A1: One of the stagnant pools with litter in the informal settlements

Figure A2: Agricultural activities on the bank of the Jukskei

Figure A3: Sampling bottle


Figure A4: Whirl pack with a sample for *E. coli* analysis

Figure A5: Meters used for measuring pH, EC and DO.

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