AN ASSESSMENT OF THE WATER QUALITY OF THE BAYNESPRUIT RIVER AND ITS LINKAGES TO THE HEALTH OF THE SOBANTU COMMUNITY

J Govender

Submitted in fulfilment of the requirements for the degree of MSc in Hydrology

Centre for Water Resources Research

School of Agricultural, Earth and Environmental Sciences

University of KwaZulu-Natal

Pietermaritzburg

December 2016

ABSTRACT

Worldwide, water quality degradation is rife. Rivers are amongst the most susceptible water bodies to this reality. In South Africa, the use of polluted river water for activities such as crop irrigation, washing clothes and recreation, is a common practice in many rural and urban communities. The Baynespruit River, in the province of KwaZulu-Natal, South Africa, is a typical example as it serves as a vital water source to the Sobantu community. There have been numerous reports of extremely poor water quality in this river and suggestions that this may pose health risks to the community. Thus, the aim of this study was to assess the water quality of the Baynespruit River and its linkages to the health of the Sobantu community. This was achieved through analyses of river water quality, river sediment, soil and crop samples, as well as an investigation of the pathways through which community members are exposed to the polluted river and finally, an analysis of urine from a sample of volunteers who are regularly exposed to the river water.

The water quality assessment considered pH, electrical conductivity, As, Cd, Cu, Hg, Pb, Zn and *E.coli*, while the analysis of river sediment comprised of 23 elements including the aforementioned heavy metals. Using microwave acid digestion (EPA 3052) and Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES), soil and crop samples from farming sites in Sobantu were analysed for Cd, Cr, Cu, Pb and Zn, and compared against the South African Water Quality Guidelines for Crop Irrigation. These results showed that *E.coli* contamination was high, there were extremely low concentrations of the heavy metals apart from infrequent elevated detections of Cu and Pb, as well as infrequent occurrences of acidic water. While the heavy metal concentrations of surface water were low, the sediment analysis suggested elevated concentrations of As, Cd, Cr, Cu, Ni, Pb, Zn, Fe, Mn and Ag. Analyses of soils and irrigated crops showed concentrations of heavy metals in excess of national and international guidelines, respectively. It is suggested that these soil and crop results indicate historical flooding events, which mobilized heavy metals in the river sediments and transferred them onto the floodplain where the farming sites are located. Furthermore, long-term irrigation with low concentrations of heavy metals may have also resulted in the build-up of these contaminants in the soil and eventually the crops.

A workshop was held in the Sobantu community which included a questionnaire and separate open-ended conversations conducted with various community members, in order to determine the exposure pathways to the river and the associated health issues of participants. The questionnaire and open-ended conversations indicated that the most common exposure pathways to the river included using river water for crop irrigation, consuming irrigated crops, washing clothes and children swimming in the river. The questionnaire and open-ended conversations also highlighted many cases of skin rashes, as a result of being in direct contact with river water, with one reported case of diarrhoea. The confirmation of the presence of heavy metals in the Baynespruit River and its surrounding environment gave rise to a urine analysis, which used microwave digestion and ICP-OES to determine whether community members who volunteered for the study incurred heavy metal toxicities. However, the analysis did not show any severe cases of heavy metal toxicities to exposed volunteers and the high levels of Pb noted could not be attributed to exposure to the Baynespruit River and/or its surrounding environments, since similar levels of Pb were found in the control volunteers. It was therefore unclear as to whether the health of the exposed people of Sobantu was compromised by heavy metal toxicities. The persistent mention of skin rashes in the questionnaire and open-ended conversations suggests that water-related health issues in the community require further investigation. It was concluded overall that the water quality of the Baynespruit River is severely degraded however, a clear link between this poor water quality and the perceived health issues in the Sobantu community, could not be established. A key recommendation from this study would be for further investigation, i.e. through a detailed health monitoring programme, confirming the health issues that community members have associated with polluted river water.

DECLARATION 1: PLAGIARISM

I, Jédine Govender, declare that:

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DECLARATION 2: PUBLICATIONS

DETAILS OF CONTRIBUTIONS TO PUBLICATIONS that form part of and/or include research presented in this dissertation (including publications submitted and published, giving details of the contributions of each author to the research and writing of each publication):

Publication 1 – Chapter 3

Govender, J, Stuart-Hill, SI and Jewitt, GPW. 2016. The effects of the water quality of the Baynespruit River on edible crops in the Sobantu community. *In preparation for submission to WaterSA.*

The analysis for this publication was conducted by J Govender. The publication was written entirely by J Govender and all figures, tables and graphs were produced by the same unless otherwise referenced in the text of the paper. The water and sediment samples were collected by J Govender, whereas the analyses were carried out by the Umgeni Water Laboratory. The editing and advice regarding interpretation were provided by Dr. SI Stuart-Hill and Prof. GPW Jewitt.

Publication 2 – Chapter 4

Govender, J, Stuart-Hill, SI and Jewitt, GPW. 2016. Establishing a link between the water quality of the Baynespruit River and the health of the Sobantu community. *In preparation for submission to WaterSA.*

The analysis for this publication was conducted by J Govender. The publication was written entirely by J Govender and all figures, tables and graphs were produced by the same unless otherwise referenced in the text of the paper. The editing and advice regarding interpretation were provided by Dr. SI Stuart-Hill and Prof. GPW Jewitt.

PREFACE

The work described in this dissertation was carried out in the Centre for Water Resources Research, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg under the supervision of Dr. Sabine I Stuart-Hill and Professor Graham PW Jewitt. The research represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

ACKNOWLEDGEMENTS

The research presented in this dissertation formed a component of a Water Research Commission (WRC) Project (K5/2354) titled “Demonstration of how healthy ecological infrastructure can be utilised to secure water for the benefit of society and the green economy through a programmatic research approach based on selected landscapes”. I wish to thank the WRC and the National Research Foundation (NRF) for funding this project. I would also like to acknowledge the following persons and extend my gratitude for their assistance with this dissertation:

Dr. SI Stuart-Hill (CWRR, UKZN), my supervisor, for her time, tremendous effort, sound advice and continuous encouragement provided throughout this dissertation;

Prof. GPW Jewitt (CWRR, UKZN), for his invaluable guidance, advice and support;

Mr. Steve Terry (Umgeni Water), for his expert advice pertaining to water quality monitoring, sediment analyses and the Baynespruit catchment, as well as the time and effort provided throughout the duration of this project;

Ms. Esmeralda Ramburran (Msunduzi Municipality), for her collaboration, continuous support, and provision of information regarding the Baynespruit catchment;

Dr. A Odindo (SAEES, UKZN), for his expert advice in crop science, as well as invaluable time and effort provided for this dissertation.

Prof. P Muchaonyerwa (SAEES, UKZN), for his expert advice in soil science and guidance throughout this dissertation;

Mr. M Rasalanavho (SCP, UKZN), for his expert advice in chemistry and continuous encouragement;

Mr. Mannie Sewcharran (Umgeni Water), for the provision of water quality and sediment data, as well as water sampling related materials;

Mr. Dennis Mncwabe (DUCT), for his contribution towards the foundation of information regarding the Sobantu community and Baynespruit River, as well as the provision of crops used in the analysis of this dissertation;

Mrs. Thiloshini Naidoo (SCP, UKZN), for her patience and support, as well as assistance with the ICP-OES analysis;

Mr. Zain Warasally (NHLS), for his expert advice regarding urine testing;

Mr. Vivek Naiken (CWRR, UKZN), for his time and effort expended towards the procurement of laboratory materials;

Mr. Byron Gray (CWRR, UKZN), for his assistance with weekly water sampling, as well as continuous support and invaluable friendship;

Ms. Ntombiyenkosi Nxumalo (CWRR, UKZN), for her assistance with the experimental pot trial, preparation of laboratory equipment, urine collection as well as the invaluable support and friendship;

Ms. Silindile Mtshali and Mr. Sanele Ngubane (CWRR, UKZN), for their much-appreciated assistance in the workshop as translators;

Ms. Lavinia Kisten (SAEES, UKZN), for her endless support and words of motivation throughout this dissertation, as well as invaluable friendship;

Colleagues of the CWRR, for their much-appreciated support;

Lastly, to my family for their patience, love and encouragement extended throughout this dissertation.

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1. INTRODUCTION

1.1 Rationale for Research

Water, although essential to all life-sustaining processes, is described as one of the most poorly managed resources in the world (Agbaire and Obi, 2009; du Plessis *et al*., 2014). Globally, water quality degradation is occurring at an alarming rate (Malik *et al*., 2014). This phenomenon contributes to the existing challenges of water scarcity and poor water distribution (Alves *et al*., 2014). The need for water quality research is therefore critical to contribute towards monitoring and safeguarding the available freshwater resources (Liu *et al.*, 2016).

The contamination of water resources is caused by natural and anthropogenic influences, which introduce a range of physical, chemical and microbiological contaminants into water bodies (Khatri and Tyagi, 2015). Rivers are one of the most susceptible sources to water quality degradation and it is essential to conduct water quality assessments in order to outline existing conditions, identify trends and/or determine the source of constituents that reduce water quality in them (Akpan-Idiok *et al*., 2012; Mustapha, 2012).

Approximately 1.2 million people living in developing countries are faced with the challenge of water scarcity (Balkhair, 2016). This has led to a strong reliance on polluted rivers for their daily needs (Obi *et al*., 2002). The use of polluted river water for consumable crop irrigation is a common practice in developing countries, such as South Africa (Obi *et al*., 2002). There is however, great concern associated with this practice, due to the possibility of contaminants being transferred into the food chain (Alia *et al.,* 2015). It is estimated that approximately 10% of the world's population consume crops that have been irrigated with polluted river water (Srinivasan and Reddy, 2009; Drechsel *et al*., 2010). It is therefore important to consider the effects of polluted water used for irrigation on crop quality, as this may be linked to food security and ultimately human health.

The Baynespruit River, in the province of KwaZulu-Natal, South Africa, serves as a vital water source for the daily needs of its surrounding urban communities. The water quality of the river has been compromised by illegal industrial effluent discharges, degraded sewage infrastructure, illegal dumping and littering by people who reside along the river banks (Neysmith and Dent, 2010; Ramburran, 2014). According to Ramburran (2014), the Baynespruit River is one of the most polluted rivers in South Africa.

Sobantu is both a formal and informal residential community and is situated toward the lower reaches of the Baynespruit River. The Sobantu community previously utilised the river for irrigation, fishing and swimming purposes (Neysmith and Dent, 2010). However, the current condition of the water may be unfit for such purposes and could pose health risks to the community (Gemmell and Schmidt, 2011). Nevertheless, some of the community members are still using river water for crop irrigation and possibly other activities, due to the lack of alternatives. Thus, water quality monitoring and rehabilitation of the Baynespruit River is essential, not only for legal compliance but especially for the food security and health of the Sobantu community (Gemmell and Schmidt, 2011; Luyt *et al*., 2012).

1.2 Research Aim and Objectives

The aim of this study is to assess the water quality of the Baynespruit River and its linkages to the crops grown with river water, as well as the health of the Sobantu community. The objectives of the present study are as follows:

- To determine whether there are pollutants in the Baynespruit River that exceed national crop irrigation water quality guidelines and ultimately affect human health, as well as to determine whether the level of these pollutants vary throughout the year.

- To determine whether the pollutants alluded to above are internalized by different edible crops in the Sobantu community, when irrigated with water from the Baynespruit River.

- To determine in what ways the Sobantu community are currently linked or exposed to the polluted water of the Baynespruit River and in essence, gain insight into the possible health issues experienced by people as a result of such exposure.

1.3 Outline of Dissertation

The structure of this dissertation is written in the research paper format which follows guidelines from the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal. In this format each chapter is self-contained. Accordingly, Chapter 1 is an introduction to the dissertation followed by a literature review in Chapter 2, which will provide context for assessing links between water quality, anthropogenic processes and human health. Chapter 3 contains the first research paper which entails a water quality assessment, sediment analysis, soil and crop analysis, as well as an experimental pot trial, all relating to the effects of using polluted river water for crop irrigation. Chapter 4 consists of the second research paper which describes a workshop and separate open-ended conversations, as well as a urine analysis, in order to ascertain the exposure of people to polluted water and their associated health implications. Finally, Chapter 5 provides a synthesis of the dissertation. It must be noted that some repetition of material is inevitable in the subsequent sections, due to the format selected for this dissertation.

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2. LITERATURE REVIEW

2.1 Introduction

Water quality degradation is experienced worldwide (du Plessis *et al*., 2014). The challenges of water scarcity and poor water distribution have made water quality a prominent topic, as it is critical that the quality of available freshwater resources is protected and deemed acceptable for its various uses (Alves *et al*., 2014).

The contamination of water resources results from natural and anthropogenic influences (Khatri and Tyagi, 2015). Rivers are one of the most susceptible water bodies to contamination, due to them receiving municipal and industrial wastewater, as well as catchment runoff (Mustapha, 2012). In order to understand the source and characteristics of the constituents that reduce water quality in rivers, it is necessary to highlight the natural and anthropogenic influences.

The use of polluted water from rivers for crop irrigation is considered a centuries old practice (Qishlaqi *et al*., 2007). In more recent times however, there is great concern around irrigating consumable crops with polluted river water, due to the contaminants, especially from industrial activities, which are linked to chemical pollutants, that may be present (Alia *et al.*, 2015). It is therefore important to consider the effects of polluted river water used for irrigation on crop quality, as this may be linked to food security and human health.

Wastewater introduced into rivers is commonly described as a rich source of heavy metals and pathogens (Khan *et al*., 2013a). It is estimated that approximately 10% of the world's population consume crops that have been irrigated with polluted river water (Srinivasan and Reddy, 2009; Drechsel *et al*., 2010). This practice has received extensive attention due to the potential repercussions on human health (Mahmood and Malik, 2014). It is therefore crucial to determine the different exposure pathways to using polluted river water for crop irrigation and the associated health impacts.

A comprehensive literature review has therefore been compiled, which entails: (1) the effects of natural and anthropogenic influences on water quality, (2) the use of polluted water for crop irrigation and (3) the effects of polluted water for crop irrigation on human health. The literature review will attempt to provide a context for assessing links between water quality, anthropogenic processes and human health in the Baynespruit Catchment.

2.2 Natural and Anthropogenic Influences on Water Quality

Water covers 71% of the earth's surface area, however, only 0.3% is available as freshwater for human use (Khatri and Tyagi, 2015). The available freshwater may be further curtailed by water quality problems (Liu *et al*., 2016). The quality of surface water and groundwater may be influenced by natural (e.g. hydrological, seasonality, geological, soil and biological) or anthropogenic (e.g. population growth, climate change, economic development and land use change) processes, or both in combination (Khatri and Tyagi, 2015). The following sections will provide an overview of natural and anthropogenic processes that are relevant to this study and which influence water quality degradation on a catchment scale.

2.2.1 Natural influences

Rainfall is the most dominant hydrological process responsible for influencing water quality (Oberholster, 2010). A study by Carr and Neary (2008), reported that low water levels may result in greater nutrient and ionic concentrations, which may deteriorate water quality. According to Vaishali and Punita (2013), in some instances, high flows may dilute pollutants, resulting in improved water quality. Water quantity is therefore linked to the constituent dilution capacity in water bodies, which in turn affects water quality. It is therefore important to consider rainfall data when assessing water quality.

There are numerous constituents of water quality that vary due to seasonal differences in weather conditions (Khatri and Tyagi, 2015). Verma *et al*. (2011) reported that sulphide in the Sengar River in India increased during the summer as a result of a decrease in river water volume caused by reduced flows and evaporation. Kilonzo *et al*. (2013) observed a lower electrical conductivity in the Mara River in Kenya during the wet season as a result of dilution. Thus, it is crucial to monitor water quality throughout both the wet and dry seasons, since there may be significant variations.

Soils are composed of suspended sediments and soluble materials, which are a potential source of water quality contamination (Al-Kaisi *et al*., 2009 and Apodaca *et al*., 1996). Soil erosion results in an increase in sediment load and nutrients, i.e. nitrogen and phosphorus, into water bodies, which may increase turbidity and give rise to eutrophication, respectively (Khatri and Tyagi, 2015). The leaching of organic matter and nutrients from the soil into either surface water or groundwater, or both, is a natural occurrence (Simeonov *et al*., 2003). There may also be trace amounts of heavy metals that occur naturally in soils, which are derived from the parent rock material (Plant *et al*., 2012). The processes of soil erosion and leaching may transport these heavy metals into water sources.

2.2.2 Anthropogenic influences

Worldwide, the perpetual demand for energy, food, water and living space stems from the increase in population growth and the improved standards of living (Wagener *et al*., 2010). These demands have the potential to contribute to water quality degradation; especially in many developing countries, where there is a lack of appropriate sanitation and waste disposal facilities, which leads to littering alongside riverbanks or directly into rivers (Gemmell and Schmidt, 2011; Govender *et al*., 2011). Carr and Neary (2008) have reported that as the population of developing countries expand, so too does the concentration of faecal coliform bacteria, which may be related to an increase of pathogens in surface water, having the potential to greatly impact human health. It is imperative to note that population growth fuels the anthropogenic processes of climate change, land use change, economic development and vice versa and by that is a key driver of water quality (Carr and Neary, 2008).

Economic development encompasses urbanisation, industrialisation, agricultural expansion and an improved standard of living (Astaraie-Imani *et al*., 2012; Khatri and Tyagi, 2015). The activities associated with economic development include increased domestic water use, livestock watering, irrigation, aquaculture, commercial fisheries, forestry and logging, food processing, textile industry, pulp and paper industry, mining, water storage and transportation, hydro-electrical power generation, nuclear power generation and recreation (Meybeck *et al*., 1996). These activities contribute to the deterioration of water quality through pathogens, suspended solids, decomposable organic matter, eutrophication, nitrate as a pollutant, salinisation, heavy metals, organic micro-pollutants, acidification and changes in hydrological regimes (Meybeck *et al*., 1996). Economic development with all its diverse elements as alluded to above becomes a key factor in the deterioration of water quality when not managed and monitored appropriately.

2.2.3 Conclusion

This section has covered the impacts of natural and anthropogenic influences on water quality. As mentioned, the increase in population has resulted in greater food demands and more land is transitioning into agricultural land, to meet such demands. The variety of anthropogenic influences has resulted in greater volumes of polluted water being produced and, due to water scarcity, has become a common use for crop irrigation, especially in developing countries. It is therefore important to understand the development and activities within a catchment, as to identify the sources contributing to water quality, which then can be assessed in relation to human health.

Globally, there is great concern around using polluted water for crop irrigation, which is possibly linked to the challenges of food security of an ever increasing population. Thus, the following section focuses specifically on the use of poor water quality for crop irrigation and the effects of this practice on edible crops (*cf.* section 2.3), as well as further on, the potential impacts on human health (*cf.* section 2.4).

2.3 The Use of Poor Water Quality for Crop Irrigation

Worldwide, freshwater resources are relatively scarce, especially for the water-intensive use of crop irrigation (Chen *et al*., 2013). The use of poor water quality, i.e. polluted water, for crop irrigation is a centuries old practice (Ensink *et al*., 2002; Hussain *et al*., 2002; Qishlaqi *et al*., 2007). Inadequate wastewater treatment plants and a lack of potable water supplies have often left farmers with untreated or, only partially treated water, as their only option for crop irrigation in the current days (Qadir *et al*., 2008).

The following section will review three avenues which explore the use of poor water quality for crop irrigation. Firstly, there are numerous water quality guidelines that stipulate the acceptable concentrations of constituents for crop irrigation (Schutte, 2001). It is therefore important to consider these guidelines, especially when investigating the effects of constituents on edible crops. Secondly, the use of polluted water for crop irrigation is a common occurrence and it is therefore vital to specify the advantages and disadvantages of this practice. It is widely reported that polluted water bodies, such as rivers, are a popular source of heavy metals (Khan *et al*., 2013a). Thus thirdly, reviewing the bioaccumulation of heavy metals in edible crops is crucial when considering the food security and health of people.

2.3.1 Water quality guidelines for crop irrigation

Water quality guidelines for crop irrigation provide scientific and technical information for a specific water quality constituent, which may be in the form of quantitative data as well as descriptions of the constituent's effect on the fitness of water for crop irrigation (Schutte, 2001). In this way, water quality guidelines may be used to determine whether or not polluted water is deemed acceptable for crop irrigation. Worldwide, there are numerous water quality guidelines associated with crop irrigation, e.g. FAO (1985) and DWAF (1996). These guidelines are useful, however, none have been completely satisfactory, due to the vast array of conditions that prevail in the field (FAO, 1985; Pescod, 1992). The acceptability of polluted water for crop irrigation will therefore greatly depend on climatic conditions, the physical and chemical characteristics of the soil, the type and tolerance of the crop grown and the management practices (Pescod, 1992). Nevertheless, there are recommended limits for constituents in water for crop irrigation that have been expressed through such guidelines.

In this context Table 2.1 provides a summary of recommended limits of the common constituents for crop irrigation. It is evident from this table that essential crop nutrients i.e. nitrogen, boron, copper, molybdenum and zinc, and non-essential i.e. arsenic, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, nickel, selenium, uranium and vanadium, may present beneficial impacts or are even crucial for growth (FAO, 1985). However, in some cases, depending on the concentrations, these nutrients may be harmful or detrimental to crops (FAO, 1985). In some cases, the recommended constituent limit may be exceeded, resulting in toxicities i.e. sodium, aluminium, boron, chlorine, chromium, cobalt, copper, iron, lithium, manganese, vanadium and zinc toxicity, which may cause foliar damage, reduced crop yields, delayed crop maturity, crop failure, disruptions in crop metabolic processes, as well as disruptions in crop photosynthesis, transpiration and respiration processes (FAO, 1985). The recommended limit for constituents may vary due to soil pH and/or crop type

(Table 2.1). For example, the recommended limit for aluminium in most crops is 5 mg/L; however, some crops may present aluminium toxicities at concentrations as low as 0.1- 0.5 mg/L (FAO, 1985). The concentrations of constituents stipulated in the FAO (1985) guidelines, i.e. total dissolved solids (TDS), nitrogen, aluminium, arsenic, beryllium, boron cadmium, chromium, cobalt, copper, fluoride, iron, lead, lithium, manganese, molybdenum, nickel, selenium, vanadium and zinc, were based on irrigation that was applied infrequently or as needed (Table 2.1). The concentrations of constituents expressed in the DWAF (1996) guidelines, i.e. electrical conductivity (EC), pH, sodium, chlorine, uranium, faecal coliform bacteria (*E.coli*) and helminth eggs, were based on average concentrations over the growing season (Table 2.1).

Table 2.1 Summary of the recommended limits of constituents for crop irrigation

Constituent	Limit	Comment
Salinity		
EC **(mS/m)**	< 40[a]	The total dissolved solids (TDS) represent the quantity of various inorganic salts dissolved in water. TDS is directly proportional to the electrical conductivity (EC) of water. EC is easier to measure than TDS and is therefore used as an estimate of TDS. Irrigation containing excessive salt can produce saline soils which, certain crops are sensitive to, resulting in reduced yields (DWAF, 1996)
TDS **(mg/l)**	< 450[b]	
Miscellaneous effects		
Nitrogen **(mg/l)**	< 5[b]	Essential for crop growth. However, high concentrations may result in excessive vegetation growth, delayed crop maturity and poor quality of crops (DWAF, 1996)
pH	6.5 – 8.4[a]	At high soil pH, the majority of micronutrients and heavy metals are unavailable for crop uptake and become more available at lower soil pH (DWAF, 1996)
Specific Ion Toxicity		
Sodium **(mg/l)**	70[a]	Sodium toxicity may occur in crops as a result of high amounts of sodium in irrigation water which may lead to foliar damage (DWAF, 1996)
Trace Elements (mg/l)		
Aluminium	5[b]	Many crops indicate aluminium toxicity at low concentrations with uptake of 0.1-0.5 mg/L (DWAF, 1996)
Arsenic	0.1[b]	Not an essential crop nutrient. However, at low concentrations crop growth is stimulated and at high concentrations crop yield is reduced (DWAF, 1996)
Beryllium	0.1[b]	Not a crop nutrient and even at low concentrations may be harmful to both crops and humans (DWAF, 1996)
Boron	0.75[b]	Essential to plants but becomes toxic at elevated concentrations (DWAF, 1996)
Cadmium	0.01[b]	Taken up by crops even though it is not an essential nutrient and therefore, disrupts crop metabolic processes (DWAF, 1996)
Chlorine	100[a]	Excessive chlorine in crops may result in toxicity and thus, foliar damage (DWAF, 1996)

[a] (DWAF, 1996)

[b] (FAO, 1985)

Constituent	Limit	Comment
Chromium	0.1[b]	No known crop physiological function and not an essential crop nutrient. However, at high concentrations chromium is toxic to crops and at low concentrations it is advantageous to crop growth (DWAF, 1996)
Cobalt	0.05[b]	May be essential for certain crops however, it is not considered a crop nutrient. Cobalt toxicity may be rare as it is strongly sorbed by soil (DWAF, 1996)
Copper	0.2[b]	Considered an essential crop nutrient. However, copper toxicity may occur, resulting in low crop yields or crop failure (DWAF, 1996)
Fluoride	1[b]	No effect on crop growth (DWAF, 1996)
Iron	5[b]	Iron toxicity may disrupt photosynthesis processes (DWAF, 1996)
Lead	5[b]	Low phytotoxicity and strongly sorbed by soils (DWAF, 1996)
Lithium	2.5[b]	Lithium toxicity can result in decreased crop yield (DWAF, 1996)
Manganese	0.2[b]	High levels of manganese in irrigation water may result in manganese toxicity, depending on the crop type (DWAF, 1996)
Molybdenum	0.01[b]	Essential crop nutrient in low concentrations and high concentrations taken up by crops have no harmful effects (DWAF, 1996)
Nickel	0.2[b]	Not an essential crop nutrient. Small amounts may increase crop growth whereas greater amounts decrease crop growth (DWAF, 1996)
Selenium	0.02[b]	Some crops take up large concentrations with no adverse effects (DWAF, 1996)
Uranium	0.01[a]	Crop yield will be affected depending on the crops sensitivity to uranium (DWAF, 1996)
Vanadium	0.1[b]	Toxic to many plants at low concentrations (FAO, 1985)
Zinc	2[b]	Essential crop nutrient in small concentrations. At high concentration, zinc toxicity occurs (DWAF, 1996)
Microbial Contaminants		
Faecal coliform bacteria (*E.coli*) **(MPN/100 mL)**	< 1000[a]	No effect on crop but may impact human health (DWAF, 1996)
Helminth eggs **(eggs/100 mL)**	< 1[a]	No effect on crop but may impact human health (DWAF, 1996)

2.3.2 The advantages and disadvantages [c]of polluted water for crop irrigation

There are distinct advantages of using polluted water for crop irrigation, mostly with regard to the availability and reliability of this type of resource, as well as the affordability and security of food production. Polluted water serves as an additional and cheap source of irrigation, especially in water-scarce countries (Kizilogu *et al*., 2008; Lötter, 2010; Singh, 2014). In times of water stress or drought, using poor water quality to irrigate crops may save high-quality water for other beneficial uses (Rutkowski *et al*., 2006; Kizilogu *et al*., 2008). Economically, using poor water quality for crop irrigation may even assist as a disposal

[a] (DWAF, 1996)

[b] (FAO, 1985)

activity that prevents pollution in surface water, as well as sanitary issues (Shuval, 1991; Toze, 2014; Gumbo *et al*., 2010; Chen *et al*., 2013). Polluted water, especially from rivers, is a reliable and plentiful source of irrigation which may allow for numerous cultivation cycles and the flexibility of the crops grown (Rutkowski *et al*., 2006; Qishlaqi *et al*., 2007; Qadir *et al*., 2008; Lötter, 2010; Chen *et al*., 2013). In terms of plant nutrients, polluted water usually contains nitrogen and phosphorus, which may be advantageous for plant growth, thereby reducing the need for fertilizers in crop production (Qishlaqi *et al*., 2007; Kizilogu *et al*., 2008; Qadir *et al*., 2008; Chen *et al*., 2013). The use of polluted water may therefore, allow high crop yields, annual crop production and even enable an increase in the range of crops that can be irrigated (Hussain *et al*., 2002; Jiménez, 2006).

Polluted water may, however, have severe implications for agricultural productivity, regardless of the advantages previously mentioned. Polluted water may give rise to soil salinisation (excessive soluble salts) and sodification (excessive sodium ions), which hinder crop growth and decrease crop yield (Chen *et al*., 2013; Baasuony *et al*., 2014; Becerra-Castro *et al*., 2015). The presence of high concentrations of essential crop nutrients i.e. nitrogen, magnesium, chloride and boron, and heavy metals i.e. iron, chromium, zinc, lead, nickel, cadmium and copper, in polluted water result in phytotoxicity, which severely degrades crop quality (Chandra *et al*., 2008; Baasuony *et al*., 2014; Becerra-Castro *et al*., 2015). For example, polluted water containing excessive amounts of nitrogen can cause over-fertilization, which results in reduced crop quality, excessive vegetative growth and delayed crop maturity (Ensink *et al*., 2002). The pH of polluted water, especially from industrial sources, may either be severely acidic or alkaline, which adversely affects crop growth (Hussain *et al*., 2002). According to Chandra *et al*. (2008), Chen *et al*. (2013), Jiménez (2006), Ensink *et al*. (2002), Gumbo *et al*. (2010) and Tsado (2014), concern for human health has been a critical disadvantage in the use of polluted water for crop irrigation, due to the presence of heavy metals and pathogens.

2.3.3 The heavy metal bioaccumulation potential of crops irrigated with polluted water

Water, especially from rivers that have been polluted by industrial effluents, as well as domestic and agricultural wastes may contain elevated amounts of heavy metals (Alia *et al.*, 2015). It has been observed, that crops grown on contaminated soils, as a result of polluted water used for irrigation, commonly contain large quantities of heavy metals (Mojiri, 2011; Khan *et al*., 2013b; Stasinos *et al*., 2014; Mustapha *et al*., 2014; Alia *et al.*, 2015; Qadir *et al*., 2015). Heavy metals raise environmental concern, as a result of their toxicity and cumulative behaviour in crops, which is commonly referred to as bioaccumulation (Jacob and Kakulu, 2012).

Different crops may accumulate different concentrations of heavy metals and some crops can accumulate heavy metals at levels that are toxic to other crops (Aliyu *et al*., 2014; Qadir *et al*., 2015). The structure of the crop may be favourable to high amounts of heavy metal uptake. For example, spinach and cabbage are considered high-biomass crops with broad, leafy structures and large surface areas, which are known to accumulate elevated concentrations of heavy metals (Liu *et al.*, 2011; Alia *et al*., 2015). According to Singh *et al*. (2012) root and leafy vegetables such as carrots, spinach and cabbage display a greater distribution of metals to the edible portions of the crops. Jacob and Kakulu (2012) have highlighted that leafy vegetables have a higher potential for heavy metal accumulation than grain and fruit crops, due to their higher transpiration rates. Maize has however been considered as an effective accumulator of heavy metals such as cadmium, lead and zinc (Wuana and Okieiman, 2010; Mojiri, 2011 and Aliyu *et al*., 2014). The uptake of heavy metals by crops is influenced by many factors in the soil such as pH, water content and organic matter, all of which enhance absorption and mobilization of heavy metals (Singh *et al*., 2016). The translocation of heavy metals to the edible parts of crops may be assisted by xylem and several classes of protein in the crop (Viehweger, 2014). Tangahu *et al*. 2011 have reported that micro-organisms, bacteria and fungi that live in the rhizosphere, have the ability to mobilize heavy metals, thereby increasing their bioavailability to crops. It must be assumed that water rich in *E.coli* may contain bacteria that serve this function of heavy metal mobilization (Tangahu *et al*., 2011).

It is clear from the above that the internalization of heavy metals in edible crops due to irrigation with polluted water is a common occurrence. Nevertheless, it needs to be noted that bioaccumulation studies are associated with highly variable data as field conditions and/or experimental designs influence the heavy metal uptake by crops (Alia *et al.*, 2015).

2.3.4 Conclusion

The use of polluted water for crop irrigation has been explored in this section. The urgency for investigating the effects of polluted water on consumable crops is apparent, especially in developing countries, such as South Africa where there is a backlog in service delivery and a potentially high use of polluted water. For example, due to the poor service delivery in South Africa, i.e. the lack of water distribution and management, many subsistence farmers may be forced to use polluted river water for crop irrigation.

This section has established that water quality guidelines may assist in determining whether the quality of polluted water is acceptable for crop irrigation. The practice of using polluted water for crop irrigation could be associated with high risks for the environment, as well as human health, since the water quality of most freshwater systems in developing countries is often poor. For example, heavy metal internalization occurs in consumable crops and thus raises concern for human health. The following section will therefore establish a link between poor water quality for crop irrigation and human health.

2.4 Poor Water Quality used for Crop Irrigation and Human Health

Polluted water bodies, such as rivers, are commonly described as rich sources of toxic heavy metals and pathogens (Srinivasan and Reddy, 2009; Khan *et al*., 2013a). Worldwide, approximately 20 million hectares of land has been reported to be irrigated with polluted water (Srinivasan and Reddy, 2009; Drechsel *et al*., 2010). Furthermore, it has been estimated that 10% of the world's population consume crops which are irrigated with polluted water (Srinivasan and Reddy, 2009). Consequently, the use of polluted water for food crop irrigation has received extensive attention, due to its potential to impact human health (Feenstra *et al*., 2000; Drechsel *et al*., 2010; Abakpa *et al*., 2013; Fuhriman *et al*., 2014; Mahmood and Malik, 2014). The following section will address the different pathways of human exposure to polluted water used for crop irrigation and the specific health issues associated with this practice.

2.4.1 Direct exposure of humans to polluted water used for crop irrigation

Farmers are at high risk of infection due to direct contact through the collection of polluted water and the application of this water onto crops (Drechsel *et al*., 2010). Studies in Pakistan, Vietnam, Cambodia, Nepal and India have shown that the infections contracted by humans, due to direct contact with pathogen infested water bodies include hookworm, helminth infections, diarrhoea, skin irritations, in addition to bacterial and viral infections (Drechsel *et al*., 2010; Drechsel and Keraita, 2014). Furthermore, research shows that skin exposure to polluted water containing heavy metals may result in corrosive effects on skin, irritations on skin, damage to the central nervous system, gastrointestinal disorders, as well as damage to vital organs such as the kidney and liver (Singh *et al*., 2011). A case study by Srinivasan and Reddy (2009) indicated that the Musi River in India is considered a source of polluted water used for crop irrigation. Health issues such as stomach aches, headaches, fevers and skin rashes were commonly experienced by farmers due to their direct contact with polluted water for crop irrigation (Srinivasan and Reddy, 2009).

2.4.2 Indirect exposure of humans to polluted water used for crop irrigation

Heavy metals and pathogens from polluted water used for crop irrigation are known to accumulate on the surface of crops as well as within them. Thus, the consumption of such crops by humans, especially those crops consumed raw, may be considered an indirect exposure to polluted water (Drechsel *et al*., 2010; Abakpa *et al*., 2013).

The consumption of crops irrigated with polluted water containing heavy metals has reportedly given rise to decreased immunological defences, upper gastrointestinal cancer, impaired psycho-social disabilities related to malnutrition, intra-uterine growth retardation, genomic instability, endocrine disruption, neurotoxicity and carcinogenicity (Srinivasan and Reddy, 2009; Jan *et al*., 2010). Mahmood and Malik (2014) conducted a study in Pakistan which considered numerous polluted water irrigation sources for crops. This study showed that, the daily in-take of contaminated spinach and field mustard by people, led to the accumulation of cadmium and manganese in the kidney and liver, causing nervous, cardiovascular, liver, kidney and bone disorders (Mahmood and Malik, 2014). Khan *et al*. (2013a) considered the highly polluted Nullah Aik and Palkhu streams in Pakistan. The study indicated that the daily in-take of crops containing elevated concentrations of lead, manganese, nickel and chromium due to irrigation from these streams has resulted in ill-health in humans (Khan *et al*., 2013a). Firstly, the consumption of crops with lead toxicity may result in increased blood pressure, renal infection and disruptions to haemoglobin production and the reproductive system (Khan *et al*., 2013a). Secondly, the consumption of crops with manganese toxicity may result in Parkinson's disease. Thirdly, the consumption of crops with nickel toxicity may result in headaches, skin rashes, cancer, dizziness, fatigue, heart complications and respiratory illnesses (Khan *et al*., 2013a). Lastly, the consumption of crops with chromium toxicity may result in breast cancer (Khan *et al*., 2013a). Drechsel *et al*. (2010) reported that the consumption of crops irrigated with polluted water containing pathogens resulted in significant *Ascaris lumbricoides* (parasitic worms), viral enteritis, hepatitis A, cholera and typhoid infections in humans.

The internalization of heavy metals and pathogens by crops are more detrimental to human health than surface contamination (Mahmood and Malik, 2014). Washing and sanitizing processes may, in most cases, remove contamination from crop surfaces, making it safe to consume. There are numerous studies on the internalization of heavy metals and pathogens. However, due to varying field conditions, results are not consistent and therefore more research may be required for specific cases (Hirneisen *et* al., 2012; Mahmood and Malik, 2014).

Polluted water used for crop irrigation inevitably reaches the soil and, depending on field conditions, this may result in the accumulation of heavy metals and pathogens in soils. Thus, the health of farm workers may be comprised depending on the duration and intensity of their contact with the contaminated soils (Drechsel *et al*., 2010). In Pakistan, farmers work barefoot in fields where soils were contaminated with pathogens from polluted water for crop irrigation. The pathogens were able to gain access via broken skin on their feet and, as a result, the occurrence of hookworm infections were highly pronounced (Shuval *et al*., 1991; Feenstra *et al*., 2000). A study by Drechsel and Keraita (2014) has highlighted that farm workers in Ghana, who came into contact with contaminated soils, were subjected to bacterial and viral infections, skin irritations, itching and blisters on their hands and feet, as well as nail problems such as koilonychias. According to Qadir *et al*. (2008), in many countries, women are responsible for weeding and transplanting in crop fields that have been irrigated with polluted water, thereby indirectly exposing them to pathogenic infections.

The direct and indirect exposure of humans to heavy metals and pathogens in polluted water has resulted in ill-health. It is therefore, crucial to outline the effects of specific heavy metals and pathogens on human health.

2.4.3 The effects of specific heavy metals and pathogens on human health

The intake of heavy metals and pathogens by humans via the food chain has been widely researched (Singh *et al*., 2009). Table 2.2 provides a summary of the permissible limits of heavy metals (mg/kg) in edible crops, in addition to the effects on human health. Table 2.3 provides a summary of pathogenic organisms that may be internalized by edible crops and the related human health impacts.

The most commonly encountered heavy metals in literature that compromise human health are: As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn all of which are outlined in Table 2.2 (Singh *et al*., 2009; Lokeshappa *et al*., 2012; Zango *et al*., 2013; Waseem *et al*., 2014). The most toxic heavy metals to human health are As, Cd, Hg and Pb (Lokeshappa *et al*., 2012). Table 2.2 indicates that heavy metals present in crops which exceed the permissible limits may result in cardiovascular, nervous, renal, bone diseases, neurological impairment in addition to a number of other health issues (Lokeshappa *et al*., 2012). Heavy metals which enter the food chain may have different impacts on human health depending on gender, age and immunity (Jan *et al*., 2010; WHO, 2011; FAO/WHO, 2011). The human health impacts summarized in Table 2.2, may further be dependent on long-term exposure and the cumulative intake of crops containing high concentrations of heavy metals (Bigdeli and Seilsepour, 2008; Singh *et al*., 2009; WHO, 2011; FAO/WHO, 2011; Oti and Nwabu, 2013).

Research has shown that each year over five million human deaths occur due to water-borne diseases, with more than half of the diseases being microbial intestinal infections (WHO, 2006). Table 2.3 has summarised the pathogenic microorganisms that may be present in crops (due to polluted irrigation water) and the associated human health impacts. Bacteria are the most common pathogens in polluted water with *Salmonella* and *E.coli* (*enterotoxigenic*) being the most widely reported bacterial pathogens (WHO, 2006; Odonkor *et* al., 2013). Viruses are considered the most dangerous pathogens in polluted water. The viral pathogens of concern are Polio virus, Rotavirus, Reovirus and Hepatitis A virus (WHO, 2006). Protozoa may be detected as cysts and oocysts in polluted water and both *Cryptosporidium* and *Giardia* are major protozoan pathogens of concern (WHO, 2006). It is crucial to note that there should be no presence of pathogens on the surface of edible crops or internalized by edible crops, especially those consumed raw.

Table 2.2 Summary of the permissible limits of heavy metals in crops (mg/kg) and the human health impacts

Heavy Metal	**Permissible Limit in Crops (mg/kg)**	**Human Health Impacts**
As	0.1[d]	Hyperpigmentation/hypopigmentation, peripheral neuropathy, skin/bladder/lung cancers, peripheral vascular disease, muscle spasms, headaches, fever, nausea, vomiting, hair loss, darkening of the skin, goiter, sore throat, keratosis, jaundice, kidney damage, liver damage, pallor and impaired healing (WHO, 2011; Lokeshappa *et al*., 2012; Oti and Nwabu, 2013).
Cd	0.2[d]	Cardiovascular disease, strokes, kidney damage, lung damage, osteoporosis, arthritis, headaches, anemia, hypoglycemia, diabetes, hypertension, cirrhosis and reduced fertility (Abbas *et al*., 2010; WHO, 2011; Lokeshappa *et al*., 2012).
Cr	0.05[d]	Skin irritations, respiratory problems, weakened immune system, headaches in addition to liver, kidney, nerve and circulatory damage (WHO, 2011; Lokeshappa *et al*., 2012).
Cu	73.3[d]	Diabetes, hypertension, anemia, cholesterol, arthritis, heart attacks, strokes, fatigue, headaches, acne, hair loss, tooth decay, allergies, panic attacks, depression, hyperactivity, cancer, kidney and liver dysfunction, autism, fractures of the bone and vitamin C and other vitamin deficiencies (Lokeshappa *et al*., 2012).
Fe	425[d]	Vomiting, diarrhea, gastro intestinal bleeding, ulcers, hypotension, metabolic acidosis, development of strictures, tachycardia, hepatic necrosis and cancer (Jaishankar *et al*., 2014).
Hg	0.03[d]	Hypertension, diarrhea, nausea, vomiting, lung damage, eye irritations, skin rashes, dizziness, headaches, memory loss, hearing loss, weakened muscles, limb pains, mood swings and peripheral vision loss (WHO, 2011; Lokeshappa *et al*., 2012).
Mn	500[d]	Parkinson-type syndrome, neurological diseases, weakness, leg cramps, emotional disturbances, languor, paralysis, lung damage, cardiac problems and impacts reproductive system (Crossgrove and Zheng, 2004; Fraga, 2005; WHO, 2011; Siddique *et al*., 2014).
Ni	60[d]	Kidney damage, malaise, heart attacks, low blood pressure, depression, muscle tremors, hemorrhages, paralysis, vomiting, nausea, skin problems and cancer (Lokeshappa *et al*., 2012).
Pb	0.3[d]	Damage to the nervous system, brain and kidneys (which may result in death), anemia, weakness in ankles, wrist and fingers, abdominal pains, headaches, attention deficit, diabetes, arthritis, back problems, thyroid imbalances, blindness, tooth decay, constipation, depression and cancer (Abbas *et al*., 2010; Lokeshappa *et al*., 2012).
Zn	100[d]	Gastrointestinal disorders, pneumonia, diarrhea, hemoglobinuria, vomiting, stomatitis, depression, tremors, paralysis, loss of appetite, impaired healing, skin sores and decrease in sense of smell and taste (Singh *et al*., 2009; Oti and Nwabu, 2013).

[d] (FAO/WHO, 2001)

Table 2.3 Summary of pathogens and the associated human health impacts (after WHO, 2006)

Microorganism	Pathogens	Human Health Impacts
Bacteria	*E.coli* (*enterotoxigenic*)	Gastroenteritis
	Salmonella	Salmonellosis
	Vibrio cholerae	Cholera
	Campylobacter	Gastroenteritis
	Yersinia	Gastroenteritis
	Leptospira	Leptospirosis
Viruses	Hepatitis A virus	Infectious hepatitis
	Polio virus	Paralysis
	Reovirus	Not clearly established
	Rotavirus	Gastroenteritis
	Norwalk virus	Gastroenteritis
	Echovirus	Aseptic Meningitis
	Adenovirus	Respiratory disease
Protozoa, helminths and other parasites	Ascaris lumbricoides	Ascariasis
	Giardia intestinalis	Diarrhea
	Cryptosporidium parvum	Diarrhea
	Ancylostoma	Hookworm infection
	Entamoeba histolytica	Amoebic dysentery
	Trichuris trichuria	Trichuriasis
	Tenia solium	Teniasis

2.5 Conclusion

The literature review provides a context for assessing links between water quality, anthropogenic processes and human health on a catchment scale. A link between polluted water used for crop irrigation and exposure pathways to humans was established and reviewed. This has shown that the greatest risk of using polluted water for crop irrigation is the detrimental impacts on human health, where indirect exposure to polluted water may be of greater concern than direct exposure, since people may be unaware of the potential exposure and resulting impacts. The internalization of heavy metals and pathogens by crops, due to irrigation with polluted water, may severely affect human health via consumption and has been highlighted as one of the most critical indirect exposures. It is furthermore important to consider the duration of exposure to polluted water when determining human health impacts.

However, due to varying field conditions, experimental designs, heavy metals, pathogens and crop type, results are not consistent and therefore more research will be required for specific cases.

The present study has identified such a case as highlighted by the aim and objectives in section 1.2 and will attempt to link the water quality of the Baynespruit River to the health of the Sobantu community. The Baynespruit River has been flagged due to numerous reports of poor water quality, but the river serves as a source of irrigation for crops in the Sobantu community. Furthermore, the literature review has emphasized the importance of investigating the indirect exposure i.e. the consumption of crops contaminated via the internalization of heavy metals or pathogens. This indirect exposure is likely to exist in the case of the Sobantu community as many inhabitants consume crops irrigated with polluted water. The following sections will define the approaches used to address the objectives mentioned in section 1.2.

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3. THE EFFECTS OF THE WATER QUALITY OF THE BAYNESPRUIT RIVER ON EDIBLE CROPS IN THE SOBANTU COMMUNITY

Govender, J.[1]; Stuart-Hill, SI.[1] and Jewitt, GPW[1]

[1]Centre for Water Resources Research, University of KwaZulu-Natal, Pietermaritzburg, South Africa

ABSTRACT

The utilisation of polluted river water for crop irrigation is a reality in many rural and urban communities in South Africa. The Baynespruit River, in the province of KwaZulu-Natal, South Africa, has come under the spotlight due to poor water quality, which is utilised by the Sobantu community for crop irrigation. The objectives of this study were to conduct a water quality assessment and sediment analysis of pollutants in the Baynespruit River, as well as determine the effects of these pollutants on the soil and crops that have been irrigated with river water. The water quality assessment considered pH, electrical conductivity, As, Cd, Cu, Hg, Pb, Zn and *E.coli*, while the sediment analysis comprised of 23 elements including the aforementioned heavy metals. Using microwave acid digestion (EPA 3052) and ICP-OES, soil and crop samples from the farming sites in Sobantu, where vegetables are grown, were analysed for Cd, Cr, Cu, Pb and Zn. The water quality results were compared against the South African Water Quality Guidelines for Crop Irrigation. High levels of *E.coli* were present and there were extremely low concentrations of heavy metals, i.e. As, Cu, Hg, Pb and Zn, with sporadic detections of Cu and Pb pollution events, as well as acidic water. While the heavy metal concentrations in the surface water presented in low concentrations, the sediment analysis had concentrations of As, Cd, Cr, Cu, Ni, Pb, Zn, Fe, Mn and Ag, which has the potential to degrade water quality. The soil and crop analysis showed high concentrations of total heavy metals relative to national and international guidelines, respectively. It is suggested that these soil and crop results are indicative of historical flooding, which mobilized heavy metals in river sediments and transferred them onto the floodplain, on which the farming sites are located. Furthermore, long-term irrigation with low concentrations of heavy metals may have also resulted in the build-up of these contaminants in the soil and eventually the crops. Overall, it was concluded that the water quality of the Baynespruit River

is contaminated with *E.coli* and that a variety of heavy metals are present in the river sediment, which has resulted in high levels of heavy metals which are internalized by the soil and crops grown by the Sobantu community.

Keywords: *water quality; heavy metals; crop irrigation; edible crop*

3.1 Introduction

Worldwide, rivers constitute one of the major sources for the water-intensive use of crop irrigation (Akpan-Idiok *et al*., 2012; Chen *et al*., 2013). The water quality of many river systems has however, been adversely affected by anthropogenic influences. There are many impoverished communities in developing countries that are faced with inadequate potable water supplies (Balkhair, 2016). This has led to a strong reliance on polluted rivers for their daily needs, including crop irrigation, which may be linked to the livelihoods and food security of people (Wanda *et al*., 2015; Wolterdorf *et al*., 2015).

The water from polluted rivers usually contains a plethora of contaminants, which reduce water quality (Atibu *et al*., 2013). Heavy metals are among some of the most problematic contaminants and are introduced into rivers through domestic, agricultural and industrial activities (Mothusi, 2014). The removal of heavy metals from river systems presents as a challenge due to their non-biodegradable nature and persistence in the environment (Sardar *et* al., 2013). Furthermore, it has been observed that river sediments act as a reservoir for heavy metals and have the ability to accumulate higher concentrations than the surface water (Tshibanda *et al*., 2014). It is therefore essential to conduct both water quality assessments and sediment analyses, which may be used to outline existing conditions, identify trends and/or determine sources of contamination (Akpan-Idiok *et al*., 2012). This water quality and river sediment information also may be useful when determining the suitability of river water for crop irrigation (Etteieb *et al*., 2015).

The role of water quality in the production of crops is highly significant when considering crop yield and quality (Palanaippan *et al*., 2010; Drechsel and Keraita, 2014). There are various water quality guidelines that stipulate the maximum permissible limits of heavy metals for crop irrigation, in order to achieve optimal growth (Assubaie, 2015). According to Suresh and Nagesh (2015), the quality of irrigation water has a direct impact on the soil and crops. A study by Sardar *et al*. (2013) revealed that long-term irrigation with polluted water containing low concentrations of heavy metals resulted in the build-up of heavy metals in the soil. The bioaccumulation of heavy metals in crops, associated with the practice of polluted water used for crop irrigation, has been well-documented (Alia *et al.*, 2015). It is therefore crucial to analyse both soil and crops that have been irrigated with polluted water, since heavy metals may easily be introduced into the food chain through this practice. There are however, inconsistent results due to varying field conditions, and further research may be required for specific cases (Hirneisen *et al*., 2012; Mahmood and Malik, 2014).

The water quality of the Baynespruit River in KwaZulu-Natal, South Africa, has been compromised due to illegal effluent discharges, land degradation, broken sewage infrastructure and illegal dumping. It may therefore be assumed that a host of pollutants is present in the river and that this includes heavy metals and microbial constituents. The Sobantu community located toward the lower reaches of the Baynespruit River utilise this source for crop irrigation. Thus, the objectives of this paper are to determine what constituents are problematic in the Baynespruit River, i.e. in terms of crop irrigation and ultimately human health, by conducting a water quality assessment and sediment analysis, as well as to determine the effects of these constituents on the soil and crops that have been irrigated with water from the river. The information generated from this paper may prove useful to decision-makers involved in the effort to rehabilitate the Baynespruit Catchment.

3.2 Methodology

3.2.1 Site description

The Baynespruit River is a tributary of the Msunduzi River, located in Pietermaritzburg, KwaZulu-Natal (Figure 3.1). The Baynespruit River originates in the residential area of Northdale and flows approximately 9 km through the Willowton Industrial Area before reaching its confluence with the Msunduzi River just east of the residential community of Sobantu (Figure 3.1). The upper catchment of the Baynespruit River consists of high-density formal residential development, the middle reaches are comprised of numerous trade effluent regulated industries and located downstream are high-density formal and informal residential areas.

The Baynespruit Catchment is located within the Msunduzi municipal boundary and thus, its characteristics can be associated with this municipal area (Figure 3.1). Table 3.1 summarizes a variety of factors which characterise the Msunduzi municipal area i.e. climatology, geology, topography, soils, hydrology, biodiversity, sanitation and solid waste, storm water and the socio-economic environment. It is evident from Table 3.1 that the relationship between the slope and geology in the municipal area is complex, which may result in erosion and the transportation of sediments and soil into water bodies. In addition, the municipal area has great potential for agriculture due to the topography, rainfall, geology and soils characteristics; however, much of this land has been utilised for industrial and residential purposes. Table 3.1 highlights characteristics such as hydrology and biodiversity, which have been compromised as a result of anthropogenic activities in the municipal area. According to Table 3.1, the solid waste and sanitation, as well as the storm water characteristics of the municipal area, may significantly impact water quality. Finally, with regard to the socio-economic environment of the municipal area, there may be a poor standard of living and economic losses experienced, as a result of insufficient municipal capabilities and the degradation of ecosystems.

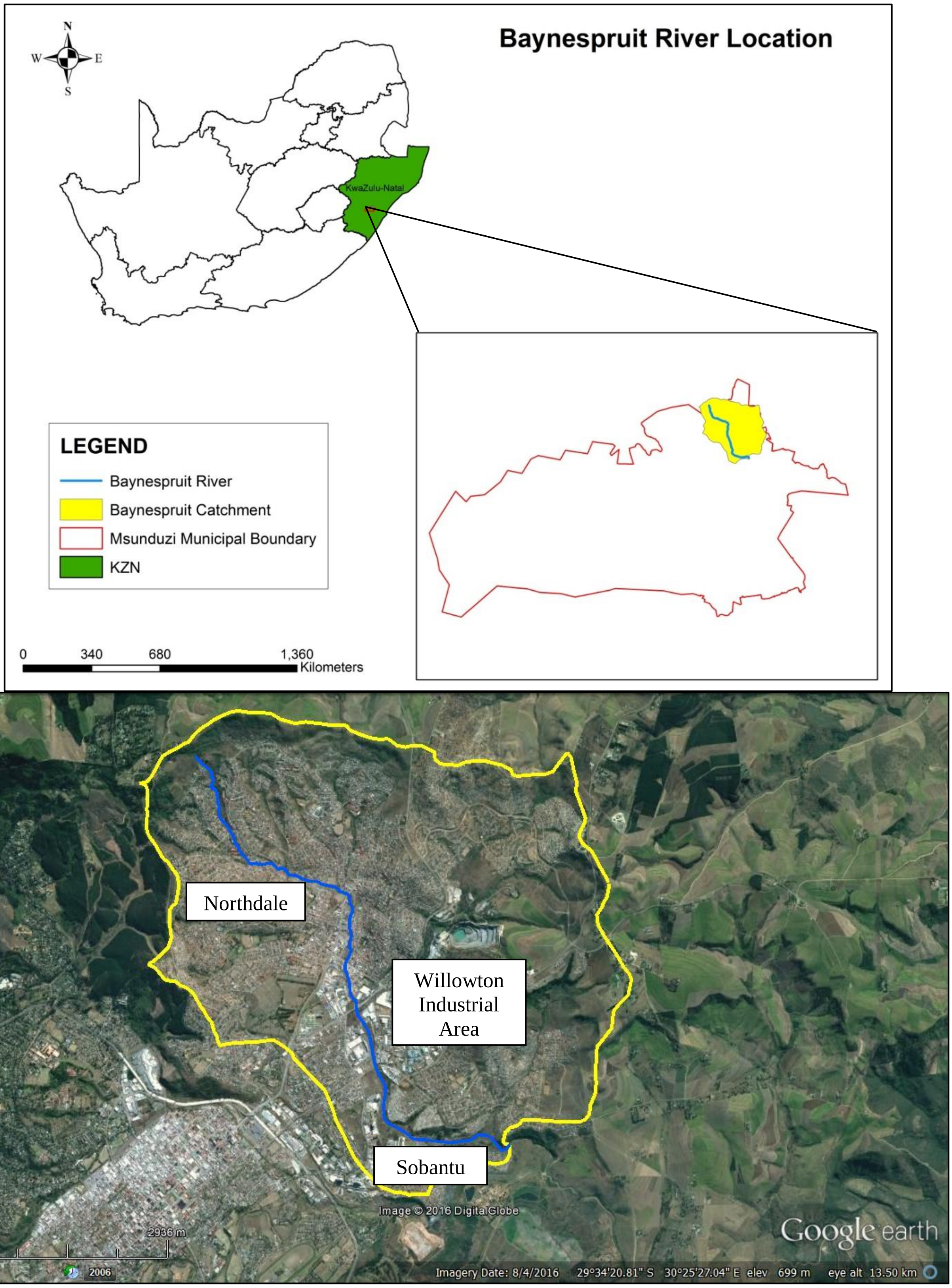

Figure 3.1 Location of the Baynespruit River and Sobantu community in the province of KwaZulu-Natal, South Africa

Table 3.1 Summary of the characteristics of the Msunduzi municipal area and the Baynespruit Catchment

Characteristics	
Climatology	MAP (mm): 900 – 999 per annum Average temperature (^{0}C): 24.8
Topography	Altitude: 495 -1795 m.a.s.l Slope: West to East
Geology	The municipal area is dominated by sedimentary rocks of the Ecca Group and Dwyka Formation. These sediments are intruded by Jurassic post-Karoo dolerite sheets, dykes and sills which outcrop across the municipal area. Thus, the relationship between the slope and geology in the municipal area is regarded as complex.
Soils and Vegetative Cover	According to Ramburran (2014), the soils within the municipal area vary significantly. Northdale: The vegetative cover comprises of Moist Coast Hinterland Ngongoni Veld, with soils which are acidic and leached. Willowton: The vegetative cover comprises of Dry Coast Hinterland Ngongoni Veld. Sobantu: The vegetative cover comprises of Coast Hinterland Thornveld.
Hydrology	Runoff (mm): 150 – 199 mm per annum Rivers in the municipal area form part of the riparian corridors that may be vulnerable to flooding (Ramburran, 2014). Wetlands have been transformed and are currently degraded as a result of inappropriate land use and inadequate catchment management (Ramburran, 2014).
Biodiversity	There are diverse habitats and species richness within the municipal area, for example, 56 animal species, 20 plant species and 8 vegetation types. However, due to anthropogenic transformations, there is a major loss of biodiversity, especially in the Baynespruit River (Ramburran, 2014).
Solid Waste and Sanitation	Solid waste is disposed of at the New England Road landfill. However, this site may soon reach its carrying capacity. Illegal dumping poses a threat to storm water and sewer reticulation in addition to the water quality of water sources such as the Baynespruit River. The sanitation network requires replacement and upgrading of infrastructure along the middle reaches of the Baynespruit River.
Storm Water	The expansion of high-density settlements has given rise to hardened surfaces which increase storm water runoff. Thus, the risk of downstream (i.e. the Sobantu community) flooding and transportation of numerous constituents has increased over time.
Social Environment	Rapid population growth has resulted in the inappropriate development and land degradation. Furthermore, the municipality has insufficient resources and capacity to provide the required services to these expanding high-density settlements, which results in a poor standard of living in the area.
Economic Environment	The ecosystems goods and services within the municipal area generate economic benefits. For example, untransformed regions of the municipal area comprise of grassland plants, indigenous trees and indigenous animals which are utilised by traditional healers and medicinal plant collectors for informal trading. Thus, the loss of such species will diminish financial prospects.

A specific site of interest within the Baynespruit Catchment is the Sobantu community ($29^0$35'33.86"S, $30^0$25'12.73"E), which is located toward the lower reaches of the Baynespruit River, as depicted in Figure 3.1. The Sobantu community is described as a high-density formal and informal residential area, situated on a floodplain with high agricultural potential (Ramburran, 2014). The Baynespruit River serves as an irrigation source for subsistence and small-scale market farming sites. Irrigation is carried out manually and directly onto the crops, using watering cans and/or an electric water pump. The crops that are grown in the Sobantu community usually consist of *Spinacia oleracea* (Spinach), *Daucus carota* (Carrot), *Brassica oleracea* (Cabbage) and *Zea mays* (Maize), as well as various others depending on the farmers' preference. The current study considered three farming sites located on the floodplain of the river, within the Sobantu community, i.e. farming site 1, farming site 2 and farming site 3 (Figure 3.2). All three sites were maintained by farmers in the community in order to keep the field conditions for each site unchanged. The characteristics of each site have been summarized in Table 3.2. Each farming site contained different crops grown in both summer and winter however; spinach was common across all farming sites in both seasons (Table 3.2). It is important to note that these three farming sites, each with different forms of irrigation, i.e. polluted water from the Baynespruit river, water from a nearby wetland pond and water from a communal tap, were considered in order to compare the effects on crops. Farming site 1 was considered the control site since it has never been irrigated with water from the Baynespruit River (Table 3.2). Farming site 2 was last irrigated with water from the river in 2005 however, due to poor water quality, the irrigation source is currently a nearby wetland pond (Table 3.2).

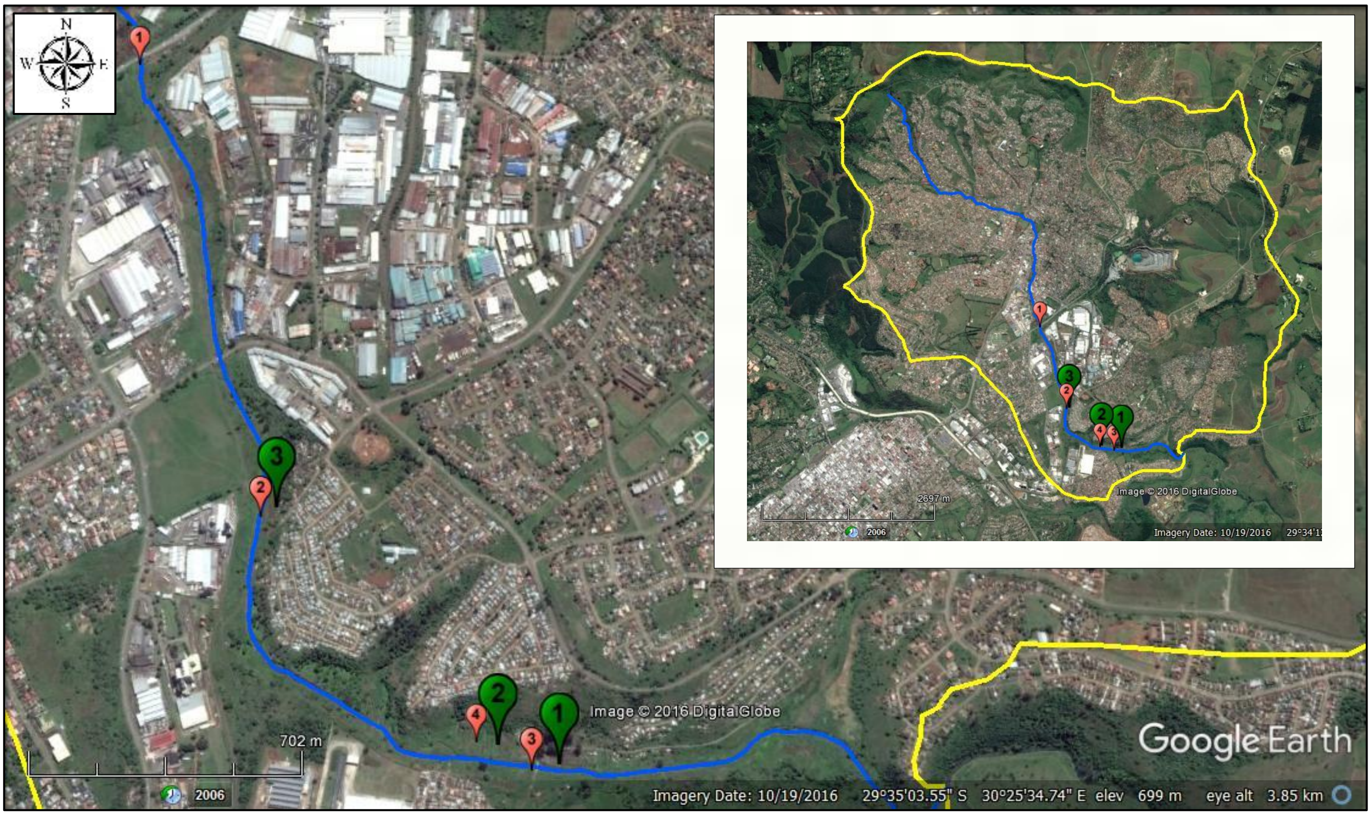

Figure 3.2 Location of the farming sites (green) in the Sobantu community, as well as the water sampling points (red) along the Baynespruit River and wetland pond

Table 3.2 Summary of the characteristics for each of the three farming sites under consideration

Characteristics	Farming Site 1	Farming Site 2	Farming Site 3
Co-ordinates	29^0 35'33.88" S : 30^0 25' 22.63" E	29^0 35'37.38" S : 30^0 25' 17.99" E	29^0 35'37.38" S : 30^0 25' 17.99" E
Area (m^2)	84	10 200	2700
Crops	Winter 2016: spinach and carrots Summer 2016: spinach and carrots	Winter 2015: spinach and carrots Summer 2016: spinach and pumpkin	Winter 2015: spinach and cabbage Summer 2016: spinach and maize
Irrigation Source	Communal tap	Wetland pond	Baynespruit river
Fertilizer	No	No	Yes
Comments	• Site 1 is considered the reference site since it has never been irrigated with water from the Baynespruit river • Crops grown annually • Irrigation applied as the farmer sees fit	• Crops grown annually • Last irrigated with water from the Baynespruit river in 2005 • The wetland pond is not connected to the Baynespruit river • Irrigation applied as the farmer sees fit	• Crops grown annually • Irrigation applied as the farmer sees fit

3.2.2 Water quality assessment and sediment analysis

It may be assumed that a wide range of physical, chemical and microbiological constituents are present in the Baynespruit River. The Msunduzi municipality and Umgeni Water have reported that illegal effluent discharges and poor sewage disposal infrastructure, significantly contribute to water quality degradation of the Baynespruit River.

Industrial effluent is a rich source of heavy metals, which may have harmful effects on the environment, as well as human health (Khan *et al*., 2013a). Thus, a confidential industrial effluent report, provided by Umgeni Water[e], was used in this study to determine which physicochemical constituents, including heavy metals, to monitor. This report contained an inventory of pollutants in the effluent from industries in the Baynespruit Catchment.

The microbial constituent considered for the water quality assessment needed to be an overall indicator of contamination, since conducting individual tests for monitoring specific bacteria and pathogens, were beyond the scope of this study. It was therefore decided that *E.coli* would be a suitable indicator to measure the level of microbial contamination in the Baynespruit River, as a result of broken sewage infrastructure.

The constituents were chosen based on their volumes in the effluent, their ability to adversely affect crops, as well as their level of health risks to humans. Ultimately, the following constituents were monitored: pH, electrical conductivity (EC), arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg), zinc (Zn) and *E.coli*, at four sampling points (Figure 3.2).

The first point was selected to represent the water quality before the point of irrigation extraction. The second point represented the water quality at the point of irrigation extraction used at farming site 3. The third point represented the water quality of lower reaches of the river. Finally, the fourth point represented the water quality of the wetland pond which was used to irrigate farming site 2.

[e] Umgeni Water – A water services provider located in Pietermaritzburg, KwaZulu-Natal, South Africa

Water sampling was conducted weekly for the duration of one year (17/06/2015 – 15/06/2016) to show temporal extent, including seasonal variations. The days on which water samples were collected were random and usually occurred between 9 and 11am, specifically for safety reasons. The type and the volume of bottles used for sampling varied according to the constituent being analysed. A 500 ml plastic bottle with a sodium thiosulphate preservative was used to submit samples for *E.coli* analysis, a 500 ml plastic bottle with a nitric acid preservative was used for the analysis of cadmium, copper, lead and zinc, a 250 ml plastic bottle with a hydrochloric acid preservative was used for the analysis of arsenic and finally, a 250 ml glass bottle with a hydrochloric acid preservative was used for the analysis of mercury. Thus, one sample was obtained from each point in different collection bottles. All samples were transported to the Umgeni Water laboratory immediately after sampling. The chemical and microbial analyses were conducted with the assistance of Umgeni Water, whereas the pH and electrical conductivity were measured on site using a Hanna combo pH and electrical conductivity meter.

Literature has stipulated that constituents may not always be detected in overlying water and may show a greater presence in the rivers surface sediments (Tshibanda *et al*., 2014). Hence, a sediment analysis was carried out in order to compliment the water quality monitoring. The sediment analysis was conducted with the assistance of Umgeni Water which offered the determination of 23 elements in sludge samples, i.e. river sediments. All 23 elements were chosen, which included the routine heavy metals, in order to obtain a thorough screening of the river sediment and determine which constituents exceeded the maximum permissible limits for contaminants in freshwater sediments, according to USA Freshwater Sediment Guidelines (1996). Therefore, the following constituents were considered in the sediment analyses: Ag, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, total phosphorus, V, volatile solids (VS) and Zn. The sediment sampling occurred at the end of August 2015 and at the end of February 2016, in order to represent the winter and summer periods, respectively. A scoop was used to collect the surface sediments from an approximate depth of 5 cm, which was then bottled into 250 ml plastic containers. A total of eight samples were collected from point 1, 2 and 3 in the river (Figure 3.2). At point 1, one composite sample containing five sub-samples was collected. At point 2, six composite samples comprising of five sub-samples were collected to thoroughly assess the sediments at the point of irrigation extraction for farming site 3 and achieve representativeness. Finally, at point 3, one composite sample consisting of five sub-samples was collected. The sediment analysis was conducted with the assistance of Umgeni Water.

Literature has highlighted the importance of considering rainfall when conducting water quality monitoring, which may be related to the constituent dilution capacity. Rainfall data was therefore obtained from the weather station at the Darvill Wastewater Treatment Works ($29^0$36’05.21”S and $30^0$25’45.10” E), which is located on the outskirts of Sobantu. The rainfall record consisted of daily data for the period 17/06/15-15/06/16 and was made available by Umgeni Water.

3.2.3 The determination of heavy metal internalization by soil and edible crops

The analysis of total Cd, Cu, Cr, Pb and Zn concentrations (mg/kg) in both the soil and crop samples were executed. The soil and crop samples were acquired from the aforementioned farming sites 1, 2 and 3 in the Sobantu community as described in sections 3.2.3.1 and 3.2.3.2. The instruments utilised in this experiment consisted of a Mars 6 closed vessel microwave digestion system and a Perkin Elmer Optima 5300 DV ICP-OES (Inductively Coupled Plasma – Optical Emission Spectrometry), located in the Soil Science department at the University of KwaZulu-Natal, Pietermaritzburg and the Chemistry department at the University of KwaZulu-Natal, Westville, respectively. The analytes As and Hg were omitted from the analysis due to regulations enforced by the chemistry laboratory, which aimed to protect the efficiency of the ICP-OES since these analytes have the ability to create interferences within the instrument. The analyte Cr was considered in the analysis since it was flagged in the industrial effluent surveys, however, not in concentrations as high as the routine heavy metals investigated in the water quality assessment.

3.2.3.1 Soil sampling

The soil sampling technique used in the current study was adopted from Hue *et al*. (2000). The soil samples were collected in May 2015. A Dutch auger was used to sample the soil at a depth of 20 cm since the majority of the crop root biomass exists at this depth. The soil was randomly sampled from each farming site, in a zigzag pattern, to achieve representative soil samples of each farming site. The area of each farming site varied and therefore the number of soil samples that were taken for each farming site differed. At farming site 1 (12 m x 7 m) one composite sample was obtained which consisted of two soil samples. At farming site 2 (170 m x 60 m) four samples were taken and two samples were obtained from the wetland which bordered farming site 2. At farming site 3 (90 m x 30 m) four samples were taken. A total of eleven soil samples were collected, which were then air dried, sieved through a 2 mm steel sieve and stored in 250 ml plastic containers until the digestion procedure commenced.

3.2.3.2 Crop sampling

The crops under consideration were sampled during the summer (January – February 2016) and winter periods (July – August 2015) in order to identify possible seasonal trends in heavy metal internalization. Hence, during the summer, spinach and carrots were sampled from farming site 1, spinach and pumpkin from farming site 2, as well as spinach and maize from farming site 3. Furthermore, during the winter, spinach and carrots were sampled from farming site 1, spinach and carrots were sampled from farming site 2 and spinach and cabbage from farming site 3. The number of crops sampled followed the sampling procedures described by Hue *et al*. (2000). Therefore, ten samples of each crop were collected in each farming site in order to achieve representativeness. Furthermore, only the edible portions of each crop were sampled for the specific purpose of the current study, i.e. to investigate links to human health. However, the carrots were not peeled and the spinach stalks were left intact since the people of Sobantu consume these crops as stated. The crop samples were thoroughly washed with water in order to remove soil. Thereafter, the samples were oven dried at 55^0C for 24 hours or more if necessary. The dried crop material was ground in a motorised mill, sieved through a 2 mm steel sieve and stored in 50 ml plastic containers until microwave digestion commenced.

3.2.3.3 Microwave digestion

The preparation for microwave digestion began by using triplicates of each sample. All microwave vessels were cleaned with detergent and nitric acid (55%) prior to digestion. The digestion procedure, according to EPA Method 3052[f] for both soil and crop samples was as follows:

1. 0.5 g of sample was weighed into each polymeric microwave vessels.
2. 9 ml of nitric acid (55%) and 3 ml of hydrochloric acid (32%) were added to each vessel in a fume hood.
3. The vessels were sealed and placed into the microwave system.
4. The EPA Method 3052 was selected and the digestion process was then initiated.
5. After the digestion had completed, the vessels were allowed to cool for a minimum of 5 minutes before removing them from the microwave system.
6. The vessels were uncapped in the fume hood and the extracts were filtered through 90 mm Whatman filter paper into 25 ml volumetric flasks.
7. The filtered extracts were diluted with distilled water to a volume of 25 ml and thereafter transferred into 50 mL acid-cleaned bottles, which were stored in a fridge. Prior to ICP-OES analysis, all samples were filtered through 0.45 μm filters into 15 mL plastic ICP vials.

3.2.3.4 ICP-OES analysis

The ICP-OES calibration procedure utilised 1000 ppm stock standards (Cd, Cr, Cu, Pb and Zn) supplied by Merck. A multi-element set of five standard solutions were produced by diluting each stock with nitric acid (2%). The calibration standards were based on the expected concentration ranges, of the heavy metals of interest in the samples, and were determined based on previous literature (Mojiri, 2011; Khan *et al.*, 2013b; Stasinos *et al.*, 2014; Mustapha *et al.*, 2014; Alia *et al.*, 2015; Qadir *et al.*, 2015). Thus, the calibration

[f] EPA Method 3052 – A methodology from the Environmental Protection Agency (EPA) commonly used for microwave assisted acid digestion of soil and crop samples

standards were as follows (mg/L): 0.01, 0.05, 0.25, 1.25 and 6.25 for Cd, Cr and Pb, as well as 0.1, 0.5, 2.5, 12.5 and 62.5 for Cu and Zn. Furthermore, a calibration blank was used which consisted of nitric acid (2%). Lastly, a reagent blank was prepared for both the soil and crop analyses, which consisted of a digestion of 9mL nitric acid (55%) and 3mL hydrochloric acid (32%), which was diluted to volume (25mL) using distilled water. All ICP-OES operating conditions have been displayed in Appendix A. The wavelengths (nm) which provided the greatest intensities were selected as such: Cd (226.502), Cr (283.563), Cu (324.752), Pb (220.353) and Zn (213.857). The limits of detection (mg/L) for Cd, Cr, Cu, Pb and Zn were 0.01, 0.01, 0.1, 0.01 and 0.1, respectively. A Certified Reference Material (CRM) for soil (ERA 540 Heavy Metals in Soil) was analysed as a means of validating the digestion methodology, as well as checking the accuracy of the ICP-OES.

3.2.4 Experimental glasshouse pot trial

An experimental glasshouse pot trial was introduced into the study in order to obtain a control site located away from the floodplain of the Baynespruit River. The glasshouse was located at the University of KwaZulu- Natal, Pietermaritzburg. The experiment included soil from farming sites 1, 2, 3 and a control site ($29^0$33’13.31”S and $30^0$24’02.52” E) from a home garden located in the residential area of Northdale, i.e. within the Baynespruit Catchment, where there were no sources of contamination that may have led to heavy metal contamination.

Approximately 75 kg of soil was randomly sampled from each farming site and the control site at a depth of 20 cm. The trial consisted of 60 pots, which each contained approximately 5 kg of soil from the aforementioned farming site and control site, i.e. 15 pots represented each site 1 including the control site. The trial considered three crops, i.e. spinach, cabbages and carrots since these were sampled as part of the current study and are commonly grown in the Sobantu community. Five seedlings of each crop were grown for all four different soils.

The crops were irrigated daily with tap water using a watering can. According to Ramburran (2014), the soils in the Sobantu community have high agricultural potential. Therefore, it was assumed that the soils from farming site 1, 2 and 3 were highly fertile. However, fertilizer was used in the trial to ensure that all the essential nutrients i.e. nitrogen, phosphorus and potassium, were provided to the crops and that any yellowing of the leaves or stunted growth may possibly be an attribute of heavy metal uptake. The fertilizer (NPK 2:1:2 (43)) requirement for each crop type, i.e. spinach, cabbages and carrots grown on highly fertile soils, was adapted from Bame (2012) and applied accordingly.

It was also necessary to spray the crops with Ripcord insecticide for protection against a variety of insects and to achieve optimal quality. The soils and crops were analysed using microwave digestion and ICP-OES as previously described in section 3.2.3.

Soil pH plays a pivotal role in the availability of heavy metals in the soil. A soil with low pH will result in increased solubility and thus bioavailability of heavy metals, which may be extracted by crops. Accordingly, the soil pH from farming sites 1, 2, 3 and the control site was analysed using both deionized water and 1M KCl solutions. The use of an electrolyte solution, i.e. 1M KCl, is important when measuring soil pH as it provides a similar representation of the soil solution. A Crison pH meter Basic 20 was utilised and calibrated using pH 4 and pH 7 standard buffers. The procedure for measuring soil pH using deionized water was as follows: 10 g of the four different soils were measured into four separate beakers, 25 ml of deionized water was added to each beaker and vigorously stirred. The mixture was allowed to stand for 15 mins after which the pH electrode was placed into the clear supernatant and a pH reading was obtained. The procedure for measuring soil pH using 1M KCl was as described above. However, instead of deionized water, 25 ml of 1M KCl solution was added to each beaker.

3.2.5 Statistical analyses

The GenStat (18^{th} ed.) statistical package was used to determine the significance of the water quality and sediment results, where applicable. Statistical analyses of heavy metal variability in soil and crops were carried out using a general ANOVA and unbalanced ANOVA in GenStat, respectively.

3.3 Results

3.3.1 Water quality monitoring

The water quality monitoring revealed that most of the physicochemical constituents, i.e. pH, EC and heavy metals, were below the permissible limits for crop irrigation, as stipulated by the South African Water Quality Guidelines (DWAF, 1996). However, the microbial constituent that was measured, i.e. *E.coli*, greatly exceeded the permissible limit.

It is important to note that the concentrations of constituents expressed in the DWAF (1996) guidelines were based on average values over a crop growing season. The current study represents infrequent high values of heavy metals rather than elevated average concentrations over a period of one year. Thus, for the purpose of this study, it was assumed that the guideline values were an absolute limit.

3.3.1.1 pH and EC

The majority of pH values across all sampling points conformed to the standard range 6.5 – 8.4 (DWAF, 1996) (Figure 3.3). However, a number of cases which were mostly below the lower pH limit occurred. The detection of acidic water quality generally occurred between September 2015 – November 2015 and August 2015 – November 2015, in the river and in the wetland pond, respectively. However, there were two cases that exceeded the upper pH limit, i.e. 8.44 at point 1 (8/10/2015) and 9.47 at point 2 (8/10/2015). The pH was not influenced by rainfall as displayed in Figure 3.3. According to the Box Plot in Figure 3.5, there was no statistically significant difference in pH across the sampling points (n-value = 52).

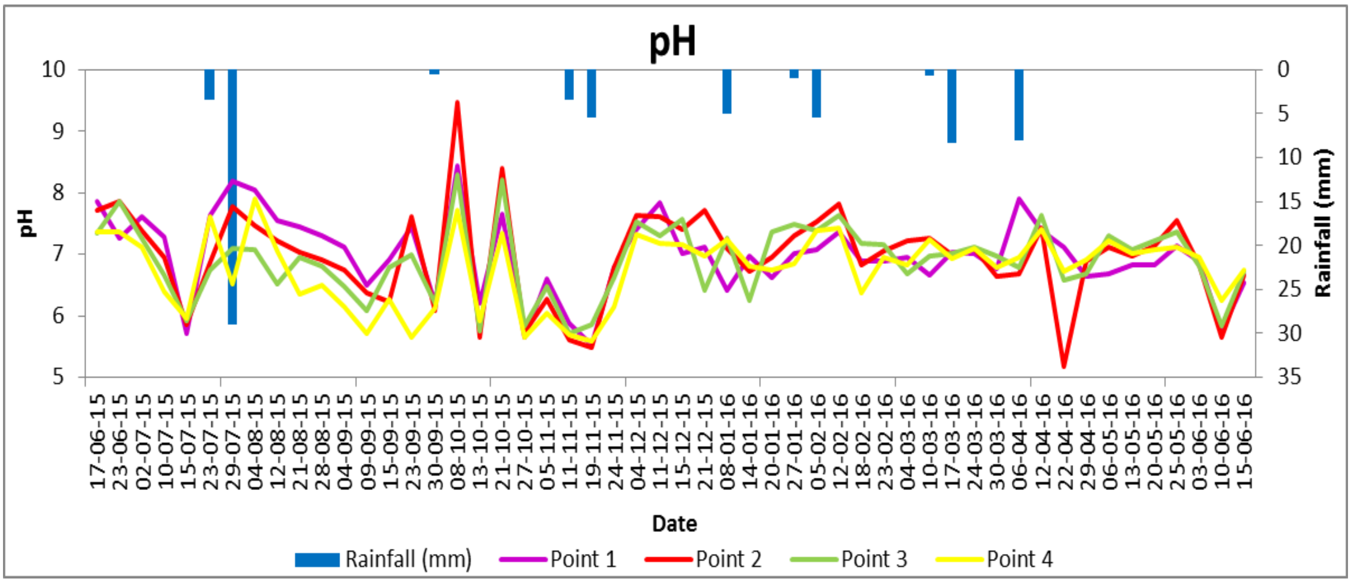

Figure 3.3 Comparison of pH across sampling points (Permissible Range: 6.5 – 8.4)

The greater portion of the EC measurements at points 1 and 3, excluding a few occurrences, were below the permissible limit of 40 mS/m (DWAF, 1996) (Figure 3.4). It was observed that all EC measurements at point 2 fell below the permissible limit. In contrast, the majority of the EC measurements at point 4 were above the permissible limit (Figure 3.4). The EC generally increased from point 1 to point 3 in the river with the point 4 recording the highest EC of all the sampling points. The EC was not influenced by rainfall as shown in Figure 3.4. Figure 3.5 established that the EC at point 1, 2 and 3 in the river did not statistically differ significantly (n-value = 52). However, point 1 and 2 in the river did statistically differ significantly from point 4 in the wetland pond (Figure 3.5).

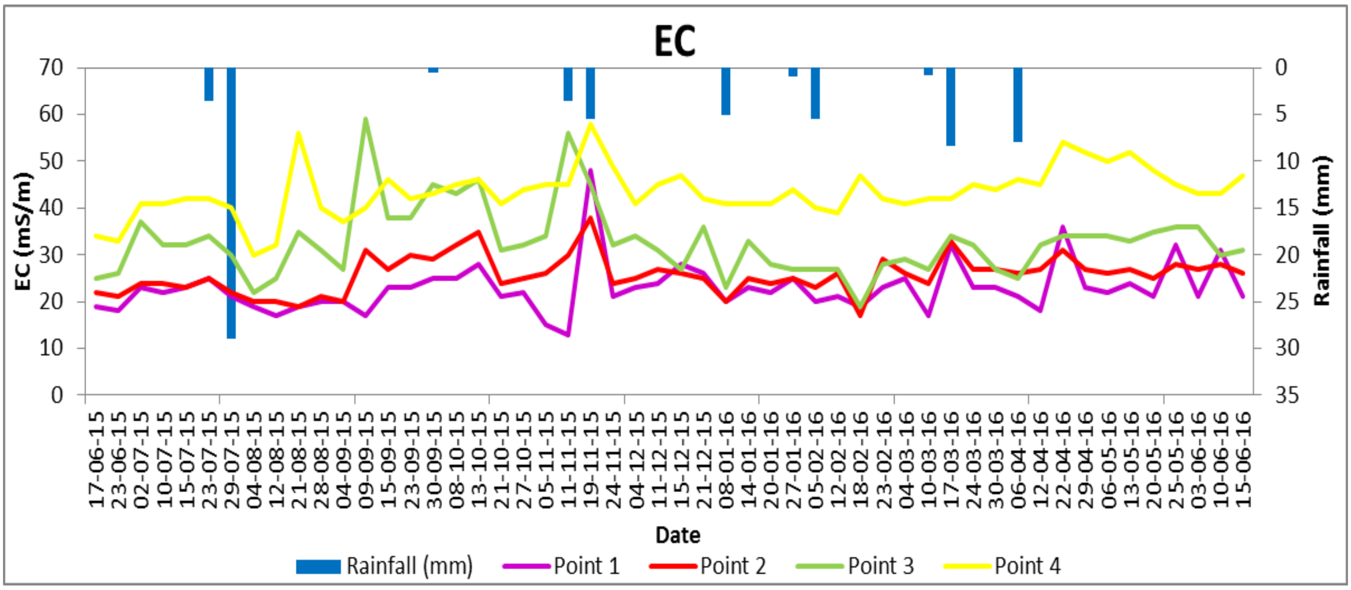

Figure 3.4 Comparison of EC across sampling points (Permissible Limit: 40 mS/m)

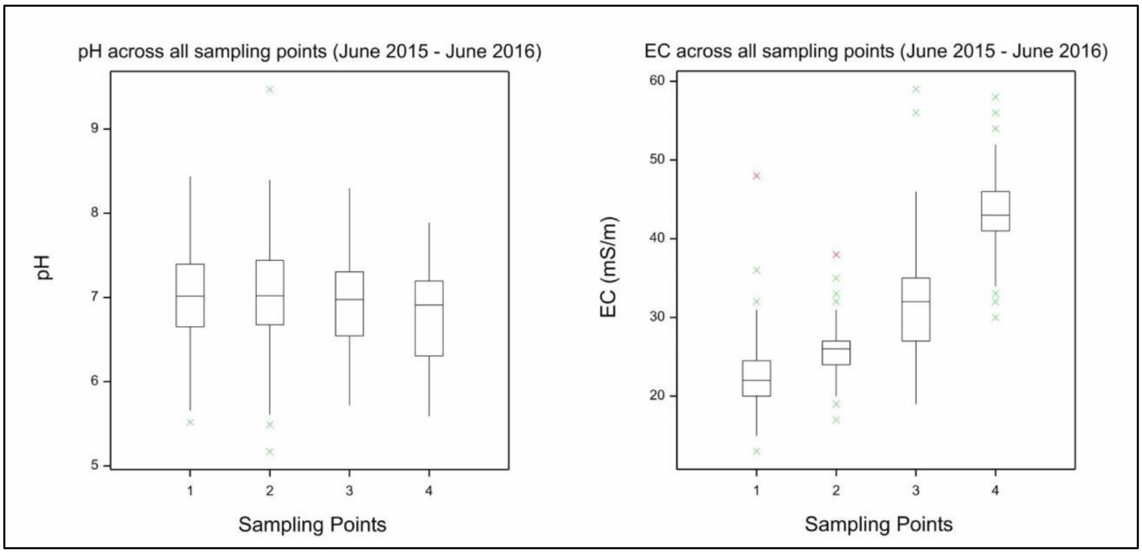

Figure 3.5 Box Plots displaying pH and EC across sampling points

3.3.1.2 Heavy metals

The heavy metal results provided by Umgeni Water included limits of detection, which were considered by the laboratory to be the acceptable concentrations to report on for each analysis. Thus, the limits were as follows: As <2.00 (μg/L), Cd <1.00 (μg/L), Cu <0.05 (mg/L), Hg <0.50 (μg/L), Pb <4.00 (μg/L) and Zn <0.03 (mg/L). The GenStat software does not accept data with limits and was therefore not used to analyse the heavy metal results.

The majority of the heavy metals detected in the water quality assessment were below the permissible limits for crop irrigation (DWAF, 1996), except for the cases stipulated below. The concentrations of As, Cd and Hg detected at all four points were less than the permissible limits, i.e. 100 μg/L, 10 μg/L and 50 μg/L, respectively (Figure 3.6 – 3.8). It was found that Cu values exceeded the permissible limit, i.e. 0.2 mg/L, with values of 0.63 mg/L at point 1 (28/08/2015), 0.74 mg/L at point 2 (28/08/2015), 0.36 mg/L at point 4 (04/08/2015) and 0.43 mg/L at point 4 (21/08/2015) (Figure 3.9). The levels of Pb at point 4 in the wetland pond greatly exceeded the permissible limit i.e. 200 μg/L, with values such as 2557 μg/L (04/08/2015), 1371 μg/L (12/08/2015) and 3599 μg/L (21/08/2015) (Figure 3.10). It was also observed that Zn was greater than the permissible limit, i.e. 1 mg/L, with concentrations of 1.03 mg/L at point 3 (04/09/2015) and 1.90 mg/L at point 4 (21/08/2015) (Figure 3.11). It can be seen in (Figure 3.6 – 3.11), that the concentrations of heavy metals detected were not influenced by rainfall, based on the weekly sampling routine over a period of one year. A summary of the number of heavy metals detected at each point, that were greater than the limits of detection provided by Umgeni Water, has been compiled (Table 3.3). It is evident from Table 3.3 that at point 1 As had been detected the most, i.e. 7 times, at point 2 both As and Pb had the highest number of detections, i.e. 7 times each, at point 3 Zn had been detected the most, i.e. 28 times and lastly, at point 4 Pb had the highest number of detections, i.e. 28 times. It can be seen that when comparing sampling points in the river, point 3 incurred the greatest number of heavy metal detections. Overall, the wetland pond had the highest number of heavy metal detections when compared across all sampling points. The frequency of heavy metal detections and the sporadic detections that exceeded the MPL were low in the river water, which suggested that heavy metal pollution was not problematic for the purpose of crop irrigation.

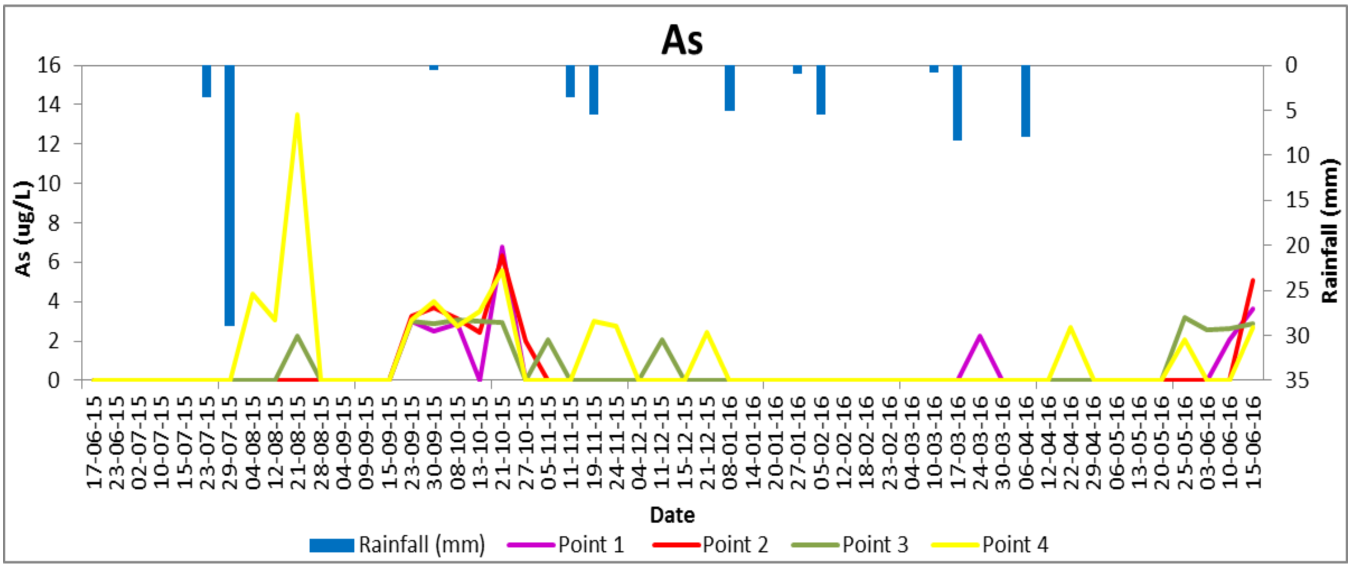

Figure 3.6 Comparison of As across sampling points (Permissible Limit: 100 µg/L)

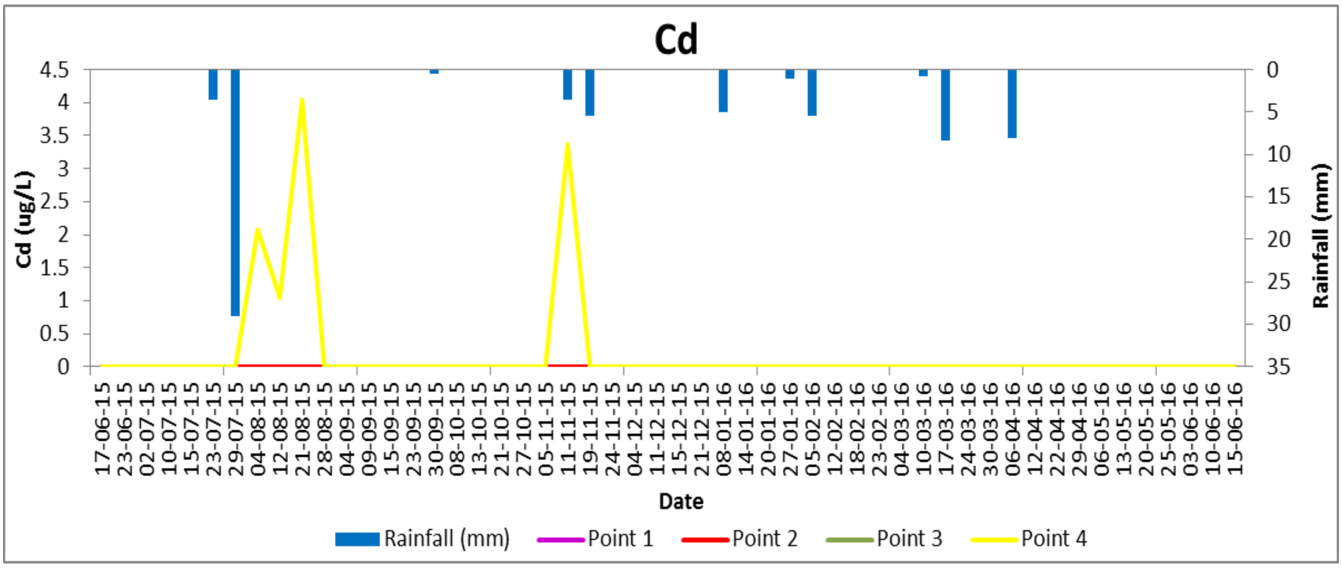

Figure 3.7 Comparison of Cd across sampling points (Permissible Limit: 10 µg/L)

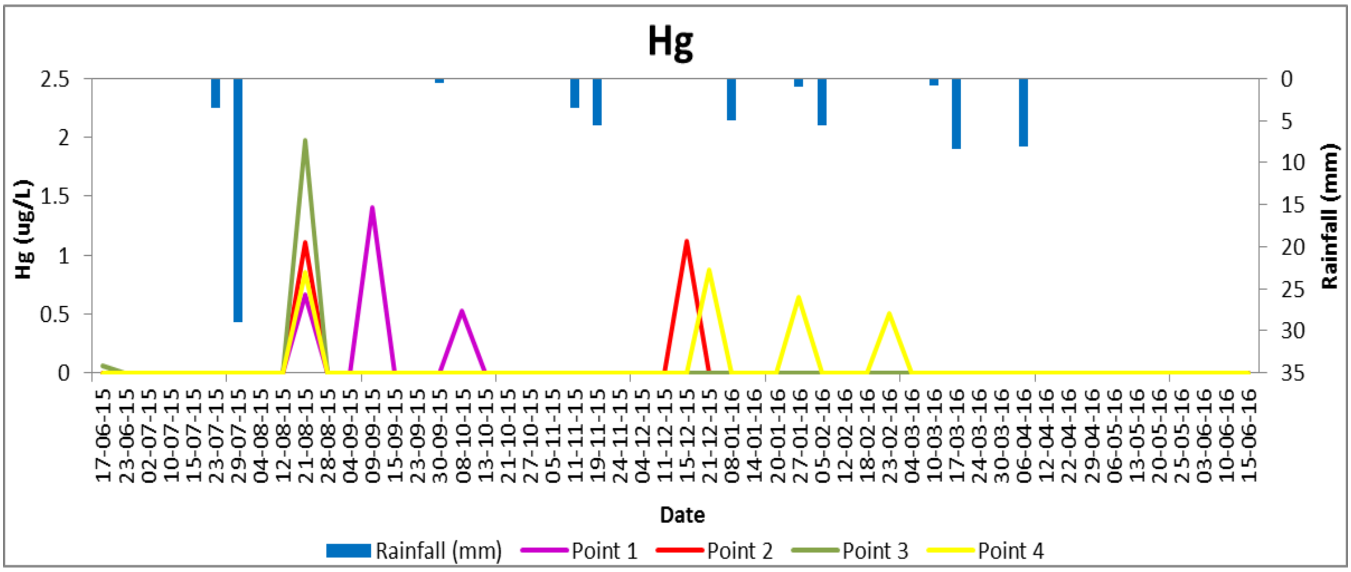

Figure 3.8 Comparison of Hg across sampling points (Permissible Limit: 50 μg/L)

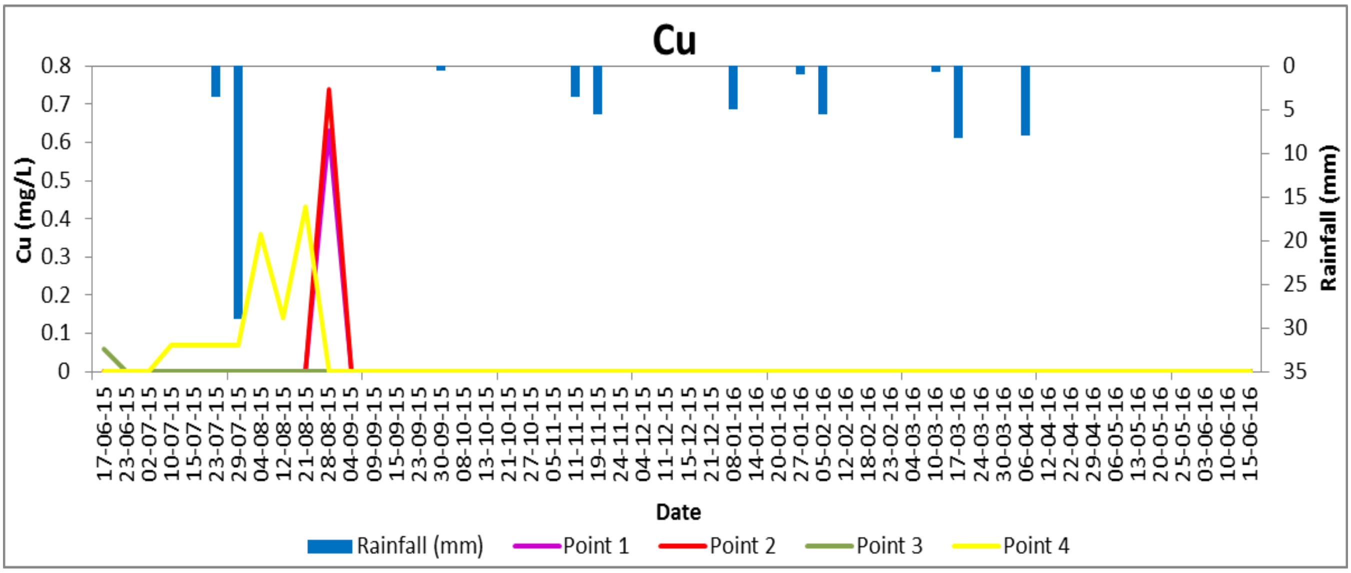

Figure 3.9 Comparison of Cu across sampling points (Permissible Limit: 0.2 mg/L)

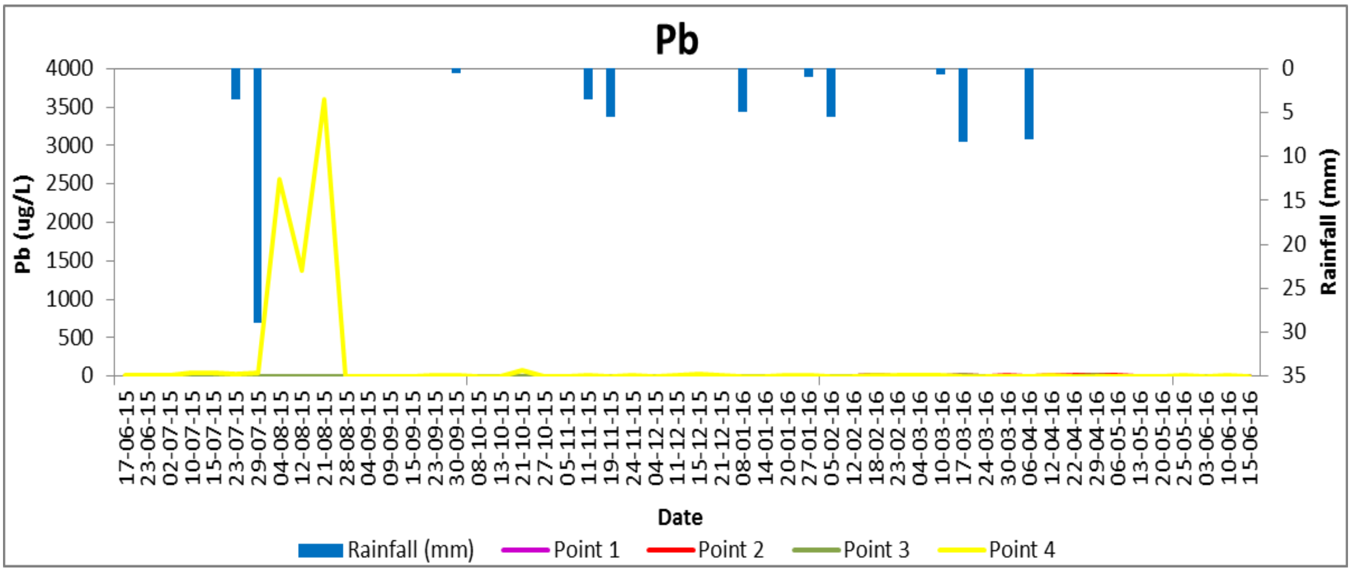

Figure 3.10 Comparison of Pb across sampling points (Permissible Limit: 200 µg/L)

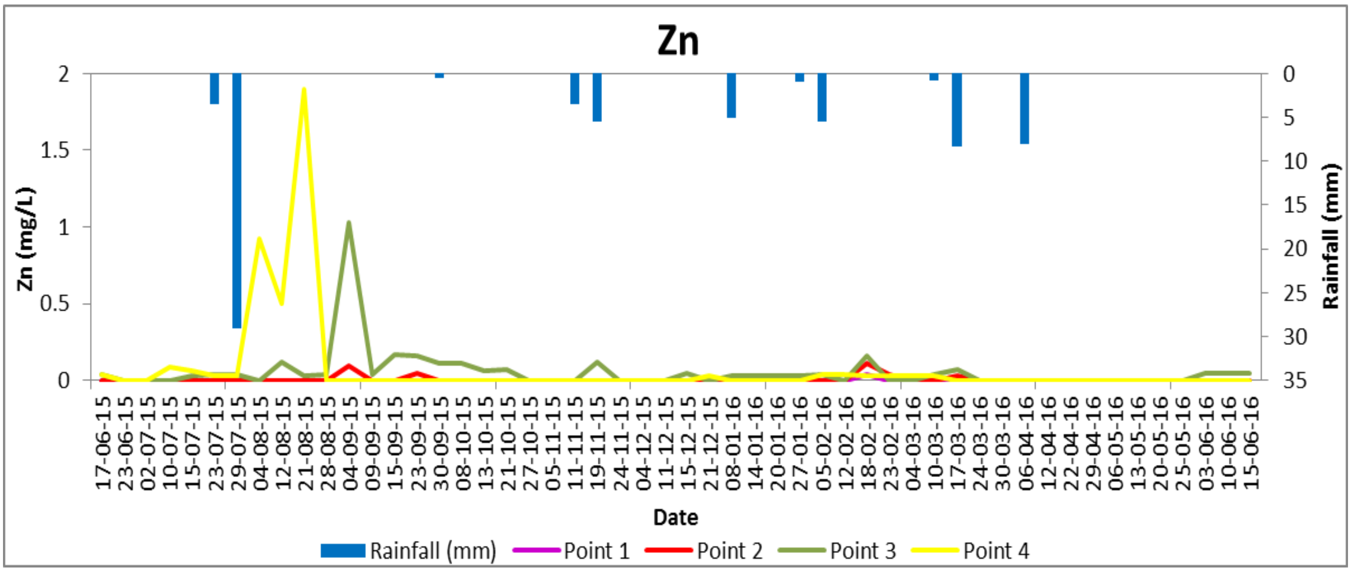

Figure 3.11 Comparison of Zn across sampling points (Permissible Limit: 1 mg/L)

Table 3.3 A summary of the number of heavy metal detections at each sampling point

	As	**Cd**	**Cu**	**Hg**	**Pb**	**Zn**
Point 1	7	0	1	3	2	1
Point 2	7	0	1	2	7	5
Point 3	12	0	1	1	4	28
Point 4	14	4	7	4	27	15

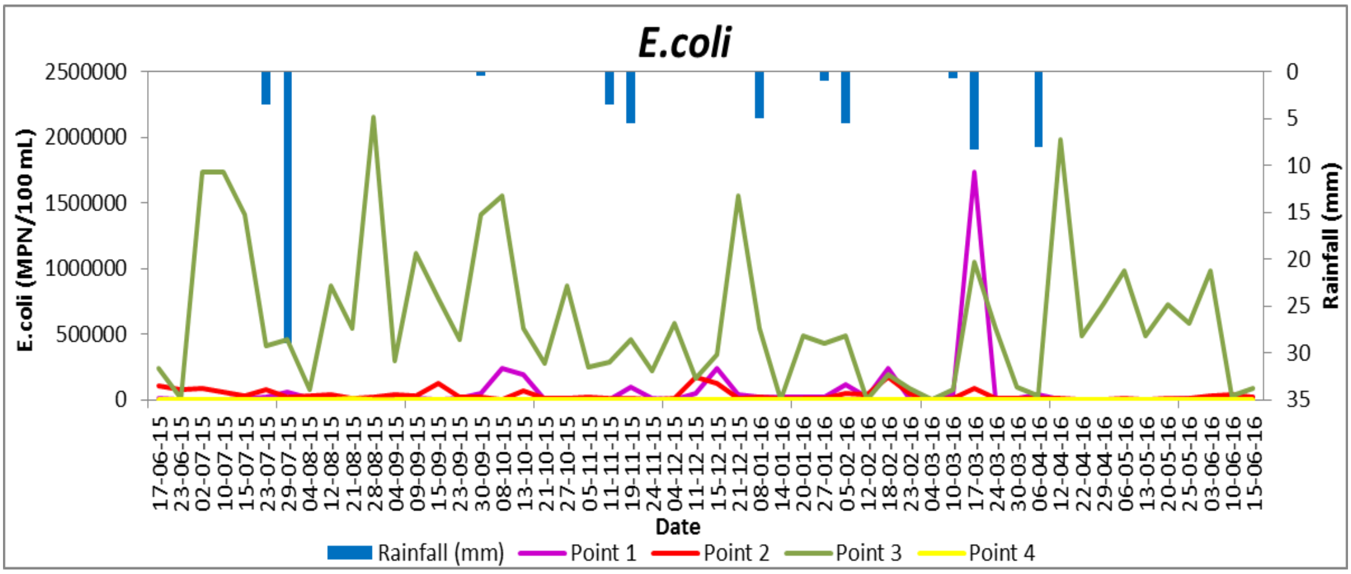

Figure 3.12 Comparison of *E.coli* across sampling points (Permissible Limit: 1000 MPN/100 mL)

3.3.2 Sediment analysis

The total concentration of elements in the Baynespruit river sediment samples for winter and summer are presented in Table 3.4. The sediment results provided by Umgeni Water included limits of detection, which were considered by the laboratory to be the acceptable reporting concentrations for each analysis. The GenStat software does not accept data with limits and was therefore not used to analyse the sediment results. Table 3.4 indicates that the limits of detection for Cd, Cu, Co, Hg, Zn and Ag exceeded the maximum permissible limits (MPL) for elements in freshwater sediments however, the exact concentrations are unknown and may therefore be incomparable with the MPL. Furthermore, the summer analysis for Cu, Co and Ag could not be accredited by Umgeni Water due to analytical issues and caution should be taken when interpreting these results.

There are no sediment quality guidelines derived for South Africa thus, the MPL were adopted from the USA Freshwater Sediment Guidelines (1996). It is important to note that the values represent an average of the six composite samples taken for each analysis at point 2. The analysis for Hg was not conducted for the summer sediment samples due to the failure of analytical equipment and procurement issues experienced by the Umgeni Water laboratory.

Table 3.4 revealed that As, Cr, Ni, Pb, Fe and Mn in sediments were problematic at all three points for both seasons since their concentrations exceeded the respective MPL. The Cu and Ag concentrations exceeded the MPL at all three points in winter only. The Cd and Zn concentrations were only greater than the MPL at point 1 in summer and at point 2 in winter, respectively.

The concentration of As, Fe, Mo, Sb and V was higher at point 2 and 3 in summer however, higher at point 1 in winter. It was found that the concentration Cr, Ni, Pb, Ba, Ca, Na and Se were greater at all three points in summer, whereas the concentration of Cu, VS, TP, Co, K, Mg and Ag was higher at all three points in winter. It was observed that Mn was greater at point 1 and 3 in winter however, greater at point 2 in summer. Overall, the concentration of elements was greater at point 2 and 3 in summer, whereas point 1 had a greater concentration of elements in winter (Table 3.4).

Table 3.4 The total concentration (mg/kg) of elements from the Baynespruit river sediment samples for winter (W) and summer (S) with concentrations exceeding the respective MPL highlighted in yellow

	MPL	Point 1W	Point 1S	Point 2W	Point 2S	Point 3W	Point 3 S	Comment
As	6	21.80	16.50	21.13	24.30	24.60	26.20	As exceeded the MPL at all three points with point 2 and 3 having higher concentrations in summer and point 1 having higher concentrations in winter
Cd	0.6	<2	2.86	<2	<2	<2	<2	Cd exceeded the MPL only at point 1 in the summer
Cr	26	202	351	220.50	654.50	253	699	Cr exceeded the MPL at all three points for both seasons with summer having higher concentrations
Cu	16	9008	<200	6319.50	<200	5809	<200	Cu greatly exceeded the MPL for winter
Hg	0.2	<1	-	<1	-	<1	-	Hg detected in unknown concentrations of <1 mg/kg at all three points in winter.
Ni	16	39.90	62.10	43.37	71.95	40.50	73.20	Ni exceeded the MPL at all three points in both seasons with summer having higher concentrations
Pb	31	51.70	62.90	48.50	48.75	46.50	61.20	Pb exceeded the MPL at all three points for both seasons with summer having higher concentrations
VS	-	5.49	3.37	6.01	3.61	5.53	3.51	VS% was low across all three points but was found to be greater in winter when comparing seasons
TP	600	1343	257	1443.83	336	1481	393	TP exceeded the MPL in winter and recorded below the MPL in summer at all three points
Zn	120	<200	<200	278	<200	<200	<200	Zn exceeded the MPL only at point 2 in winter
Ba	-	205	175419	234.25	139538	<200	126272	Ba was higher in summer at all three points
Ca	-	1402	4697	1531.67	5734.67	941	5551	Ca was higher in summer at all three points
Co	50	21.30	<2	25.03	<2	25.00	<2	Co recorded below the MPL at all three points for both seasons but had a higher detection concentration in winter
Fe	2	117722	91487	108201	154040	123433	152706	Fe exceeded the MPL at all three points for both seasons with point 2 and 3 having higher concentrations in summer and point 1 having a higher concentration in winter
K	-	2988	2736	2972.33	2225	2665	2582	K was higher in winter at all three points
Mg	-	3356	2655	3511.50	3083.83	3102	2826	Mg was greater in winter at all three points
Mn	460	776	713	899.50	924.83	734	673	Mn exceeded the MPL at all three points for both seasons with point 1 and 3 having higher concentrations in winter and point 2 having a higher concentration in summer
Mo	-	3.40	2.49	3.72	3.91	3.20	4.17	Mo was higher at point 2 and 3 in summer but higher at point 1 in winter
Na	-	935	1074	1196	3560.20	955	3396	Na was greater in summer at all three points
Sb	-	2.95	2.46	2.12	2.72	2.19	2.64	Sb was higher at point 2 and 3 in summer but higher at point 1 in winter
Se	-	4.16	5.15	4.41	4.82	4.29	5.67	Se was higher in summer at all three points
V	-	163	143	188.50	213.67	221	254	V is greater at point 2 and 3 in summer and greater at point 1 in winter
Ag	0.5	1780	< 200	2293	<200	418	<200	Ag greatly exceeded the MPL in winter at all three points

3.3.3 Soil analysis

The CRM (ERA 540 Heavy Metals in Soil) experimental concentrations (mg/kg) for Cr, Cu and Zn fell within the certified quality control performance acceptance limits (mg/kg), with Cd and Pb following closely to the respective lower limits (Table 3.5). The recovery (%) values were calculated based on the lower limits of the certified quality control performance acceptance limits, i.e. Recovery (%) = (Experimental Concentration/Lower Limit of Certified Value)*100 (AOAC, 1998). According to AOAC (1998), the accuracy of the methodology was confirmed by the acceptable recovery values, i.e. 80 – 123%.

Table 3.5 Experimental concentrations of heavy metals in the CRM compared to the certified ranges and the respective recovery percentages

Heavy Metal	Experimental Concentration (mg/kg)	Certified Quality Control Performance Acceptance Limits (mg/kg)	Recovery (%)
Cd	97.48	116 - 169	84
Cr	78.28	69.30 - 104	113
Cu	251.23	219 - 317	115
Pb	64.25	80 - 116	80
Zn	130.10	106 - 155	123

The results in Figure 3.13 show the mean concentrations (mg/kg) of Cd, Cr, Cu, Pb and Zn, as well as the standard errors (SE), in the soil of the respective farming sites. A statistical analysis of heavy metal variability in soil was carried out using a general structure treatment ANOVA in GenStat (18^{th} ed.). According to Figure 3.13, Cd ($P<0.001$), Cr ($P=0.035$), Cu ($P<0.001$), Pb ($P<0.001$) and Zn ($P<0.001$) differed significantly between each of the three farming sites. The highest concentrations of Cd (6.97 mg/kg), Cu (79 mg/kg), Pb (442 mg/kg) and Zn (306 mg/kg) were observed at farming site 2, while the lowest concentrations were observed at farming site 3, i.e. Cd (4.20 mg/kg), Cu (6.90 mg/kg) and Pb (1 mg/kg). The concentration of Cr differed significantly ($P=0.035$) with farming site 1 and 3 having the highest (44.30 mg/kg) and lowest (31.50 mg/kg) concentrations, respectively. The maximum permissible limits (MPL) for heavy metals in soils were obtained from WRC (1997). As shown in Figure 3.13, the concentration of Cd, Cu and Zn exceeded the maximum permissible limit (MPL), i.e. 2, 6.6 and 46.5 mg/kg respectively, for heavy metals in soil at all three farming sites. The concentration of Pb exceeded the MPL, i.e. 6.6 mg/kg, at farming site 1 and 2 only. The concentration of Cr was below the MPL, i.e. 80 mg/kg, at all three farming sites.

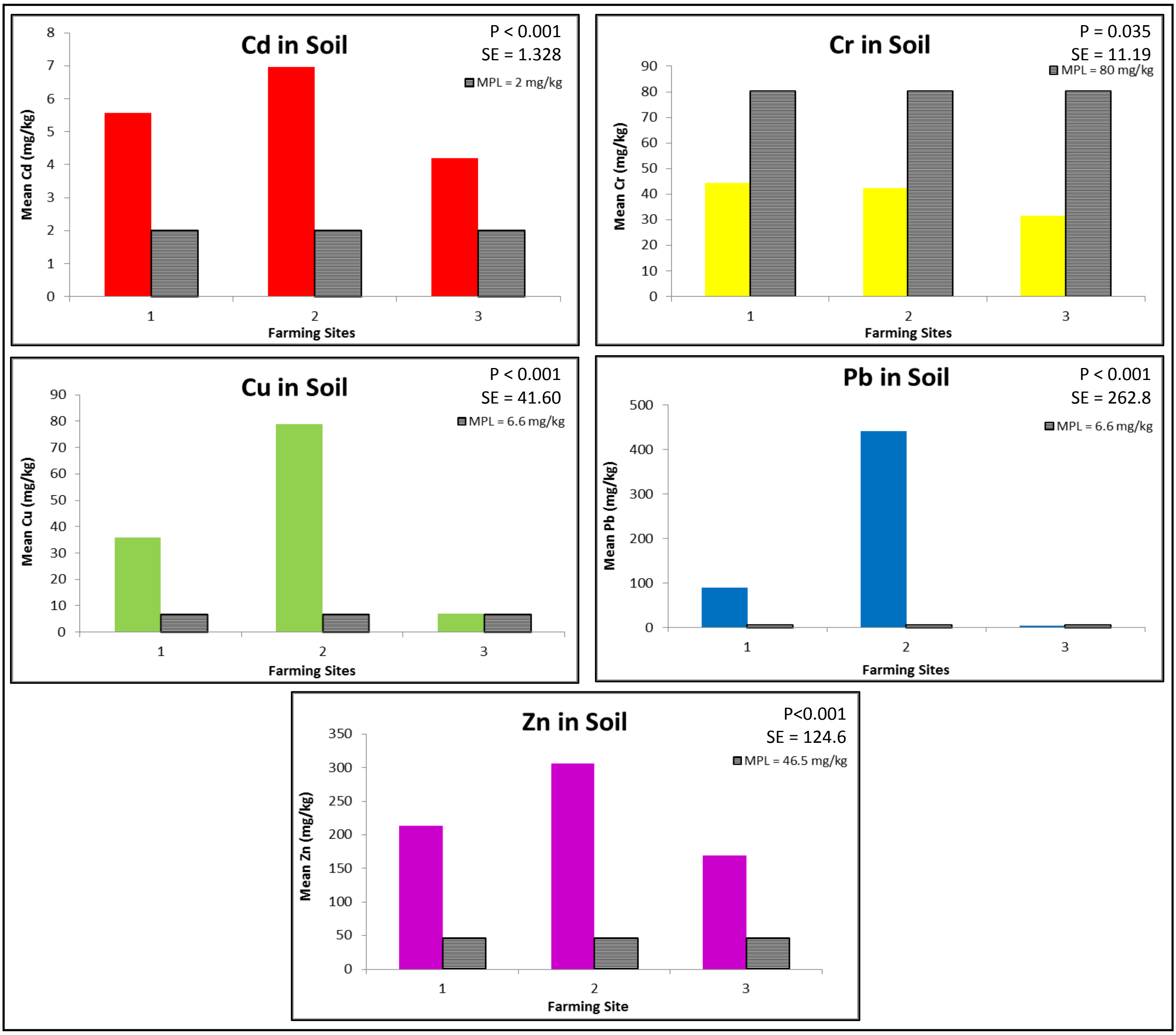

Figure 3.13 Mean concentration (mg/kg) of heavy metals found in the soil at the three farming sites

3.3.4 Crop analysis

The results in Table 3.6 show the mean concentrations of Cd, Cr, Cu, Pb and Zn in spinach, carrots, maize, pumpkin and cabbage. An unbalanced ANOVA design was used in GenStat (18th ed.) to determine the heavy metal variability between different crops. The statistical analysis suggested that the concentrations of Cd, Cr, Cu, Pb and Zn varied significantly ($P<0.001$) between the different crops. Table 3.6 illustrates the MPL of heavy metals in crop according to FAO/WHO (2001) and where concentrations have exceeded the MPL these have been highlighted in yellow.

Table 3.6 indicates that Cd internalization occurred in spinach, carrots and cabbage at concentrations greater than the MPL, i.e. 0.2 mg/kg, whereas the concentrations in maize and pumpkin were below the MPL. The Cr and Pb concentrations in all crops across all farming sites exceeded the MPL, i.e. 0.05 mg/kg and 0.3 mg/kg, respectively. The concentration of Cu in all crops was below the MPL, i.e. 73.3 mg/kg. The concentration of Zn in spinach across all farming sites was above the MPL, i.e. 100 mg/kg. Overall, it can be seen from Table 3.6 that spinach, carrots and cabbage were more favourable to heavy metal internalization than maize and pumpkin.

Table 3.6 The mean concentration (mg/kg) of heavy metals in crops with concentrations exceeding the respective MPL highlighted in yellow

Cd in Crop MPL = 0.2 mg/kg	**Farming Site 1**	**Farming Site 2**	**Farming Site 3**
Spinach	0.26	0.31	0.94
Carrots	0.27	0.58	-
Maize	-	-	0.01
Pumpkin	-	0.04	-
Cabbage	-	-	0.27
Cr in Crop MPL = 0.05 mg/kg	**Farming Site 1**	**Farming Site 2**	**Farming Site 3**
Spinach	0.23	4.42	7.71
Carrots	1.01	5.34	-
Maize	-	-	2.76
Pumpkin	-	0.46	-
Cabbage	-	-	6.26
Cu in Crop MPL = 73.3 mg/kg	**Farming Site 1**	**Farming Site 2**	**Farming Site 3**
Spinach	12.00	8.38	9.62
Carrots	6.15	4.35	-
Maize	-	-	2.36
Pumpkin	-	3.47	-
Cabbage	-	-	5.71
Pb in Crop MPL = 0.3 mg/kg	**Farming Site 1**	**Farming Site 2**	**Farming Site 3**
Spinach	1.89	3.45	0.94
Carrots	3.45	3.76	-
Maize	-	-	1.07
Pumpkin	-	1.54	-
Cabbage	-	-	0.80
Zn in Crop MPL = 100 mg/kg	**Farming Site 1**	**Farming Site 2**	**Farming Site 3**
Spinach	112.22	210.72	209.46
Carrots	54.80	94.18	-
Maize	-	-	39.67
Pumpkin	-	33.53	-
Cabbage	-	-	66.35

The results in Table 3.7 compare the difference of heavy metal internalization by spinach between the farming sites, as well as summer and winter. The standard errors of differences of means (SED) are also displayed in Table 3.7. It is important to note that spinach was used individually for this comparison since it was the only common crop grown across all three farming sites in both summer and winter. A general ANOVA design was undertaken in GenStat (18th ed.) to determine the variability of heavy metal internalization by spinach between the farming sites and the seasons.

The statistical analysis indicated that the concentrations of Cd (P<0.001), Cr (P<0.001), Cu (P<0.001), Pb (P<0.001) and Zn (P=0.055) in spinach were significantly variable across the three farming sites (Table 3.7). The concentrations of Cd (0.942 mg/kg) and Cr (7.710 mg/kg) were the highest in spinach grown at farming site 3 (Table 3.7). The concentration of Cu (12 mg/kg) was the highest in spinach grown at farming site 1 (Table 3.7). The concentrations of Pb (3.450 mg/kg) and Zn (209 mg/kg) were the highest in spinach grown at farming site 2 (Table 3.7). It was found that spinach grown at all three farming sites contained levels of Cd, Cr, Pb and Zn that exceeded the MPL, i.e. 0.2, 0.05, 0.3 and 100 mg/kg, respectively (Table 3.7). The concentration of Cu in spinach was below the MPL, i.e. 73.3 mg/kg, at all three farming sites (Table 3.7).

The statistical analysis showed that the concentrations of Cd (P<0.001), Cr (P<0.001), Pb (P<0.001) and Zn (P<0.001) in spinach differed significantly between the seasons, whereas Cu concentrations (P=0.343) were not significantly different. Table 3.7 shows that the concentration of Cd, Cr and Zn in spinach was highest during the winter, while the Cu and Pb concentrations in spinach presented higher in summer. The concentrations of Cd, Cr, Pb and Zn in spinach exceed the MPL, i.e. 0.2, 0.05, 0.3 and 100 mg/kg, in both summer and winter. It was observed that the Cu concentration in spinach was below the MPL, i.e. 73.3 mg/kg, during both seasons.

Table 3.7 Comparison of the mean concentration (mg/kg) of heavy metals in spinach between farming sites and seasons with exceeding concentrations highlighted in yellow

Farming Site	**Cd MPL = 0.2 mg/kg**	**Cr MPL = 0.05 mg/kg**	**Cu MPL = 73.3 mg/kg**	**Pb MPL = 0.3 mg/kg**	**Zn MPL = 100 mg/kg**
1	0.26	0.23	12.00	1.89	112.00
2	0.31	4.42	8.38	3.45	211.00
3	0.94	7.71	9.62	0.94	209.00
P - value	P<0.001	P<0.001	P<0.001	P<0.001	P = 0.055
SED	0.07	0.61	0.70	0.45	46.60
Season	**Cd MPL = 0.2 mg/kg**	**Cr MPL = 0.05 mg/kg**	**Cu MPL = 73.3 mg/kg**	**Pb MPL = 0.3 mg/kg**	**Zn MPL = 100 mg/kg**
Summer	0.41	1.98	10.27	2.79	105.00
Winter	0.59	6.26	9.73	1.39	250.00
P - value	P<0.001	P<0.001	P = 0.343	P<0.001	P<0.001
SED	0.05	0.50	0.57	0.37	38.00

3.3.5 Experimental pot trial

The results in Figure 3.14 show the mean concentrations (mg/kg) of Cd, Cr, Cu, Pb and Zn in the soil used in the experimental pot trial from the control site and farming sites. The standard errors (SE) are also indicated in Figure 3.14. A statistical analysis of heavy metal variability in soil from the different sites was carried out, using a general ANOVA design in GenStat (18^{th} ed.). According to Figure 3.15, Cd, Cr, Cu, Pb and Zn differed significantly (P<0.001) between each of the soils from the respective sites.

It can be seen from Figure 3.14 that Cd, Cu, Pb and Zn had the highest concentrations at farming site 2, while Cr had the highest concentration at farming site 1. The concentration of Cd exceeded the MPL, i.e. 2 mg/kg, at farming site 1 (4.77 mg/kg), farming site 2 (6.35 mg/kg) and farming site 3 (3.78 mg/kg) however, the concentration in the control soil (1.08 mg/kg) remained below the MPL. The level of Cr was found to be below the MPL, i.e. 80 mg/kg, in all four soils. The concentration of Cu exceeded the MPL, i.e. 6.6 mg/kg, in all four soils. The concentration of Pb exceeded the MPL, i.e. 6.6 mg/kg, in the control soil (8.7 mg/kg), at farming site 1 (80.1 mg/kg) and farming site 2 (289.8 mg/kg), while the concentration at farming site 3 (5 mg/kg) remained below the MPL. The level of Zn exceeded in the MPL, i.e. 46.5 mg/kg, in all four soils. The control soil contained the lowest concentration of heavy metals when compared to the soils of the farming sites (Figure 3.14). The soil results obtained in the experimental pot trial had similar but slightly lower concentrations to the soil results obtained from the field data.

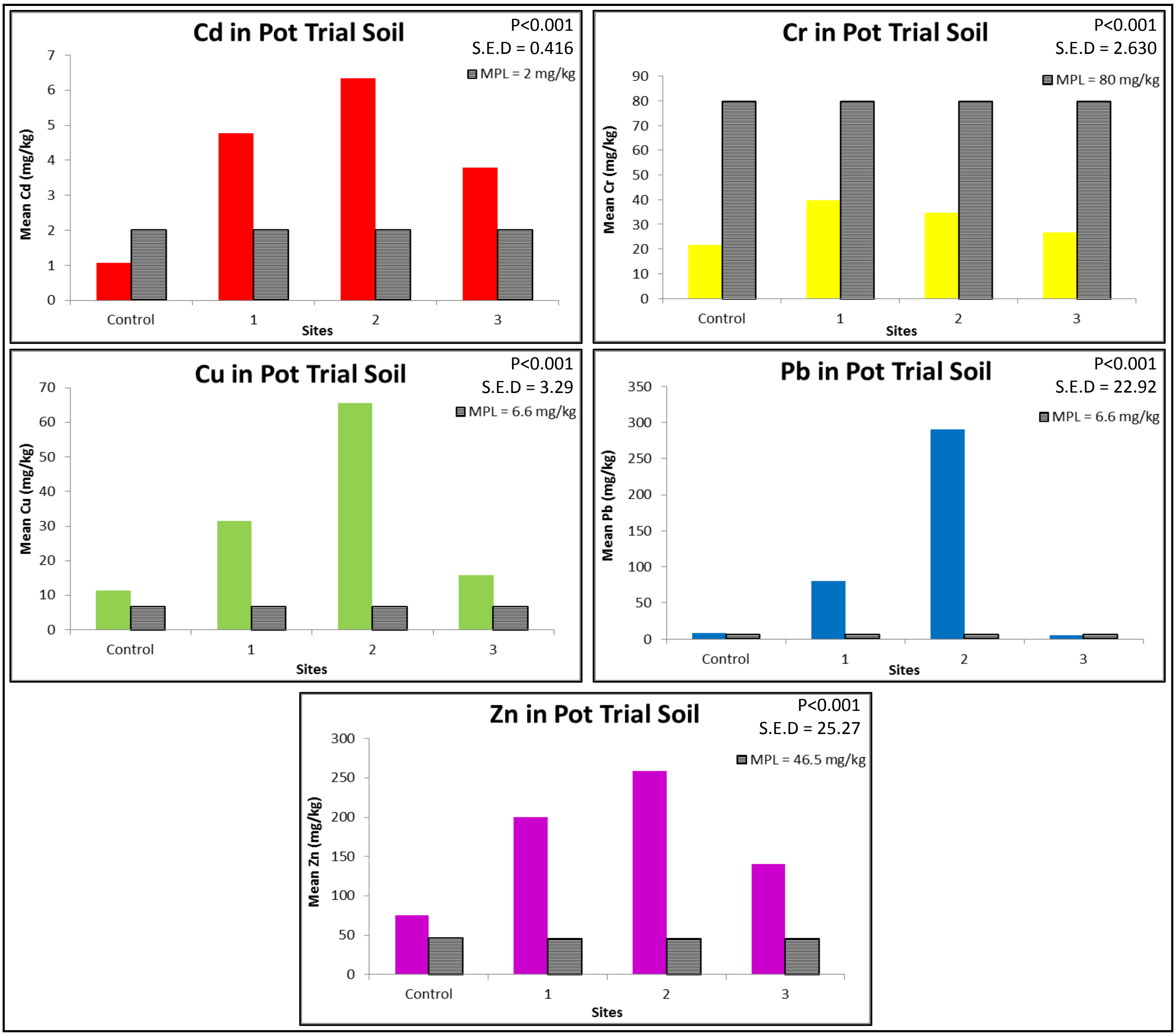

Figure 3.14 The mean concentration (mg/kg) of heavy metals in soil used in experimental pot trial

The soil pH results are summarized in Table 3.8. It is important to note that soil pH_{KCl} was considered over soil pH_w since it is a closer representation to the actual soil solution. Table 3.8 shows that the soil pH_{KCl} was acidic, i.e. below pH 7, across all sites. The values of soil pH_{KCl} in ascending order are as follows: 4.67 (site 3), 5.14 (site 1), 5.46 (control) and 5.81 (site 2).

Table 3.8 Soil pH measured in experimental pot trial

	Control	**Soil - Site 1**	**Soil - Site 2**	**Soil - Site 3**
pH w	6.46	5.85	6.85	5.86
pH KCl	5.46	5.14	5.81	4.67

The results in Figure 3.15 display the mean concentrations of Cd, Cr, Cu, Pb and Zn in spinach, carrots and cabbage in the experimental pot trial, as well the standard errors (SE). A general ANOVA design in GenStat (18^{th} ed.) was used to determine the variability of heavy metals in crops grown on soils from the respective sites. The statistical analysis revealed that the concentration of heavy metals in crops differed significantly ($P<0.001$) across the four different soils.

The concentrations of heavy metals in all crops were below the respective MPL, at the control site (Figure 3.15). The control crops internalized the lowest concentrations of heavy metals when compared to the crops grown at farming site 1, 2 and 3. Figure 3.15 indicates that Cd, Cu and Zn internalized the highest concentrations in spinach, while Cr and Pb internalized the highest concentrations in carrots when comparing crops. It can be observed that when comparing sites, site 3 had the greatest concentration of Cd, Cr and Cu; site 2 presented the highest concentration of Pb and site 1 displayed the greatest concentration of Zn, in crops collectively (Figure 3.15).

The concentration of Cd exceeded the MPL in spinach (site 1, 2 and 3) and cabbage (site 3) (Figure 3.15). It was found that Cr in carrots (site 1, 2 and 3), spinach (site 2 and 3) and cabbage (site 3) exceeded the MPL (Figure 3.15). The concentrations of Pb in spinach and carrots (site 2) as well as carrots (site 3) exceeded the MPL. Figure 3.15 shows that the concentration of Cu and Zn at all four sites in all crops remained below the respective MPL.

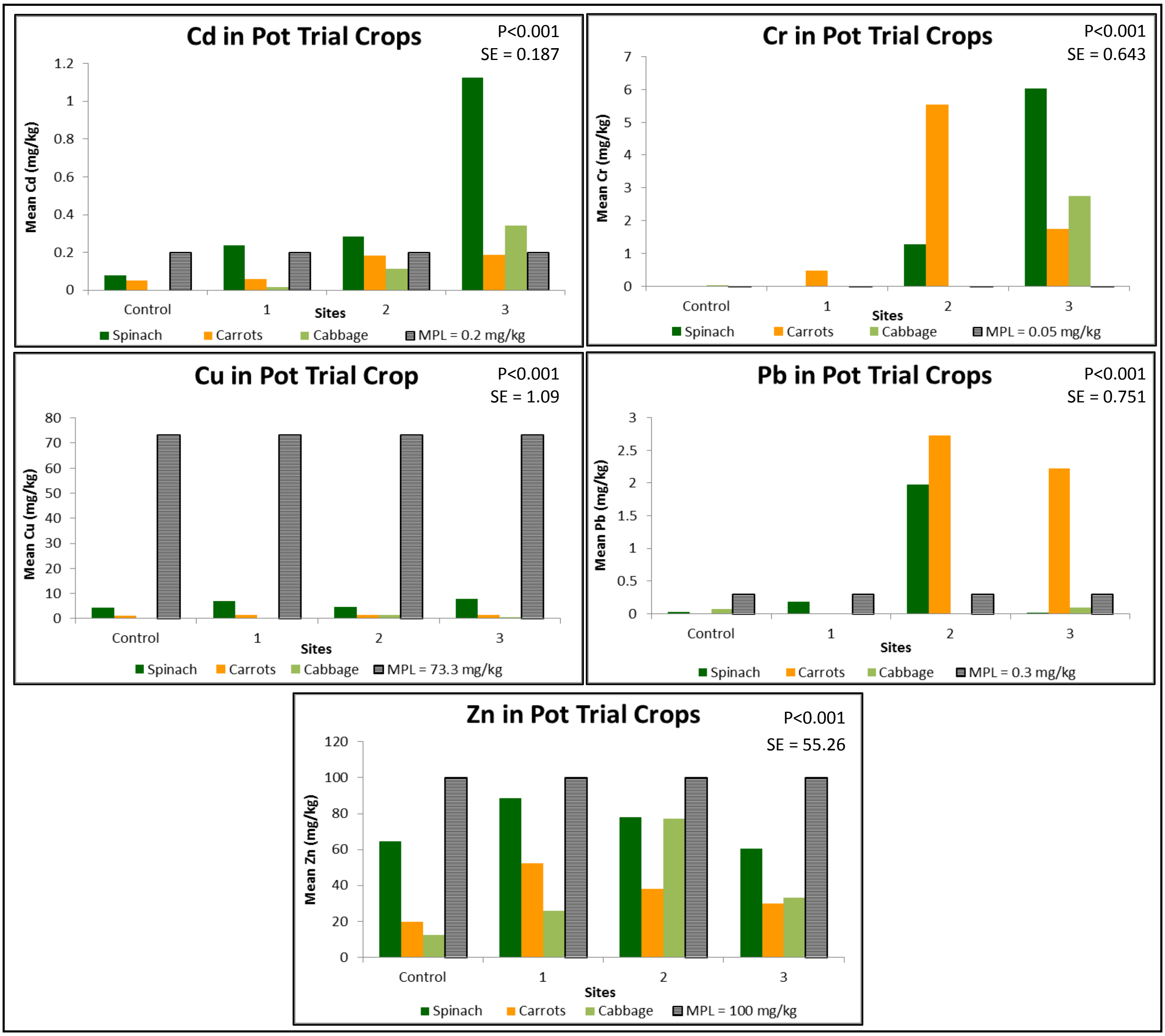

Figure 3.15 The mean concentrations of heavy metals (mg/kg) in experimental pot trial crops

3.4 Discussion

The objectives of this paper were to monitor the water quality of the Baynespruit River by conducting a water quality assessment and sediment analysis of problematic pollutants, as well as determining the effects of these pollutants on soil and crops that were irrigated with water from the river.

The water quality assessment suggested that the majority of the physicochemical constituents, i.e. pH, EC and heavy metals, in the river, were below the maximum permissible limits (MPL) according to the South African Water Quality Guidelines for Crop Irrigation (DWAF. 1996). There were however, sporadic occasions between August and November 2015 where acidic water quality was detected and heavy metal concentrations exceeded the MPL, which may be defined as single pollution events. The frequency of heavy metal detections and the sporadic detections that exceeded the MPL were low, which suggested that long-term heavy metal pollution in the river water was not problematic for the purpose of crop irrigation. The water quality results of the wetland pond indicated high concentrations of EC, whereas pH conformed to the MPL. It was also observed that the wetland pond incurred more heavy metal detections and exceeded the MPL for these more often than in the river. The wetland pond is situated at the bottom of a steep slope containing illegally disposed litter. It is therefore possible that contamination may have originated from this slope through runoff. The *E.coli* greatly exceeded the MPL for crop irrigation throughout the year, at all three points in the river, while the *E.coli* recorded in the wetland pond infrequently exceeded the MPL. The *E.coli* results obtained in the current study corresponded with work conducted by Gemmell and Schmidt (2011), which concluded that the faecal coliform count frequently exceeded the MPL for crop irrigation in the Baynespruit River. It can be confirmed that the reports of broken sewage infrastructure surrounding the Baynespruit River have resulted in severe microbial contamination (Ramburran, 2014).

The sediment analysis revealed that As, Cd, Cr, Cu, Ni, Pb, Zn, Fe, Mn and Ag exceeded the MPL for elements in freshwater sediments according to the USA Freshwater Sediment Guidelines (1996). It must be reiterated that As, Cd, Cu, Pb and Zn that were monitored in the water quality assessment frequently presented in concentrations below the detection limit or occasionally in low concentrations. According to Tshibanda *et al*. (2014), river sediments act as a reservoir for heavy metals and have the ability to accumulate higher concentrations than the surface water, which is apparent in this study. In general, during summer the concentration of elements was highest at the downstream region of the river, i.e. point 2 and 3, this may relate to water quantity and high flows during the wet season, which allows for transportation of elements downstream. During winter however, the concentration of elements was higher upstream, i.e. point 1, which may relate to the decrease in water quantity and low flows associated with the dry season, resulting in low transportation downstream. The water quality assessment showed that the highest number of heavy metal detections above the MPL was found at point 2 and 3, which corresponds to the high concentrations of elements found at point 2 and 3 in the river sediment. A study by Shanbehzadeh *et al*. 2014, observed that where there was an increase in heavy metals in water samples downstream, the concentration of heavy metals in the river sediment downstream increased as well, a situation which is reflected in the present study. The sediment analysis suggested that the routine heavy metals, i.e. As, Cd, Cu, Pb and Zn, as well as other elements, presented as problematic in the Baynespruit River.

The accuracy of the soil results was confirmed by the acceptable recovery values (80 – 123%) retrieved from the CRM. The soil analysis showed that Cd, Cu and Zn presented as problematic by exceeding the MPL for heavy metals in soil at all three farming sites, while Pb exceeded the MPL at farming site 1 and 2 only. The concentration of Cr remained below the MPL at all three sites however, concentrations were still relatively high. In general, the order of highest to lowest concentrations of heavy metals was found at farming site 2, 1 and 3. It must be reiterated that water from the wetland pond was used for irrigation at farming site 2 and the Pb concentrations in this pond were at times well above the MPL, which can be linked to the high concentration of Pb in the soil at farming site 2. The water quality results occasionally detected concentrations of Cu and Zn at point 2 in the river, while the sediment analysis detected very high concentrations of Cd, Cu and Zn at point 2 in the river. These results therefore relate to the high concentrations of Cd, Cu and Zn in the soil at farming site 3, since irrigation for this site is extracted from point 2 in the river. The area of farming site 1 was never irrigated with water from the Baynespruit River however; this site had the second highest concentration of heavy metals in the soil when compared to the others. This suggests that since all three farming sites are located on the primary floodplain of the river, as a result of historical flooding, which mobilized contaminants from river sediments; heavy metal accumulation has occurred in the floodplain soils over time. Ramburran (2014) highlighted that rivers, i.e. the Baynespruit River, within the Msunduzi municipal boundary are vulnerable to flooding. A study by Ciszewski and Grygar (2016) has verified the channel-to-floodplain transfer of heavy metals, whereby flooding mobilized heavy metals that were stored in river sediments and subsequently transported these onto the floodplain, which may be apparent in the current study. Sardar *et al*. (2013) reported that long-term irrigation with polluted water containing low concentrations of heavy metals resulted in the build-up of heavy metals in the soil, which may be plausible in the current study as contaminated irrigation is used at farming sites 2 and 3. It must be reiterated that farming site 2 was last irrigated with water from the Baynespruit River in 2005, which may have resulted in an accumulation of heavy metals in the soil.

The crop analysis indicated that heavy metal internalization occurred in a variety of crops grown across all three farming sites. It was found that elevated concentrations of Cd, Cr, Pb and Zn internalization was more favourable in spinach, carrots and cabbage than in maize and pumpkin when comparing different crops, while Cu was internalized in low concentrations by all crops. These findings correspond with literature which stipulates that spinach, carrots and cabbages are considered hyperaccumulators of heavy metals (Moreno-Jimenez *et al*., 2012; Abah *et al*., 2014; Alia *et al*., 2015). This is due to their broad and leafy crop structures in the case of spinach and cabbages, whereas carrots are considered edible roots which concentrate high levels of heavy metals. An individual comparison of spinach was conducted in order to compare heavy metal internalization across all three farming sites and in both seasons. This comparison showed that spinach grown at farming site 3 contained the highest concentrations of Cd and Cr, which both exceeded the respective MPL for heavy metals in crops. The spinach grown at farming site 2 contained the highest concentrations of Pb and Zn, which also exceeded the respective MPL. The concentration of Cu in spinach grown across all three farming sites was below the MPL. According to Aliyu (2014), crops grown in soils containing elevated concentrations of heavy metals enhance uptake and have high heavy metal content. This phenomenon was observed in the current study where the soil at farming site 3 contained excessive concentrations of Cd, which resulted in high concentrations in spinach. The Cr concentration in the soil at farming site 3 was substantial, i.e. 31.5 mg/kg, even though it was below the MPL, i.e. 80 mg/kg, which resulted in high uptake by spinach. A similar observation can be made at farming site 2 where the Pb and Zn concentrations were excessive in the soil, resulting in elevated uptake in spinach. The concentration of Cu in spinach grown across all three farming sites was below the MPL, even though the concentration of Cu in soil exceeded the MPL. However, as alluded to above, none of the crops grown on any of the three farming sites internalized extreme concentrations of Cu. The comparison of heavy metal internalization in spinach between summer and winter suggested that Cd, Cr and Zn had the greatest concentrations in winter. It was observed that Pb and Cu had the highest concentrations in summer. The concentrations of Cd, Cr, Pb and Zn exceeded the respective MPL in both seasons, with Cu remaining below the MPL in both seasons.

The experimental pot trial was conducted in order to include a control site away from the floodplain of Baynespruit River. The control soil contained the lowest concentration of heavy metals when compared to the soils of the farming sites. The soil results obtained in the experimental pot trial had similar trends but slightly lower heavy metal concentrations to the soil results obtained from the field data. It was determined that the soil pH from the all four sites were acidic, which suggests that the heavy metals in the soil are bioavailable to crops. The concentrations of heavy metals in all crops were below the respective MPL for the control soil. This was expected considering the extremely low concentrations of heavy metals found in the soil. The control crops internalized the lowest concentrations of heavy metals when compared to the crops grown at farming site 1, 2 and 3. The concentration of Cd exceeded the MPL in spinach (site 1, 2 and 3) and cabbage (site 3). It was found that Cr in carrots (site 1, 2 and 3), spinach (site 2 and 3) and cabbage (site 3) exceeded the MPL. The concentrations of Pb in spinach and carrots (site 2) as well as carrots (site 3) exceeded the MPL. It was observed that the concentration of Cu and Zn at all four sites in all crops remained below the respective MPL. The pot trial crops followed similar trends to the field crops, in terms of exceeding the MPL at specific sites. The experimental pot trial confirmed that the farming sites situated on the floodplain of the Baynespruit River are contaminated by heavy metals. This allowed for high uptake mostly by spinach, carrots and cabbage, whereas the control site, which was not contaminated, accordingly produced crops without heavy metal contamination.

3.5 Conclusion

The water quality of the Baynespruit River presented as problematic with regards to *E.coli* contamination. There were infrequent low concentrations of heavy metals detected, i.e. As, Cu, Hg, Pb and Zn, with sporadic detections of Cu and Pb pollution events, as well as acidic water, which suggested that these did not result in long-term toxicity of surface water. The majority of the water quality results, excluding *E.coli*, conformed to the South African Water Quality Guidelines for Crop Irrigation throughout the year. The water quality of the wetland pond was found to be a concern since heavy metals and high measurements of EC were detected more frequently than in the river. While the water quality assessment suggested that the routine heavy metals were not problematic in the river, the sediment analysis stipulated otherwise, presenting As, Cd, Cr, Cu, Ni, Pb, Zn, Fe, Mn and Ag in high concentrations, possibly reflecting historical events. In essence, the contaminants residing in the river sediment may contribute to water quality degradation. The soil and crop analysis showed high heavy metal internalization, not only at the farming site irrigated with water from the river but across all three farming sites on the floodplain of the river. These findings were confirmed by the experimental pot trail which also included a control site away from the farming sites showing minimal or no heavy metal contamination. This may imply that the floodplain has been compromised, due to historical flooding, which allowed the accumulation of heavy metals in soils through channel-to-floodplain transfer. Long-term irrigation with water from the river and wetland pond, which contain low concentrations of heavy metals, may have also contributed to the build-up of heavy metals in the respective farming sites. Ultimately, this paper has concluded that the water quality of the Baynespruit River has been compromised by *E.coli* and heavy metals. Furthermore, this poor water quality has contributed to high concentrations of heavy metals in the soil and crops grown in the Sobantu community, all of which may have the potential to adversely affect human health. Accordingly, a key recommendation from this paper would be to establish a link between the poor water quality of the Baynespruit River and the health of the Sobantu community.

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4. ESTABLISHING A LINK BETWEEN THE WATER QUALITY OF THE BAYNESPRUIT RIVER AND THE HEALTH OF THE SOBANTU COMMUNITY

Govender, J.[1]; Stuart-Hill, SI.[1] and Jewitt, GPW[1]

[1]Centre for Water Resources Research, University of KwaZulu-Natal, Pietermaritzburg, South Africa

ABSTRACT

The use of polluted river water by impoverished communities in South Africa is a common occurrence. The Baynespruit River, in the province of KwaZulu-Natal, South Africa, serves as a vital water source to the Sobantu community for crop irrigation and other activities. However, poor water quality in the Baynespruit River has been reported, which may pose health threats to the Sobantu community. Thus, the objective of this study was to determine the exposure pathways of the Sobantu community to the river, as well as gain insight into the potential health issues faced by the community as a result of such exposure. A workshop was held in the Sobantu community which included a questionnaire and separate open-ended conversations with various community members to determine the exposure pathways to the river and the associated health issues of participants. The workshop and open-ended conversations indicated that the most common exposure pathways to the river included using river water for crop irrigation, consuming irrigated crops, washing clothes and children swimming in the river. Additionally, many cases of skin rashes were highlighted, as result of being in direct contact with river water, with one reported case of diarrhoea. The persistence of heavy metals in the Baynespruit River and its surrounding environment gave rise to an experiment where urine from 20 volunteers from the community that have been exposed to the river water, sediments, soil or crops irrigated from it, was analysed and compared to a control sample from outside of the community. This analysis used microwave digestion and ICP-OES to determine whether highly exposed community members incurred heavy metal toxicities. The urine analysis did not show any severe cases of heavy metal toxicities to exposed volunteers. The exposed volunteers that presented high levels of Pb could not be attributed to exposure to the Baynespruit River and/or its surrounding environments, since similar levels of Pb were found in control volunteers. It was therefore unclear as to whether the health of the exposed people of Sobantu was compromised by heavy metal toxicities. The persistent mention of skin rashes in the questionnaire and open-ended conversations suggested that perceived water-related health issues in the community require further investigation. This paper concluded that there were many exposure pathways to the Baynespruit River, however, a clear link between the polluted river water and health issues of people could not be established. Accordingly, a key recommendation would be to establish a health monitoring programme for people who are exposed to the Baynespruit River, in order to clearly define their associated health issues.

Keywords: water quality; exposure pathways; community health

4.1 Introduction

Worldwide, rivers serve as a lifeline to many rural and urban communities without access to potable water (Malik *et al*., 2014). These vital water sources may be used for domestic, irrigation and recreational purposes (Obi *et al*., 2002). There are however, many anthropogenic stressors, which have degraded the water quality of rivers throughout the world (Behmel *et al*., 2016). A lack of alternative water sources, results in a significant reliance on such rivers by rural and urban communities, which raise concerns for human health (Atibu *et al*., 2013).

In South Africa, the absence of service delivery from municipalities has resulted in limited to no potable water supplies in many rural and urban communities (Rivett *et al*., 2012). The use of river water for their daily needs of these communities is therefore of paramount importance. However, the water quality of numerous rivers in South Africa has declined, amongst other reasons, due to the influx of industrial effluents, agricultural practices, illegal dumping and leaking sewers (Gemmell and Schmidt, 2011; Ramburran, 2014). Thus, the health of communities may be threatened, by virtue of their inevitable interactions with contaminated rivers (Singh and Lin, 2014).

The increase of anthropogenic activities in catchments has introduced contaminants such as heavy metals and pathogens into rivers (Drechsel *et al*., 2010; Drechsel and Keraita, 2014).

The most toxic heavy metals to human health are Arsenic (As), Cadmium (Cd), Mercury (Hg) and (Lead) Pb (Lokeshappa *et al*., 2012). These and other heavy metals may cause organ damage, physical impairments, skin irritations, bone deficiencies and a variety of additional health impacts (Oti and Nwabu, 2013). The most harmful pathogens to humans, that may be present in polluted rivers, include *E.coli*, *Salmonella*, *Vibrio*, Hepatitis A Virus, Ascaris lumbricoides, *Giardia lamblia* and *Cryptosporidium parvum* (Olaolu *et al*., 2014). The health impacts associated with pathogens consist mainly of diarrhoea, vomiting and nausea (Odonkor *et* al., 2013; Olaolu *et al*., 2014).

There are different, i.e. direct and indirect, exposure pathways to contaminated river water that may affect human health. Direct exposure involves activities such as drinking, swimming and water collection for irrigation or domestic use (Drechsel *et al*., 2010; Drechsel and Keraita, 2014). Indirect exposure includes consumption of crops and interaction with soil that has been irrigated with polluted water (Drechsel *et al*., 2010; Abakpa *et al*., 2013). It is therefore important to investigate the likely exposure pathways when linking water quality and human health.

The Baynespruit River is one of the most polluted rivers in South Africa, due to illegal effluent discharges, sewage discharges, land degradation and illegal dumping. The Sobantu community interacts with the Baynespruit River through various activities, making this case suitable to investigate the potential links between poor water quality and human health. The objectives of this paper are (1) to determine how members of the Sobantu community are exposed to the Baynespruit River and (2) to gain insight into the health threats faced by the community should they be subject to prolonged exposure. The information generated from this paper may prove useful to decision-makers who aspire to rehabilitate the Baynespruit River, not only for legal compliance but for the well-being of its surrounding communities.

4.2 Methodology

4.2.1 Study area

The Baynespruit River is a tributary of the Msunduzi River, located in Pietermaritzburg, KwaZulu-Natal (Figure 4.1). The land uses surrounding the river consist of numerous trade effluent regulated industries, as well as high-density formal and informal residential areas.

The Sobantu community comprises of formal and informal residential areas and is located toward the lower reaches of the Baynespruit River (Figure 4.1). The informal settlements of Sobantu, consisting of approximately 100 people, are established on the floodplain of the river and furthermore, farmers, i.e. from both the formal and informal communities, utilise this floodplain for agriculture. The Baynespruit River serves as a source of irrigation for subsistence and small-scale market farming sites. The Sobantu community consumes crops irrigated with river water and interact with the river through various activities.

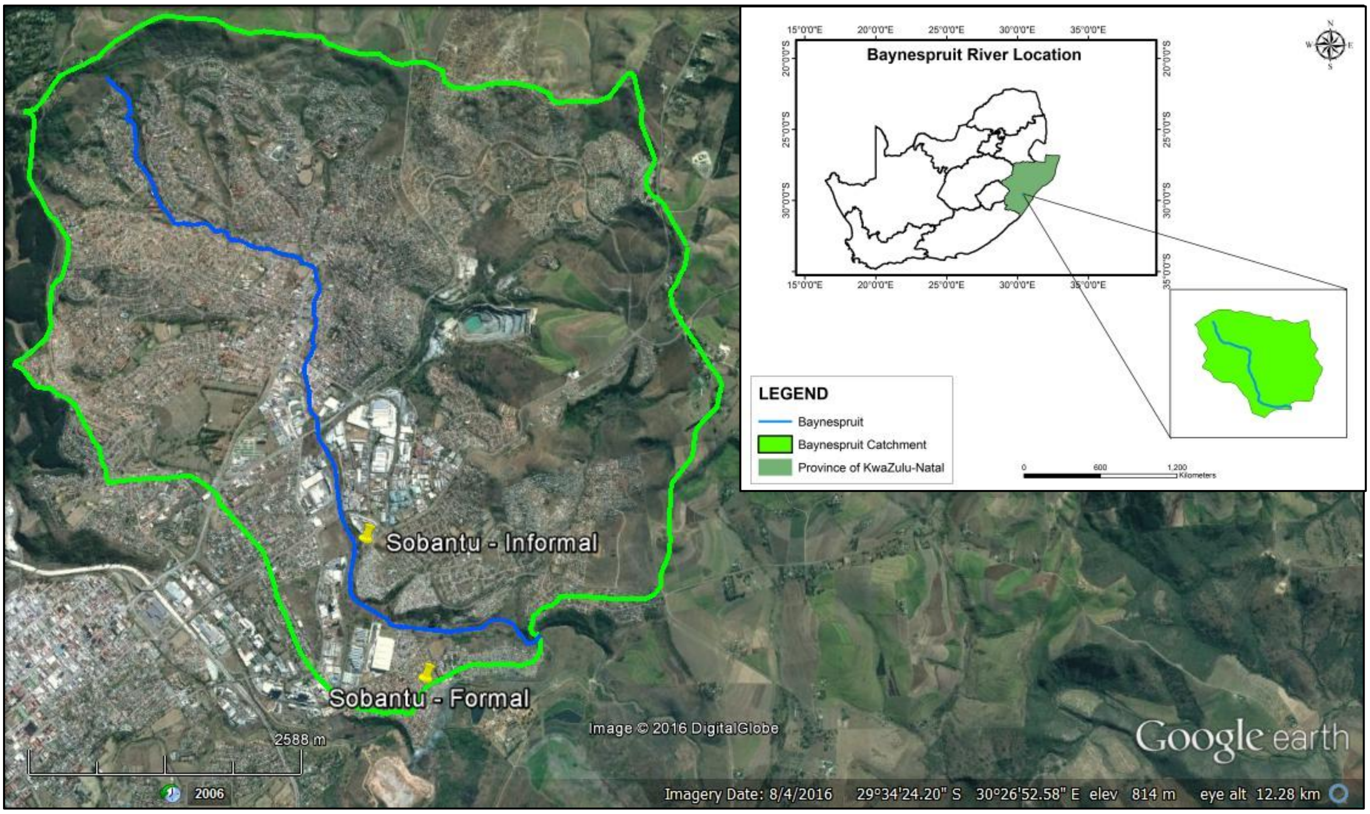

Figure 4.1 Location of the Baynespruit River and Sobantu community in the Baynespruit Catchment, South Africa

4.2.2 Data informing the study

The outcomes, i.e. water quality, river sediment, soil, crop and experimental pot trial results, from Govender *et al*. (2016) (*cf.* chapter 3) were adapted to relate to human health in the present study. All site characteristics, field work, experimental designs and data acquisitions related to achieving these outcomes has been previously described by Govender *et al*. (2016)

(*cf.* chapter 3). A summary table of the aforementioned results was therefore produced in Table 4.1. This is then the departure point for the methodology in this paper to gain insight into exposure pathways of the Sobantu community to contaminated water, soil and/or crops. It must be noted that the comparison of water quality results against SANS 241-1: Drinking Water (2015) was not carried out by Govender *et al*. (2016) (*cf.* chapter 3) nevertheless; this comparison will be illustrated in Appendix B and explained in Table 4.1.

According to Govender *et al*. (2016) (*cf.* chapter 3) the water quality of the Baynespruit River was shown to be unsafe for crop irrigation with regard to *E.coli* contamination, whereas the infrequent acidic and heavy metal pollution events were seen as unproblematic (Table 4.1). It can be seen from Appendix B that all constituents, except for *E.coli* in the river, conformed to the drinking water quality guidelines, whereas As, Cd and Pb occasionally presented unsafe concentrations in the wetland pond. The sediment analysis indicated that a variety of heavy metals were found in excessive concentrations, which confirms that the river sediment acts as a reservoir of pollution, thereby have the potential to degrade water quality (Table 4.1). Govender *et al*. 2016 reported that all farming sites contained heavy metal contamination in the soil, especially those irrigated with water from the river and nearby wetland pond. According to Govender *et al*., 2016 (*cf.* chapter 3), it is possible that these floodplain farming sites may have been previously contaminated through historical flooding, where contamination stemmed from heavy metals reserved in the river sediment. A crop analysis showed elevated concentrations of heavy metals in spinach, carrots and cabbages, which are often consumed by community members (Table 4.1). It was therefore concluded that the Baynespruit River and its surrounding environment has been contaminated with heavy metals (Govender *et al*., 2016) (*cf.* chapter 3). The outcomes of that study provide substantial motivation to further investigate the exposure pathways of the Sobantu community, to this environment, and ultimately determine whether these persistent heavy metals pose a threat to human health. The following section will focus on outlining the exposure pathways to the poor water quality of Baynespruit River and its surrounding environment.

Table 4.1 Summary of outcomes from Govender *et al*. (2016) used to justify the methodology in Chapter 4

Outcome	Comment
Water Quality	Comparison against South African Water Quality Guidelines for Crop Irrigation (DWAF, 1996): *E.coli* always exceeded the maximum permissible limit (MPL), i.e. 1000 MPN/100 mL. The heavy metals, i.e. Arsenic (As), Cadmium (Cd), Copper (Cu), Mercury (Hg), Lead (Pb) and Zinc (Zn), conformed to the respective guidelines, with occasional pollution events of Cu and Pb exceeding 0.2 mg/L and 200 µg/L, respectively. Acidic water, i.e. pH below 6.5, was also sporadically detected. The water quality of the wetland pond showed frequent detections of low concentrations of heavy metals, which were below the MPL, however, Cu, Pb and Zn were occasionally found in concentrations exceeding 0.2 mg/L, 200 µg/L and 1 mg/L, respectively. EC measurements frequently exceeded the MPL of 40 mS/m in the wetland pond, while the *E.coli* count infrequently exceeded the MPL. Comparison against SANS 241 - 2015 Drinking Water Quality Guidelines (Appendix B): The water quality of the river conformed to the drinking water quality guidelines with respect to pH, EC and the aforementioned heavy metals however, the *E.coli* count presented as unsafe, i.e. exceeding 0 MPN/100 mL. The water quality of the wetland pond showed that As, Cd and Pb occasionally exceeded the MPL of 10 µg/L, 3 µg/L and 10 µg/L, respectively. In essence, the water quality of the Baynespruit River is mainly degraded due to *E.coli* contamination.
River Sediment	The sediment analysis suggested that As, Cd, Cr, Cu, Ni, Pb, Zn, Fe, Mn and Ag exceeded the limits for heavy metals as stipulated in the freshwater sediment guidelines according to USA Freshwater Sediment Guidelines (1996), thereby having the potential to degrade water quality.
Soil	The soil analysis indicated that Cd, Cu, Pb and Zn were found in concentrations that exceeded the MPL for heavy metals in soils according to WRC (1997), while Cr was found below the MPL however in substantial concentrations. Thus, heavy metal contamination in farming soils was evident.
Crop	The crop analysis showed that spinach, carrots and cabbages internalized concentrations of Cd, Cr, Pb and Zn at levels that exceeded the MPL for heavy metals in crops according to FAO/WHO (2001).
Experimental Pot Trial	The experimental pot trial corresponded to the soil and crop results found in the field samples, which expressed heavy metal contamination in both soil and crops above respective MPL.

4.2.3 Determining exposure pathways to the Baynespruit River

A workshop was held in the Sobantu community, in December 2015, to gain insight into understanding the possible exposure pathways to members of the community to the Baynespruit River. Firstly, ethical clearance from the University of KwaZulu-Natal

Humanities and Social Sciences Research Ethics Committee had to be obtained prior to engaging with the community (Appendix C). DUCT[g] (Duzi uMngeni Conservation Trust) were invited to the workshop since they work closely with community farmers and are aware of people's interactions with the river, which was how participants were identified and approached to partake in the workshop. All participants had the option of rejecting the offer to partake or withdraw from the workshop at any stage. It was made clear to all participants that their identities would remain anonymous should they agree to participate. A sample size of 50 participants, i.e. half of the approximated informal population, was intended for the workshop based on an estimate given by DUCT of how many people could be using river water. The workshop included a questionnaire the objective of which was to determine the exposure pathways of people to the poor water quality of the Baynespruit River and how this exposure may be linked to their health (Table 4.2). Home visits were conducted to distribute the questionnaire which addressed both males and females of different ages, in order to gain a representative perspective of the community. The questionnaire was available in isiZulu and translators were also present for the open-ended conversations in order to accommodate isiZulu-speaking participants. This study also included open-ended conversations, between January 2016 and August 2016, with members of the community who did not want to fill out a questionnaire but had useful information to share regarding their observations, opinions and/or interactions with the river.

Table 4.2 Questionnaire provided to the Sobantu community to determine their interactions with the Baynespruit River and associated health impacts

Questionnaire
What do you use river water for?
How long have you been using this water source for?
Have you experienced any health issues from using river water?
Can you describe the health issue/s you have experienced?

[g] DUCT – A local organization that actively engages in river health projects, i.e. including the Baynespruit River, as well as collaborates with communities in order to raise awareness and make a difference to the health of their rivers.

4.2.4 Urine analysis

4.2.4.1 Volunteers

Urine testing has been applied as an indication of the extent to which one may be exposed to heavy metal contaminated river water, soil and/or crops (Adotey *et al*., 2011). Prior to conducting the urine analysis in this study, ethical clearance was granted by the University of KwaZulu-Natal Biomedical Research Ethics Committee (Appendix D). The urine analysis included some participants from the workshop, as well as other highly exposed community members who were unavailable for the workshop but were willing to volunteer. It is important to note that ethical clearance allowed for minors to participate in the urine analysis, only if the minor was willing and their parent/guardian signed a consent form on their behalf. The sample size was not predetermined as volunteers had the option of rejecting the offer to partake in the study or withdraw from the study at any stage. The urine analysis only considered participants that were highly exposed to the Baynespruit River. The inclusion criteria for high exposure encompassed: direct exposure, i.e. collecting water for crop irrigation, swimming and washing clothes, as well as indirect exposure, i.e. consuming contaminated crops and coming into contact with contaminated soil in the farming fields. The control group was initially meant to include volunteers from the formal Sobantu community however; many people rejected the offer to participate in the study. It was thereafter decided that students from the University of KwaZulu-Natal (UKZN) and Athlone Primary School, who reside in Pietermaritzburg, would be considered as the control group. Each volunteer was required to complete a questionnaire which addressed the following: gender, age, type of exposure, smoker, alcohol consumption, last meal, time residing in the community and occupation, which may be useful when interpreting the urine analysis results.

4.2.4.2 Urine collection

The National Health Laboratory Service Handbook (NHLS) (2015) was employed to obtain the procedure for random urine collection. In the case of the Sobantu volunteers, this was the most appropriate type of collection, which suited their daily routines. Furthermore, a 24-hour urine collection was disregarded in this study, due to the likelihood of sample contamination. The urine collection was conducted over two days to accommodate all volunteers, i.e. once during a weekday and once during a weekend, between 8.30 and 10.30 am, in the privacy of the volunteer's home. A 50 mL sterile plastic container was provided to each volunteer, which was supplied by Lancet Laboratory. It must be noted that one urine sample was collected from each volunteer. After collection, the specimens were transported directly to UKZN, Pietermaritzburg for microwave acid digestion.

4.2.4.3 Urine acid digestion

A closed vessel Mars 6 microwave instrument was used to digest the urine samples. The Mars 6 microwave contained a built-in methodology for digesting human urine, which was adopted for the current analysis. This methodology was approved by a medical scientist from the National Health Laboratory Service – Inkosi Albert Luthuli Central Hospital – Chemical Pathology Department, who has experience in testing urine for heavy metal toxicities and has previously adopted a similar method (Zain Warasally, pers. communication, 2015). The preparation for digestion began by using triplicates of each urine sample. All polymetric microwave vessels were washed with detergents and rinsed in nitric acid (55%) prior to digesting. The built-in digestion methodology called for 4 mL of urine, 4 mL of nitric acid (55%) and 2 mL of hydrogen peroxide (30%) to be added into each vessel. The digested extracts were transferred through funnels into 25 mL volumetric flasks, which were made up to volume, i.e. 25 mL, with distilled water and thereafter decanted into 50 mL glass bottles to be stored in a fridge. All samples were filtered through 0.45 μm filters into 15 mL plastic ICP vials prior to ICP-OES analysis.

4.2.4.4 Urine analysis (ICP-OES)

The urine samples were analysed using ICP-OES for Cd, Cu, Cr, Pb and Zn at UKZN School of Chemistry, Westville. The aforementioned heavy metals were highlighted as problematic in the water quality (excluding Cr), sediment, soil and crop analyses. In particular, some heavy metals were found in elevated concentrations in different media. This substantiated the need for these heavy metals to be analysed in the urine samples, which may link the contamination of the Baynespruit River and its surrounding environment to the health of the people exposed to it. The ICP-OES calibration procedure utilised 1000 ppm stock standards (Cd, Cr, Cu, Pb and Zn) supplied by Merck. A multi-element set of five standard solutions were produced by diluting each stock with nitric acid (2%). The calibration standards were based on the reference ranges of the heavy metals of interest, which were obtained from the Mayo Clinic online database (Mayo Clinic, 2016a; Mayo Clinic, 2016b; Mayo Clinic, 2016c; Mayo Clinic, 2016d; Mayo Clinic, 2016e). Thus, the calibration standards were as follows (mg/L): 0.001, 0.0025, 0.625, 1.25 and 3.125 for Cd, Cu, Cr, Pb and Zn. Furthermore, a calibration blank was used which consisted of nitric acid (2%). Lastly, a reagent blank was prepared which consisted of a digestion of 4mL nitric acid (55%) and 2mL hydrogen peroxide (32%), which was diluted to volume (25mL) using distilled water. The ICP-OES operating conditions have been displayed in Appendix A.

4.3 Results

4.3.1 Exposure pathways to the Baynespruit River

The results from Table 4.3 were derived from the workshop questionnaire and open-ended conversations conducted in the Sobantu community. The sample size of the questionnaire consisted of six participants, whereas 12 participants contributed through open-ended conversations. It is evident from Table 4.3 that crop irrigation, consuming irrigated crops, washing clothes and children swimming were the most common exposure pathways to the polluted water of the Baynespruit River. According to Table 4.3, the direct exposures included collecting water for crop irrigation and/or domestic cleaning, swimming, washing clothes, bathing and walking barefoot to cross the river, whereas indirect exposure included consuming irrigated crops and coming into contact with polluted soils that have been irrigated. The duration to which most people were exposed to the river was substantial, i.e. more than a year, as seen in Table 4.3. A common health issue noted was skin rashes, which was a consequence of direct contact with river water, such as collecting water for crop irrigation, washing clothes and swimming. Figure 4.2 provides images to supplement the statements provided by participants who contributed through open-ended conversations, especially the type of rash developed by a woman, as a result of washing clothes in the river. There was also mention of one case of diarrhoea, due to the frequent use of river water for washing clothes. In essence, many of the Sobantu community members frequently interacted with the Baynespruit River and were exposed through both direct and indirect pathways.

Table 4.3 Summary of outcomes from the workshop questionnaire and open-ended conversations conducted in the Sobantu community

Questionnaire			
	What do you use river water for?	**How long have you been using this water source for?**	**Have you experienced any health issues from using river water? If yes, can you describe your health issue/s?**
Participant 1	Washing clothes, cleaning, irrigation and swimming	10 years	Yes, skin rashes
Participant 2	Washing clothes and irrigation	5 years	Yes, skin rashes
Participant 3	Washing clothes, irrigation and swimming	2 years	Yes, skin rashes
Participant 4	Washing clothes	10 years	No
Participant 5	Washing clothes, irrigation and swimming	3 years	Yes, skin rashes
Participant 6	Washing clothes and irrigation	7 years	Yes, diarrhoea and skin rashes
Open-ended Conversations			
Participant 7	In morning the river is in a poor condition, usually white/green in colour and occasionally has white foam (Figure 4.2A)		
Participant 8	People use the river for washing clothes and bathing (Figure 4.2B)		
Participant 9	The industry and the people of Sobantu dump their litter alongside or in the river and this is the cause of poor water quality (Figure 4.2C)		
Participant 10	Previously used the river for crop irrigation but stopped due to the physical condition and bad smell		
Participant 11	Previously irrigated cabbages approximately four to five times a week with water from the river however, the crop grew very small		
Participant 12	Children collect water in buckets for cleaning the house		
Participant 13	In summer children frequently swim in the river		
Participant 14	People cross the river and take off their shoes to do so if need be		
Open-ended Conversations			
Participant 15	Skin rash from washing clothes (Figure 4.2D)		
Participant 16	Child previously swam in the river but has currently stopped due to skin rashes		
Participant 17	Many people in the community consume crops that have been irrigated with river water		
Participant 18	Farmer works without gloves and walks barefoot in the farming field which has been irrigated with river water		

Figure 4.2 Images to supplement the statements provided by participants from the workshop

4.3.2 Urine analysis

Table 4.4 summarizes the outcomes from the questionnaire provided to all volunteers prior to urine collection, which obtained specific characteristics of each volunteer and more importantly their type of exposure. The investigation enrolled 25 volunteers, 20 of which were highly exposed to the river and 5 that were considered as the control group, i.e. since they had no exposure to the Baynespruit River. It can be observed from Table 4.4, that the common exposures to river water by exposed volunteers were through consuming irrigated crops, washing clothes and swimming in the river.

Table 4.5 shows the mean concentration (mg/L) of heavy metals, i.e. Cd, Cr, Cu, Pb and Zn, in the urine samples of highly exposed volunteers, as well as control volunteers. The observed results were compared against reference values (mg/L) as stipulated by Mayo Clinic (Mayo Clinic, 2016a; Mayo Clinic, 2016b; Mayo Clinic, 2016c; Mayo Clinic, 2016d; Mayo Clinic, 2016e). It was found that the Cd was not detected in any of the volunteers, except for control volunteer 1 (0.001 mg/L), which was below the reference limit (0.0013 mg/L). The concentration of Zn conformed to the reference limit in all volunteers. According to the Mayo Clinic online database, there is currently no reference limit derived for Cr however, it was observed that Cr was detected in low concentrations in all volunteers. The exposed volunteers contained concentrations of Cu that were within the reference range however, control volunteer 3 (0.074 mg/L) and 4 (0.233 mg/L) displayed concentrations that exceeded the reference value (0.015 – 0.06 mg/L). The concentration of Pb was undetected in all exposed volunteers except for volunteers 4 (0.084 mg/L), 7 (0.033 mg/L) and 8 (0.126 mg/L), whose samples contained concentrations exceeding the reference limit (0.004 mg/L). It was observed that control volunteers 2 (0.026 mg/L), 3 (0.058 mg/L) and 5 (0.180 mg/L) samples also contained Pb concentrations that exceeded that reference limit (0.0014 mg/L).

A statistical analysis, i.e. ANOVA, was performed in GenStat (18^{th} ed.) to determine the variability of heavy metals in urine between the two groups of volunteers, i.e. exposed and control. Table 4.6 shows that Cd ($P=0.166$), Cr ($P=0.691$), Pb ($P=0.072$) and Zn ($P=0.212$) in urine did not differ significantly between the two groups, whereas Cu ($P<0.001$) was significantly different. The standard error of differences (SED) of means is also displayed in Table 4.6. It was found that the control group had higher concentrations of Cu, Pb and Zn in their urine, while the exposed group had higher concentrations of Cr. There was no Cd detected in the urine of either group.

Table 4.4 Summary of the characteristics of volunteers incorporated in the urine analysis

Volunteer	Gender	Age	Exposure	Smoker/Alcohol	Last Meal	Time Residing in Community	Occupation
1	Female	22	Consumes irrigated crops	None	Phuthu and watercress	3 years	None
2	Female	36	Consumes irrigated crops and washes clothes	None	Bread and tea	14 years	None
3	Female	37	Consumes irrigated crops and washes clothes	None	Phuthu and watercress	7 years	None
4	Female	50	Consumes irrigated crops, irrigates crops and washes clothes	Pulverized tobacco (snuff)	Steam bread and wors	20 years	None
5	Male	41	Consumes irrigated crops, irrigates crops and washes clothes	None	Pap and tripe	4 years	Farmer
6	Male	8	Consumes irrigated crops, washes clothes and swimming	None	Bread and coffee	8 months	Scholar
7	Male	12	Consumes irrigated crops, washes clothes and swimming	None	Phuthu and chicken curry	7 years	Scholar
8	Male	10	Consumes irrigated crops and swimming	None	Steam bread and tea	8 years	Scholar
9	Male	8	Consumes crops and swimming	None	Phuthu and milk	4 years	Scholar
10	Male	10	Consumes irrigated crops, washes clothes and swimming	None	Bread and tea	7 years	Scholar
11	Male	40	Consumes irrigated crops	Smoker and alcohol	Rice and beef curry	18 years	None
12	Female	29	Consumes irrigated crops and washes clothes	Alcohol	Phuthu and milk	10 years	None
13	Female	28	Consumes irrigated crops and washes clothes	Smoker and alcohol	Phuthu and watercress	6 years	Self-employed
14	Male	34	Washes clothes	Smoker and alcohol	Rice and baked beans	3 months	Construction worker
15	Male	44	Washes clothes	Smoker and alcohol	Cabbage and phuthu	2 years	None

Volunteer	Gender	Age	Exposure	Smoker/Alcohol	Last Meal	Time Residing in Community	Occupation
16	Male	41	Consumes irrigated crops, washes clothes and washes feet	Smoker and alcohol	Bread and milk	4 years	Self-employed
17	Male	37	Consumes irrigated crops and washes clothes	Smoker and alcohol	Phuthu and watercress	8 years	Self-employed
18	Male	40	Consumes irrigated crops and washes clothes	Pulverized tobacco (snuff) and alcohol	Bread, sausages and alcohol	6 years	Sheik's Tyres
19	Female	27	Consumes irrigated crops and washes clothes	None	Briyani	1 year	Cleaner
20	Male	43	Consumes irrigated crops, irrigates crops and washes clothes	Smoker	Cabbage, chicken, pap and water	12 years	None
Control 1	Male	25	No exposure	None	Banana and coffee	25	Student
Control 2	Male	30	No exposure	Smoker and alcohol	Coffee	30	Student
Control 3	Female	36	No exposure	Alcohol	Coffee	4	Student
Control 4	Male	9	No exposure	None	Chicken sandwich	9	Scholar
Control 5	Female	24	No exposure	Alcohol	Yogurt and tea	24	Student

Table 4.5 Mean concentration (mg/L) of heavy metals in urine samples with concentrations exceeding the reference highlighted in yellow

Volunteers	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**
Reference	**0.0013 mg/L**	**None**	**0.015 to 0.06 mg/L**	**0.004 mg/L**	**0.3 to 0.6 mg/L**
1	0	0.024	0.026	0	0.082
2	0	0.026	0.032	0	0.089
3	0	0.020	0.025	0	0.116
4	0	0.036	0.040	0.084	0.088
5	0	0.022	0.028	0	0.428
6	0	0.026	0.033	0	0.234
7	0	0.035	0.050	0.033	0.114
8	0	0.066	0.039	0.126	0.099
9	0	0.021	0.019	0	0.151
10	0	0.021	0.019	0	0.090
11	0	0.098	0.026	0	0.064
12	0	0.025	0.019	0	0.249
13	0	0.026	0.013	0	0.146
14	0	0.024	0.014	0	0.092
15	0	0.033	0.016	0	0.208
16	0	0.039	0.016	0	0.270
17	0	0.040	0.016	0	0.115
18	0	0.041	0.015	0	0.109
19	0	0.029	0.010	0	0.034
20	0	0.034	0.009	0	0.052
Control 1	0.001	0.025	0.056	0.002	0.147
Control 2	0	0.024	0.059	0.026	0.369
Control 3	0	0.037	0.074	0.058	0.135
Control 4	0	0.024	0.233	0	0.287
Control 5	0	0.044	0.060	0.180	0.087

Table 4.6 Variability of heavy metals in urine between the exposed and control volunteers with concentrations exceeding the reference highlighted in yellow

	Cd (mg/L)	**Cr (mg/L)**	**Cu (mg/L)**	**Pb (mg/L)**	**Zn (mg/L)**
Exposed	0	0.034	0.023	0.012	0.142
Control	0	0.031	0.096	0.053	0.205
P-value	0.166	0.691	<0.001	0.072	0.212
SED	0	0.017	0.034	0.044	0.099

4.4 Discussion

The objectives of this paper were to determine the exposure pathways of the Sobantu community to the Baynespruit River, as well as their associated health issues. The workshop which included a questionnaire, as well as the separate open-ended conversations conducted with various community members, revealed that many people in the community interact and utilise the river for their daily needs. The most common exposure pathways were through collecting river water for crop irrigation, consuming irrigated crops, washing clothes and children swimming in the river. A number of participants related their health issues, such as skin rashes and diarrhoea, to exposure to the river water. According to Govender *et al*. (2016) (*cf.* chapter 3) the water quality of the Baynespruit River is problematic with regard to *E.coli,* which may be linked to these health issues. The infrequent elevated heavy metal detections in the river water could not be linked to long-term exposure and health issues experienced in the Sobantu community. A study by Gemmell and Schmidt (2011) also reported severe microbial contamination in the Baynespruit River, as well as the transfer of microorganisms onto crops due to irrigation with river water, which may have placed consumers at risk. It is possible that more cases of diarrhoea have occurred in the community, as a result of the extreme levels of *E.coli* however, divulging such information is inevitably associated with apprehension and may therefore go unrecorded. The questionnaire and open-ended conversations were useful methods in determining the exposure pathways of the Sobantu community to the Baynespruit River, as well as their associated health perceptions. However, the number of people that participated in the questionnaire and open-ended conversations were too low to establish a clear link between exposure pathways and health issues in the community.

The persistence of Cd, Cr, Cu, Pb and Zn in the Baynespruit River and/or surrounding environment, as well as the high exposure of the Sobantu community to this environment, substantiated the need to investigate the possible linkages of the health of the community. However, the urine analysis did not significantly link the heavy metals in the Baynespruit River and/or surrounding environments to the health of the Sobantu community. There was no significant difference between the exposed and control groups, except for the concentration of Cu, which was higher in the control group. The Cu concentration in the urine of two control volunteers exceeded the reference limit, while the Pb concentration in the urine of three control volunteers, as well as three exposed volunteers, exceeded the reference limit. According to Adotey *et al*. (2011), the prevalence of Pb in the environment and more importantly in the food chain is common, which may relate to the concentrations found in both groups of the present study. The food chain is one of the most common exposure pathways to several heavy metals (Chary *et al*., 2007). However, a link could not be made between the high concentrations of Pb in the exposed volunteers and the Pb-contaminated crops grown in Sobantu, which are consumed by these volunteers since the control volunteers present similar concentrations of Pb. It is likely that the high levels of Pb in control volunteers 3 and 5 are a related to exposure through the food chain (Chary *et al*., 2007). It was observed that exposed volunteer 4, incurred high levels of Pb, which may be linked to the intake of pulverized tobacco (snuff). According to Ashraf (2012), tobacco is a popular source of Pb, which may be associated with the case of volunteer 4. The high Pb concentration in control volunteer 2 may also be attributed to smoking. The exposed volunteers 7 and 8 are children who are less likely to adopt thorough sanitation practices and are more exposed to contamination through recreational activities, i.e. swimming in the river and coming into contact with contaminated soil. A similar observation was reported by Kamunda *et al*. (2016), who found that children are more susceptible to heavy metal exposure as a result of their outdoor recreational activities. Inoue *et al*. (2014) have stipulated that Cu is an essential element for sustaining human life and may therefore be present in the food chain. This may relate to the slightly elevated concentrations of Cu found in control volunteer 3 and 4. It must be noted that caution should be taken when considering the results of the urine analysis since there is no strong evidence to rule out or confirm the exact exposures to high concentrations of Cu and Pb. The Zn concentrations in all volunteers were within the reference limits, whereas there was no detection of Cd in any of the volunteers, except for control volunteer 1, which was below the reference limit. The level of Cr was found to be slightly higher in the exposed group as opposed to the control group. According to Kamunda *et al*. (2016), Cr (III) is an essential element, which may explain the presence of Cr in all volunteers however, the exact form is unknown. Overall, the urine analysis did not indicate any heavy metal toxicities in people, as a result of exposure to the Baynespruit and its surrounding environment.

According to Adotey *et al*. (2011), urine testing is meant to provide an indication of the extent to which one is being exposed since heavy metals are cleared fairly rapidly. Keil *et al*. (2011)

have revealed that exposure to heavy metals may be acute, i.e. one time or short-term, which may be a possibility amongst the exposed people in Sobantu. Keil *et al*. (2011) further elaborated that an exposure may be missed if an inappropriate sample is considered, i.e. a random urine sample, where a 24-hour urine sample is usually more common and provides a comprehensive analysis. The present study utilised random urine sampling as this best suited the daily routines of the volunteers. Random urine sampling also ruled out contamination of samples, which 24-hour urine sampling would have been susceptible to in the case of the Sobantu volunteers. It is therefore unclear as to whether the health of the exposed people of Sobantu is compromised by heavy metal toxicities.

4.5 Conclusion

There are many people in the Sobantu community who utilise the Baynespruit River for their daily needs. Through a workshop which entailed a questionnaire, as well as the separate open-ended conversations conducted with various community members, it was identified that the most common exposure pathways to the river primarily included, using river water for crop irrigation, consuming irrigated crops, washing clothes and children swimming in the river. The questionnaire and open-ended conversations highlighted many cases of skin rashes, as result of being in direct contact with river water, with one reported case of diarrhoea. However, the infrequent detections of elevated heavy metal concentrations in the river water, as well as the persistence of heavy metals in the surrounding environment could not be clearly linked to long-term exposure and health impacts. The urine analysis did not show any severe cases of heavy metal toxicities to exposed volunteers. Although the exposed volunteers that presented high levels of Pb, this could not be attributed to exposure to the Baynespruit River and/or its surrounding environments, since similar levels of Pb were found in control volunteers. It is therefore unclear as to whether the health of the exposed people of Sobantu is compromised by heavy metal toxicities. The persistent mention of skin rashes in the questionnaire and open-ended conversations suggests that perceived water-related health issues in the community require further investigation. Accordingly, based on the high levels of exposure to the poor water quality of the Baynespruit River, a health monitoring programme should be conducted in the Sobantu community to establish a clear link between polluted river water and human health, as a way forward. Such a monitoring programme would need a strong interdisciplinary approach with experts from the biophysical, health and social sciences to ensure that a variety of health and well-being aspects are covered. Finally, it needs to be concluded that linking water quality issues with the health of a community is a challenging task. Although the environmental data gained from the area, i.e. water, river sediment, soil and crop data, shows elevated and problematic levels of heavy metals and partially *E.coli*, combined with the high exposure of individuals, this did not confirm a risk translating directly into a health issue. It seems this needs further investigations into other dimensions, such as individual sensitivity to the exposure and overall life-style details.

4.6 References

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5. SYNTHESIS

The phenomenon of water quality degradation is rife (Malik *et al*., 2014). It is evident that anthropogenic influences, such as industrialization, have introduced a host of physical, chemical and microbiological contaminants into water bodies (Khatri and Tyagi, 2015). There is a substantial need for water quality research to monitor and safeguard water resources, as well as the safety of its users (Liu *et al.,* 2016).

Rivers have been identified as one of the most susceptible water bodies to water quality degradation (Mustapha, 2012). In South Africa, inadequate potable water supplies in many rural and urban communities have resulted in a strong reliance on these polluted rivers for daily needs (Obi *et al*., 2002; Balkhair, 2016). It is therefore essential to conduct water quality assessments, not only for legal compliance but to outline existing conditions, identify trends and/or determine the source of constituents that reduce water quality in rivers, as well as investigate likely pathways of contaminants to humans (Akpan-Idiok *et al*., 2012). The practice of using water from polluted rivers for edible crop irrigation is common among rural and urban communities. There is however great concern associated with this practice, due to the possibility of contaminants being transferred into the food chain (Alia *et al.,* 2015). It is therefore crucial to consider the effects of polluted river water used for irrigation on crop quality, as this may be linked to food security and ultimately human health, an issue that this study has sought to address.

The Baynespruit River, in the province of KwaZulu-Natal, South Africa, serves as a vital water source to the Sobantu community for crop irrigation and other activities. There have been numerous reports of poor water quality associated with the river, which may pose a threat to the health of the community. It is therefore imperative to assess the water quality of the Baynespruit River and its linkages to crops grown with it, as well as the health of the Sobantu community.

The objectives of this dissertation were:

- To determine whether there are pollutants in the Baynespruit River that exceed national crop irrigation water quality guidelines and ultimately affect human health, as well as to determine whether the level of these pollutants vary throughout the year.

- To determine whether the pollutants alluded to above are internalized by different edible crops in the Sobantu community, when irrigated with water from the Baynespruit River.

- To determine in what ways the Sobantu community are currently linked or exposed to the polluted water of the Baynespruit River and in essence, gain insight into the possible health issues experienced by people as a result of such exposure.

The key outcomes and implications for each paper are discussed below.

5.1 The Water Quality of the Baynespruit River and its Effects on Edible Crops

The consistent reporting of poor water quality in the Baynespruit River motivated the need for water quality monitoring and sediment analyses of problematic pollutants (*cf.* Chapter 3). The reliance of the Sobantu community on river water for crop irrigation further motivated the need to determine the effects of this polluted water on edible crops (*cf.* Chapter 3).

The key outcomes of Chapter 3 were as follows:

The water quality of the Baynespruit River presented as problematic with regard to *E.coli* contamination, whereas there were low concentrations of heavy metals, i.e. As, Cu, Hg, Pb and Zn, with sporadic detections of Cu and Pb pollution events, as well as acidic water, which suggested that these constituents were unproblematic for crop irrigation. High levels of *E.coli* may pose health risks to members of the Sobantu community who are exposed to the river. Although heavy metals were detected in low concentrations in the surface water, the sediment analysis indicated that As, Cd, Cr, Cu, Ni, Pb, Zn, Fe, Mn and Ag were found in concentrations well above permissible limits, thereby having the potential to degrade water quality and render it unsafe for crop irrigation.

The soil analysis indicated that Cd, Cu, Pb and Zn were found in elevated concentrations at all three farming sites sampled. This suggests that since all three farming sites are located on the primary floodplain of the river, it is possible that historical flooding, which mobilizes contaminants in river sediments has resulted in heavy metal accumulation in the floodplain soils over time. The long-term irrigation with low concentrations of heavy metals may also contribute to the build-up of these contaminants in the soil. These high concentrations of heavy metals in soil pose risks to the crops grown on it, as well as health risks to people who are in direct contact with it, i.e. farmers or children. The crop analysis showed that spinach, carrots and cabbages internalized high concentrations of Cd, Cu, Pb and Zn, thereby having the potential to impact human health via consumption.

The limitations to the study pertaining to Chapter 3 included:

- The limits of detection in the water quality and sediment results prevented the exact determination of concentrations of heavy metals.

- The analytes As and Hg were omitted from the soil and crop analyses due to regulations enforced by the UKZN laboratory used.

5.2 The Water Quality of the Baynespruit River and its Effects on the Health of the Sobantu Community

The Sobantu community interacts with the Baynespruit River through crop irrigation and other activities. These interactions motivated the need to determine the exposure pathways to the poor water quality of the river, as well as the health threats to the community (*cf*. Chapter 4).

The key outcomes of Chapter 4 are presented below:

The most common exposure pathways were identified as collecting river water for crop irrigation, consuming irrigated crops, washing clothes and children swimming in the river. This indicated high exposure of people to contaminated river water, soil and crops. There was consistent mention of skin rashes as a result of collecting water for crop irrigation, washing clothes and swimming in the river, however, based on these exposure pathways and perceptions from a small sample size, a clear link between polluted river water and health issues could not be made.

The urine analysis did not indicate any heavy metal toxicities that could have been linked to the water quality of the Baynespruit River or its surrounding environment. The concentration of Pb in the urine of three control volunteers and three exposed volunteers were elevated. It is unclear as to the reason for such elevation in the exposed volunteers. It is however, plausible that these Pb concentrations stemmed from other exposures which are unrelated to the Baynespruit River since similar values were presented in the urine of the control volunteers. The prevalence of heavy metals in the environment and the food chain makes it difficult to define the exact exposure pathways.

The limitations encountered in the aspects of the study reported in Chapter 4 entailed:

- It was observed that many people were apprehensive when questioned about their health issues, which may have prevented them from divulging pertinent information such as diarrhoea cases.

- The number of people who volunteered to fill out questionnaires or partake in open-ended conversations was too few to establish a clear link between polluted river water and health impacts.

- The lack of detail regarding long-term exposure could not be explored for the scope of this study and therefore a clear link between the exposure pathways and health issues could not be determined.

- The sample size considered in the urine analysis could have been larger, to obtain a more comprehensive result however, as stated above, many people were apprehensive of partaking in the study in such a way.

- Random urine testing is not as comprehensive and representative as 24-hour urine sampling, which may have resulted in acute exposure episodes being missed.

5.3 Contributions to New Knowledge

The contributions to new knowledge are outlined as follows:

- A water quality data set for the lower reaches of the Baynespruit River provided an improved understanding of the concentrations of pollutants found in the river. This provides useful information to those advocating or using the river water for crop irrigation or assessing its impacts on human health.

- A winter and summer sediment analysis determined the total concentrations of 23 elements at the lower reaches of the Baynespruit River, which highlighted the importance of monitoring pollutants in river sediments when assessing water quality.

- A soil analysis of three farming sites located on the floodplain of the Baynespruit River determined the total concentrations of Cd, Cr, Cu, Pb and Zn, as well as the soil pH. This provided a new understanding of the level of heavy metal contamination in the soil and thus, information which may be useful to farmers that cultivate at these sites, as well as the general community, especially children, who may be in contact with these contaminated sites.

- The analysis of edible crops grown and consumed by the Sobantu community showed elevated concentrations of heavy metals, which generated an understanding of the level of heavy metal contamination in crops that can occur. This information may be useful to those that consume these contaminated crops as it may affect their health.

- A recognition of the health implications, i.e. skin rashes, experienced by people who are highly exposed to the Baynespruit River, have been highlighted through a workshop, open-ended conversations, as well as visual representations, which may raise awareness in the Sobantu community.

These contributions provide an understanding of the linkages between water quality and human health at a small catchment scale.

5.4 Conclusion

The aim of this dissertation was to assess the water quality of the Baynespruit River and its linkages to crops grown with it, as well as the health of the Sobantu community. This dissertation has concluded that: (1) there are pollutants such as *E.coli,* i.e. in the river water, and heavy metals, i.e. in the river sediments, in the Baynespruit River that exceed water quality guidelines for crops irrigation and ultimately have the potential to affect human health; (2) heavy metals, possibly sourced from flooding of the Baynespruit River, have contaminated the soils of the farming sites located on the floodplain, and the crops grown on these soils have internalized high concentrations of heavy metals; (3) many activities have been identified which directly or indirectly expose members of the Sobantu community to the polluted water of the Baynespruit River however, this high exposure could not be clearly linked to perceived health issues mentioned by the community. In essence, the water quality of the Baynespruit River has been severely degraded however, a clear link to the health issues in the Sobantu community could not be established.

5.5 Recommendations

The recommendations for future research are listed below:

- Conduct a detailed water quality and sediment analyses of the heavy metals that were found in exceeding concentrations in order to determine their source and whether they are persistent in the Baynespruit River.

- The determination of As and Hg in the soil of the farming sites, as well as the concentration in crops, would be useful information to obtain since these heavy metals are extremely toxic to crops and humans.

- The study design from Chapter 4 needs to be reconstructed in order to clearly link and explore exposure pathways to health issues.

- A variety of in-depth health risk assessments or medical assessments should be conducted by local clinics which may prove useful for the case of the Baynespruit

River and the Sobantu community since there was persistent mention of water-related health issues, i.e. skin rashes, by community members.

The recommendations for decision-makers in the Baynespruit Catchment are as follows:

- There is a need for potable water supplies and sanitation services for the informal settlements of Sobantu, as the Baynespruit River is not a reliable source for any of the daily needs of the communities along the river.

- The floodplain of the river should not be utilised for farming and alternative land should be allocated.

- The reports of broken sewage infrastructure need to be addressed in order to possibly reduce *E.coli* contamination.

This dissertation has comprehensively outlined the water quality degradation of the Baynespruit River and the possible linkages to the health of the Sobantu community, which may be useful to various decision-makers in the Baynespruit Catchment.

5.6 References

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6. APPENDIX A

Table 6.1 presents the operating conditions used for the ICP-OES for the soil, crop and urine analyses.

Table 6.1 ICP-OES operating conditions

Instrument	**Setting**
Plasma	15 L/min
Auxiliary	0.2 L/min
Nebulizer	0.8 L/min
Radio Frequency Power	1800 W
Pump Flow Rate	1.50mL/min
Heater	off 300C

7. APPENDIX B

Figure 7.1 – 7.9, illustrates the comparison of pH, EC, As, Cd, Cr, Hg, Pb, Zn and *E.coli* against the SANS 241: Drinking Water Quality Guidelines, in the Baynespruit river and wetland pond. It can be seen from Figure 7.1 – 7.9 that the aforementioned constituents, except for *E.coli* in the river, conformed to the guidelines, whereas As, Cd and Pb occasionally presented unsafe concentrations in the wetland pond. Furthermore, rainfall had no influence the concentration of constituents found in the river or wetland pond.

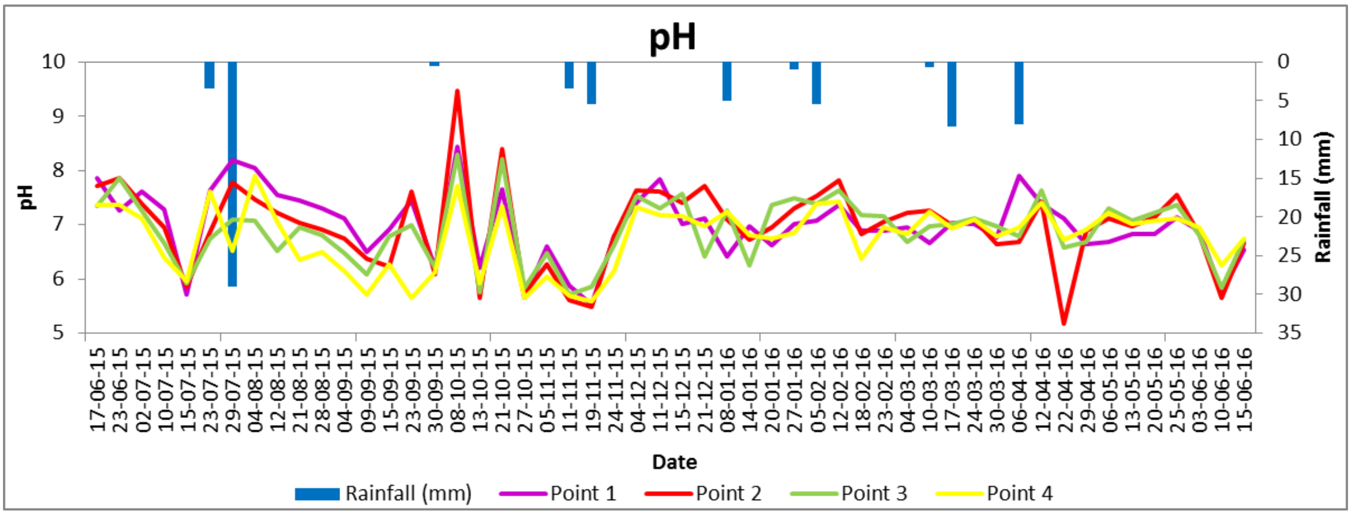

Figure 7.1 Comparison of pH across all sampling points (Permissible Range: 5-9.7)

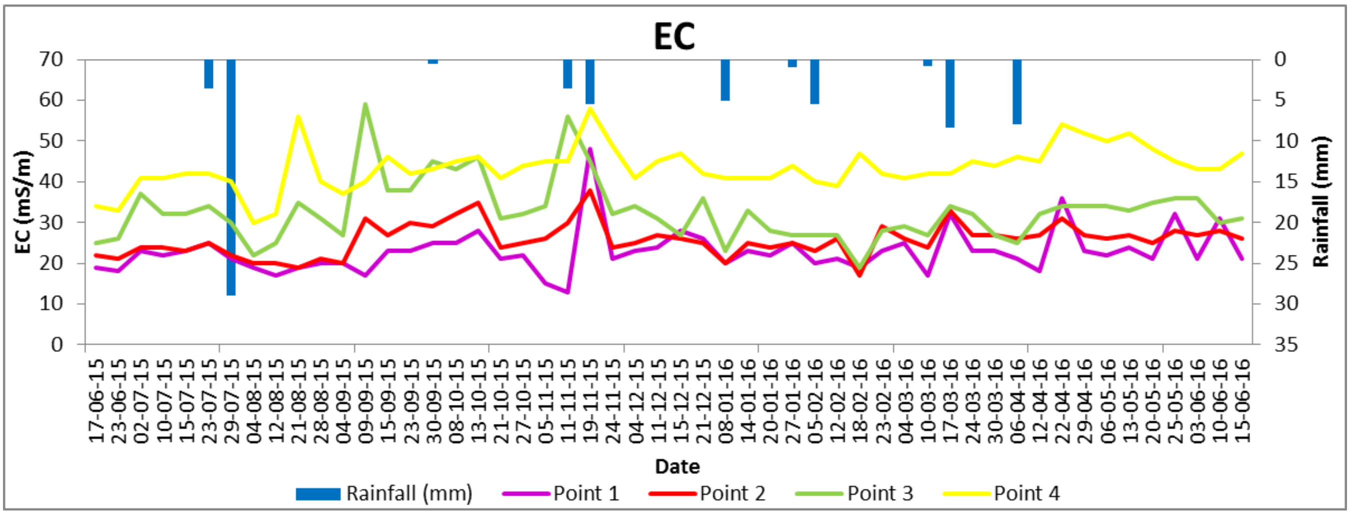

Figure 7.2 Comparison of EC across all sampling points (Permissible Limit: 170 mS/m)

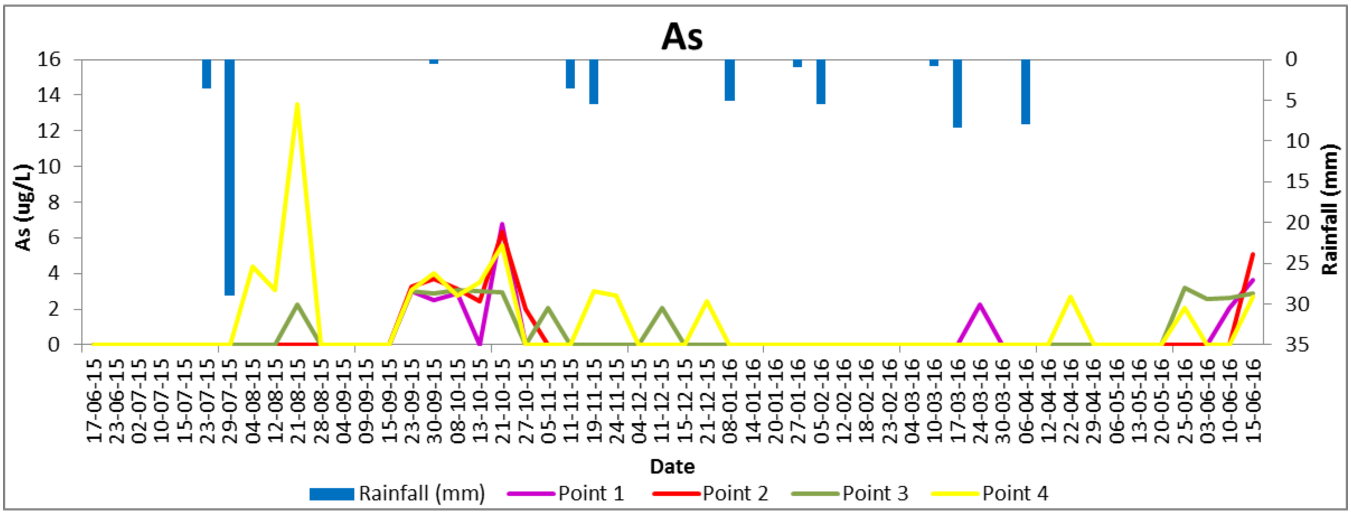

Figure 7.3 Comparison of As across all sampling points (Permissible Limit: <10 µg/L)

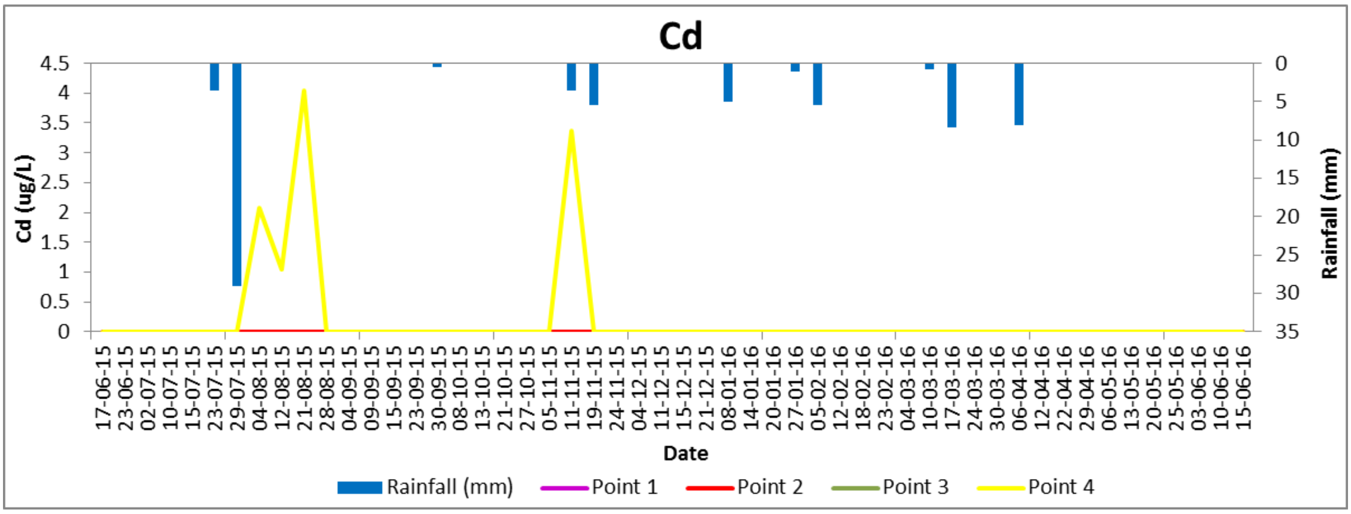

Figure 7.4 Comparison of Cd across all sampling points (Permissible Limit: <3 µg/L)

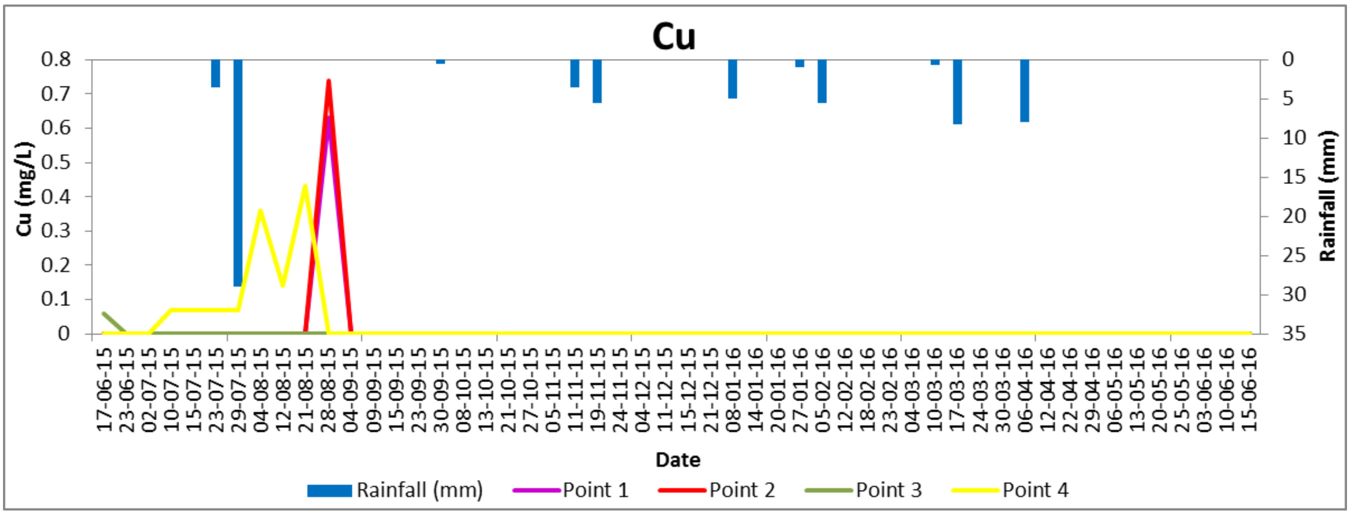

Figure 7.5 Comparison of Cu across all sampling points (Permissible Limit: <2 mg/L)

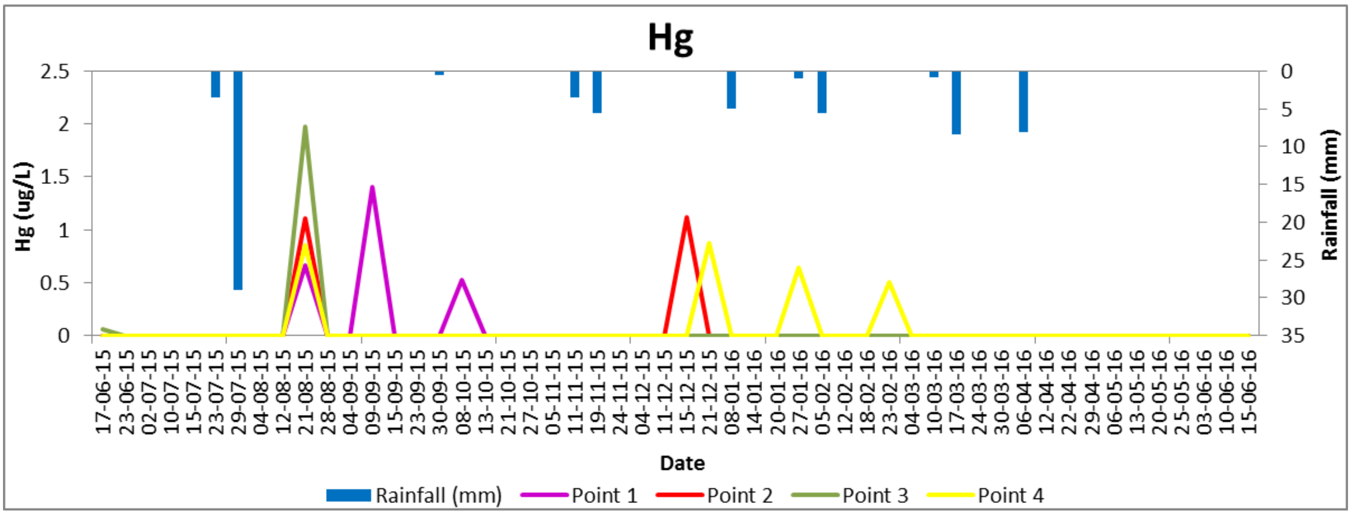

Figure 7.6 Comparison of Hg across all sampling points (Permissible Limit: <6 μg/L)

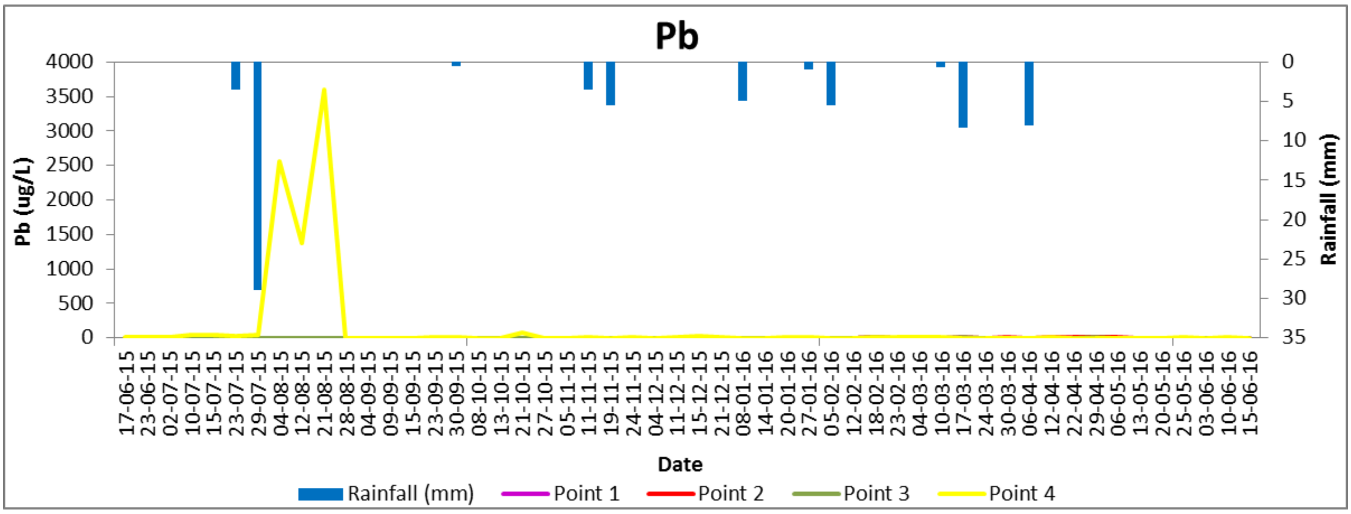

Figure 7.7 Comparison of Pb across all sampling points (Permissible Limit: <10 µg/L)

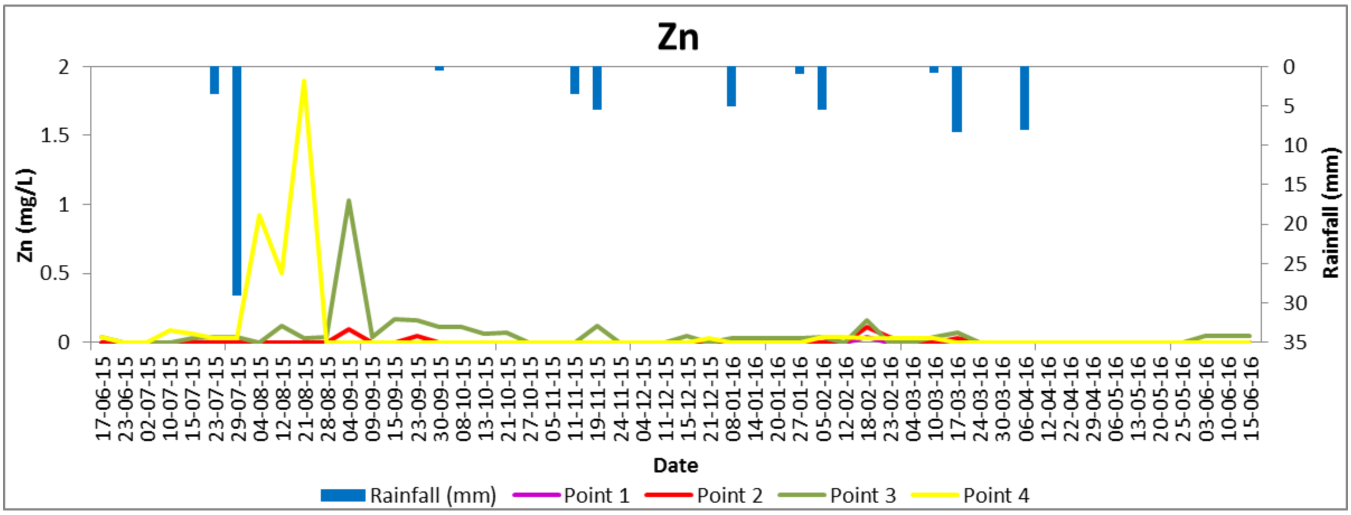

Figure 7.8 Comparison of Zn across all sampling points (Permissible Limit: <5 mg/L)

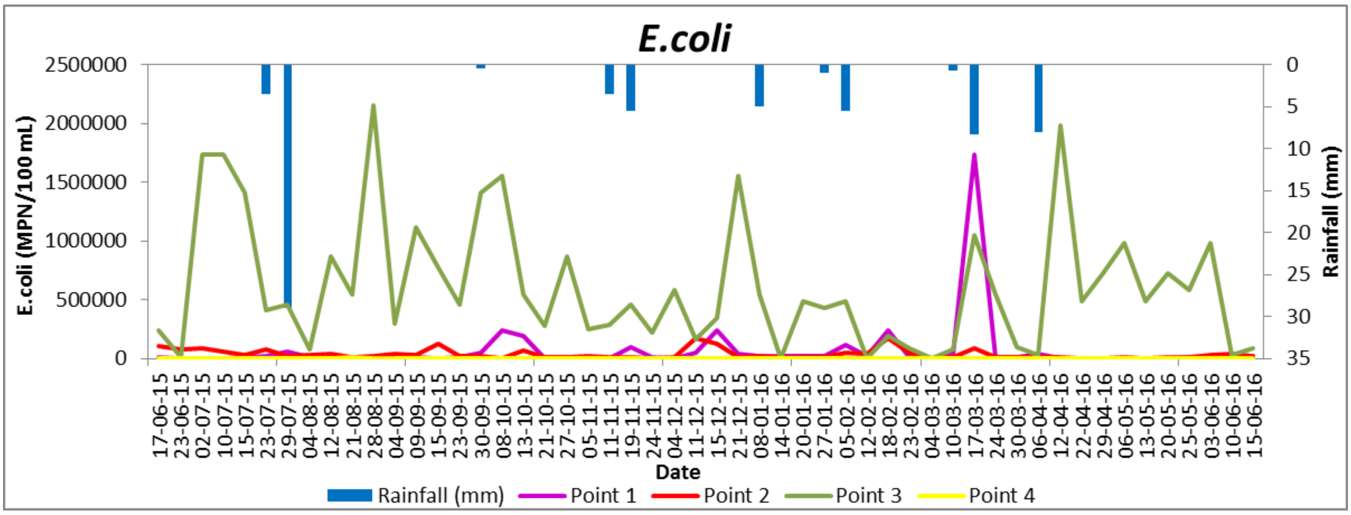

Figure 7.9 Comparison of *E.coli* across all sampling points (Permissible Limit: 0 MPN/100 mL)

8. APPENDIX C

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

13 August 2015

Ms Jédine Govender (211515641)
School of Agricultural, Earth & Environmental Sciences
Pietermaritzburg Campus

Dear Ms Govender,

Protocol reference number: HSS/0527/015M
Project title: A water quality assessment of the Baynespruit River and its linkages to the health of the Sobantu community

Full Approval – Expedited Application

In response to your application received on 20 May 2015, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol have been granted **FULL APPROVAL.**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 3 years from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

....

Professor Urmilla Bob (University Dean of Research)
On behalf of Dr Shenuka Singh (Chair)

/ms

Cc Supervisor: Dr Sabine Stuart-Hill
Cc Academic Leader Research: Professor O Mutanga
Cc School Administrator: Ms Marsha Manjoo

Humanities & Social Sciences Research Ethics Committee
Dr Shenuka Singh (Chair)
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Telephone: +27 (0) 31 260 3587/8350/4557 **Facsimile:** +27 (0) 31 260 4609 **Email:** ximbap@ukzn.ac.za / snymanm@ukzn.ac.za / mohunp@ukzn.ac.za
Website: www.ukzn.ac.za

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9. APPENDIX D

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

11 April 2016

Ms Jedine Govender
School of Agriculture Earth and Environmental Sciences
Discipline of Hydrology
jadeyg49@gmail.com

Protocol: An assessment of the water quality of the Baynespruit River and its linkage to the health of the Sobantu Community
Degree: MSc
***BREC reference* number:** BE089/16

EXPEDITED APPLICATION

The Biomedical Research Ethics Committee has considered and noted your application received on 01 March 2016.

The study was provisionally approved pending appropriate responses to queries raised. Your responses dated 05 April 2016 to queries raised on 22 March 2016 have been noted and approved by a sub-committee of the Biomedical Research Ethics Committee. The conditions have now been met and the study is given **full ethics approval.**

This approval is valid for one year from **11 April 2016.** To ensure uninterrupted approval of this study beyond the approval expiry date, an application for recertification must be submitted to BREC on the appropriate BREC form 2-3 months before the expiry date.

Any amendments to this study, unless urgently required to ensure safety of participants, must be approved by BREC prior to implementation.

Your acceptance of this approval denotes your compliance with South African National Research Ethics Guidelines (2015), South African National Good Clinical Practice Guidelines (2006) (if applicable) and with UKZN BREC ethics requirements as contained in the UKZN BREC Terms of Reference and Standard Operating Procedures, all available at http://research.ukzn.ac.za/Research-Ethics/Biomedical-Research-Ethics.aspx.

BREC is registered with the South African National Health Research Ethics Council (REC-290408-009). BREC has US Office for Human Research Protections (OHRP) Federal-wide Assurance (FWA 678).

The sub-committee's decision will be **RATIFIED** by a full Committee at its meeting taking place on **10 May 2016.**

We wish you well with this study. We would appreciate receiving copies of all publications arising out of this study.

Yours sincerely

Professor J Tsoka-Gwegweni
Chair: Biomedical Research Ethics Committee

cc supervisor: stuart-hills@ukzn.ac.za
School Administrator: manjoom@ukzn.ac.za

Biomedical Research Ethics Committee
Professor J Tsoka-Gwegweni (Chair)
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Telephone: +27 (0) 31 260 2486 **Facsimile:** +27 (0) 31 260 4609 **Email:** brec@ukzn.ac.za
Website: http://research.ukzn.ac.za/Research-Ethics/Biomedical-Research-Ethics.aspx

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