The contribution of integrated development projects to Zandspruit River water pollution, Gauteng Province, South Africa

By

ALUGUMI YESAYA NEMALILI

Student No: 9903060

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Supervisors

Dr J Zuwarimwe

Dr T Dalu

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DECLARATION

I, Alugumi Yesaya Nemalili, hereby declare that this thesis for the master's degree in Rural Development (MRDV) submitted to the Institute for Rural Development, in the Faculty of Science, Engineering and Agriculture at the University of Venda has not been submitted previously for any degree at this or another university. It is my original work in design and execution, and all reference material contained therein have been duly acknowledged.

Signature: ____________________ **Date: 12 November 2022**
Alugumi Yesaya Nemalili

ABSTRACT

Cosmo City Integrated Development Project is a mixed-use, integrated housing and inclusionary housing development for families from different income groups. The project was conceived in response to the needs of the people located close to Zandspruit River system. This research was conducted in Cosmo City to understand the contribution of the integrated development activities to pollution of Zandspruit River system upstream and downstream. Thestudy characterized and measured the major pollutant sources found in Zandspruit River system water, analysed the potential impact of pollutants associated with the Cosmo City development and recommended strategies to minimize the pollution levels. Water and sediments samples were collected from Zandspruit River system across five study sites. Thekick sampling method was used for the sediment and rocks while a handheld sweeping net was used for zig-zag approach. Macroinvertebrate samples were collected in ziplock bags andstored in polypropylene 500 mL plastic bottles. The results showed a total number of six macroinvertebrates taxa out of possible fourteen during the study periods. These included Dytiscidae, Gerridae, Hydrometridae, Aeshnidae, Chlorolestidae and Lymnaeidae. The results also showed that the volume of macroinvertebrate taxa such as Gerridae, Chlorolestidae and Lymnaeidae were high across the Zandspruit River system, implying that the river system waspolluted by human made activities. Research further indicated that the volume of macroinvertebrate taxa such as Dytiscidae, Hydrometridae and Aeshnidae were lower acrossthe river system, indicating the low level of pollution and the possible cause of this variation was from water pollution. Water pH values for April and June ranged between 5.8 to 8, respectively, across all the sites as indicated by pH, alkalinity, temperature and conductivity across Zandspruit River system perhaps due to less human made activities. The study findings indicated that sediment chemical like S, Ca, EC, Mg werehigh while OC, B, Cu, Zn, Fe, Mn were relatively lower during April as well as June. Water chemical properties like Na, alkalinity, Ca, Mg and Cl were relatively higher for both months, whereas variables such as Mn, Fe, S and K were relatively lower across streams during the same period. The possible conclusion was that different activities such as residential, fishing, farming and industrial along the Zandspruit River system have significantpollution implication. The study further concluded that residential activities have high potentialpollution contribution to Zandspruit River system. The major recommendation for minimising water pollution can be sustainable strategies to minimize the level of water pollution in development activities on adjacent rivers.

Key words: Alkalinity; Integrated Development Project; Macroinvertebrate; Water Pollution; Zandspruit River

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ABBREVIATIONS AND ACRONYMS

ASPT	Average Score Per Taxon
B	Boron
Ca	Calcium
CBD	Central Business District
CCA	Canonical Correspondence Analysis
Cl	Chlorine
CODEVCO	Developer of Cosmo City – fully owned by Basil Read Holdings
Cu	Copper
DEFF	Department of Environment, Forestry and Fisheries
DWS	Department of Water and Sanitation
EPA	Environmental Protection Agency
Fe	Iron
GIS	Geographical Information System
JMM	Johannesburg Metropolitan Municipality
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
NEMA	National Environmental Management Act
NHA	National Health Act
NWA	National Water Act
OC	Organic Carbon
S	Sulphur
SANAS	South African National Accreditation System
SAR	Sodium Adsorption Ratio
SASS	South African Scoring System

SDGs	Sustainable Development Goals
SO_4	Sulphate
SPSS	Statistical Package for the Social Sciences
TMM	Tshwane Metropolitan Municipality
UNEP	United Nations Environment Programme
WHO	World Health Organization
WPIPWM	White Paper on Integrated Pollution and Waste Management
WPWCR	White Paper on Water and Corporate Responsibility
Zn	Zinc

CHAPTER 1: INTRODUCTION

Context of the study

1.1 Background

Pollution refers to deposition of substances from residential, commercial and industrial areas to bodies that consequently interfer with the use of water (Taofeek *et al.,* 2014). Water is considered polluted if some substances or condition present are to such a degree that the water cannot be used for its intended purpose (Owa, 2014). Globally, water pollution is no longer just consideredin terms of public health but also in terms of conservation, aesthetics and preservation of naturalbeauty and resources (Khatun, 2017). Continued pollution of water in rivers and other water bodies is depleting water resources even further and will have serious repercussions on the globaldevelopment agenda if bold steps to control water pollution are not taken into consideration to improve water pollution and quality.

In Japan, the bulk of polluted water is mainly from residential, commercial and industrial areas (Afroz *et al.,* 2014). In India, agricultural activities are the major contributing factors to groundwater contamination through leaching of harmful compounds that are more prevalent in 19 states of India (Kumar & Shah, 2014). With rising levels of water pollution, surface water bodies as well as groundwater in certain parts of India are becoming unsuitable for agricultural use (Mali *et al*., 2015). However, more people who move into towns and cities in Africa, contribute to a number offactors that lead to water pollution (United Nations Environment Programme: (UNEP), 2012). In Nigeria, it has been observed that unplanned residential housing development projects with inadequate sewage system constitute a major source of water pollution especially in urban environments (Evelyn & Tyav, 2012). In Kenya, agriculture products and inputs, industry waste, municipal disposal, and other pollution one way or another end up polluting the water system (Failler *et al*., 2016).

According to Odiyo and Makungo (2012), water quality problems is a major challenge for vulnerable communities in Gauteng Province of South Africa as South Africa's scarce water resources are under threat due to extensive pollution. This makes the water less acceptable for consumption, depending on the extent, severity, and temporal nature of the pollution (Odiyo & Makungo, 2012). This is despite the consensus that water in South Africa is a vital resource for human life; hence, maintaining water quality and pollution is essential to ensure the viability of theecosystem services it provides. Generally, farming, industrial, residential, fishing and commercial activities are the mainland's major water pollutants for ground water (Garcia *et al*., 2017).

Thus, accepted that in South Africa, water pollution is a serious concern damaging not only individual plant and aquatic species and populations but also their biological communities. This isrendering much of the available water unsafe for both human consumption and utilization by theecosystems (Musingafi & Tom, 2014). Musingafi and Tom (2014) established that water sourcesin the Vhembe District were highly contaminated by the mining and agricultural activities in Limpopo Province and its southern neighbour Gauteng Province. In the Gauteng province, Tshwane Metropolitan Municipality's (TMM) boreholes and springs water located in dolomite areas and sinkholes expose the water to pollution (Musingafi & Tom, 2014). Apparently, in SouthAfrica, water is a human right and for that reason government has introduced measures to ensurethat everyone has access to safe water (Musingafi & Tom, 2014). It is unfortunate that the government of South Africa has not taken much consideration and commitment to manage water pollution control policies and their implementation as a serious governance issue, to control as well as to manage water pollution.

National Water Act (NWA) (Act 36 of 1998) mandates an owner of land to prevent water pollutionfrom occurrence and ensure that any activities that takes place on that land should not cause pollution to water resources (National Water Act 36 of 1998). Principle of National EnvironmentalManagement Act (NEMA) (Act 107 of 1998) requires that pollution and environmental degradation should be minimized and remedied. These pieces of legislation indicate that any kind of pollutionneeds to be prevented, avoided, minimized from occurrence and remedied (National Environmental Management Act 107 of 1998). However, the Department of Environment, Forestryand Fisheries (DEFF) and Department of Water and Sanitation (DWS) were responsible for enforcing these anti-pollution rules.

Dalu *et al.* (2017) mentioned that in South Africa water pollution is a critical management issue, with many rivers and streams draining urban areas being polluted by the disposal of untreated solid waste and wastewater discharge, storm water and agricultural runoff. This has implicationsfor biodiversity, and many rivers in the developing world are now considered compromised. However, the water quality on sampling sites was very poor for most sites in both the ZandspruitRiver and streams mostly due to organic pollution from the urban areas, with a few sites being ofgood water pollution and quality in the downstream and upstream sites (Dalu *et al*., 2017).

In general, based on gross observations factors that greatly contributed to the water pollution of a Zandspruit River were the human made activities of land use by humans around it such as housing development projects (Ma'arof & Hua, 2016). The expansion of Cosmo City developmentproject was to meet the community household market demand throughout the establishment of the entire project. Activities are located close to the Zandspruit River system and can potentially contribute to water pollution arisng from industrial, residential and commercial activities. This study therefore evaluated the contribution of integrated development project activities to Zandspruit River system water pollution in Cosmo City.

1.2 Research problem

The Constitution of the Republic of South Africa (Act 108 of 1996) indicates that everyone has the right to an environment that is not harmful to their health or wellbeing (Chapter 2 of Bill of Rights and Section 24 of the Constitution of South Africa Act 108 0f 1996). Although the Constitution clearly states that everyone should live in an environmental that is free from harmfulsubstances, water pollution remains persistent and requires urgent attention (Musingafi & Tom, 2014). There seems to be a disjuncture between the need to advance integrated development projects on one hand and the need to protect the environment from pollution coming from unintended consequences from integrated development programmes on the other hand (Musingafi & Tom, 2014). One such initiative is the Cosmo City development project which has impact of the pollutants associated with the Cosmo City development whose mainthrust was to drive industrial, commercial and residential development. The development of Cosmo City was aimed at addressing the housing needs of the residents of Zevenfontein and Riverbendinformal settlements in the Gauteng Province of South Africa.

The activities of the project included industrial, residential and commercial development. However, downstream and upstream, outside Cosmo City, are also activities such as agriculture, fishing, recreation, water extraction and habitat for aquatic ecosystem, which are likely to be affected if there is serious pollution of water. Given that not much is known about the extent to which the growth of Cosmo City is polluting the Zandspruit River system, this study evaluated the contribution of the Cosmo City development project to the pollution of the river. In South Africa the household wastewater in the environment with high levels of fecal pollution made clear that household wastewater could not be managed separately from the other waste streams, namely, sewage, solid waste, and storm water (Govender *et al.,* 2011). This however harm community health, pollute the environment especially water sources, and risk deepening poverty in the very settlements created to ameliorate it (Govender *et al.,* 2011).

1.3 Justification/rationale for the study

The research results will benefit the Zandspruit River catchment community and the Johannesburg Metropolitan Municipality (JMM) officials who are accountable for the managementof quality water. Johannesburg Metropolitan Municipality environmental management officials accountable for management of quality water stand to benefit by being informed on how best toenforce water quality management in the face of rapid growth of human settlement. TheDeveloper of Cosmo City – fully owned by Basil Read Holdings (CODEVCO) stands to benefit from the findings of study in terms of being informed about how best they can manage the waterpollution, given the fact that human settlement expansion is a necessity. The research results may be useful in enabling the country to achieve the Sustainable Development Goals (SDGs), namely goal 9 (Industry, innovation and infrastructure), goal 11 (Sustainable cities and communities) and goal 15 (Life on land). The JMM policy makers also stand to benefit from this research in terms of how they can implement the suitable water pollution control measures.

There is a challenge in the implementation and enforcement of environmental policies for controlof water pollution in Cosmo City in the Johannesburg Metropolitan Municipality, hence the research results will suggest ways of enforcing policies that deal with water pollution and how polluters could be made to account. The findings of this study might benefit researchers and the academia in terms of knowledge generated on the issue of water pollution, particularly the controlof the water pollution in river systems. The study contributed to the body of knowledge by evaluating the contribution of development projects in the pollution of river systems. This might lead to finding strategies to prevent water pollution from occurrence. The research results may help promote the water quality at Zandspruit River system in Cosmo City and community awareness on water quality and pollution.

1.4 Research objectives

1.4.1 Main objective

The main objective of this research was to evaluate the contribution of integrated development project activities to Zandspruit River system water pollution in Cosmo City in the Gauteng Province of South Africa.

1.4.2 Specific objectives

The specific objectives were to:

a) Characterize and measure the major pollutants in the Zandspruit River system associatedwith Cosmo City development.

b) Analyse the potential impact of the pollutants associated to the Cosmo City development projects on the downstream.

c) Recommend strategies to minimize the level of pollution caused by integrateddevelopment activities in adjacent river.

1.5 Research questions

a) What is the level of pollution by Cosmo City development projects in the Zandspruit River system?

b) What is the extent of the pollution by Cosmo City development projects in the Zandspruit Riversystem?

c) What is the impact of the Zandspruit River system pollution on the downstream development activities?

1.6 Theoretical framework of the Study

The conceptual framework was divided into two aspects which was the water pollution problems and the water pollution solutions. The first aspect of water pollution was to identify the ground water pollution problems and surface water pollution, especially those related to Zandspruit River system pollution problem and the impacts of polluted river water. The second aspect of water pollution was the solution aspect which was the awareness of water pollution on river water as well as the streams water pollution. This was done through the identified the best ways of managing water pollution and human made activities across Cosmo City development to ensure that there was minimal water pollution on river and streams. Lastly, the research was also delved into the aspect of water pollution and measuring impacts thereof. Furthermore, it was very crucial to deal with the aspect of river, streams water pollution and human made activities. There was a need to deal with water pollution aspect in order to prevent water pollution from occurrence and reduce effects on community human health water bodies.

The community of Cosmo City development needs to be protected from water pollution of low-cost housing development project. Based on the above-mentioned it was considered that the research through theoretical framework indicates that it was covered the range of city-related water pollution or hazard by scale and type for water pollution conditions as determinants in the study area. These were measured by specific monitoring and evaluation indicators. The principle of the specific monitoring and evaluation indicators was to determine the water pollution or aspects for the study area. There was a need to consider the following composition of each components: community citizens, community leaders, councillor, Johannesburg Metropolitan Municipality, GPDHS, environmental manager, environmental officer, environmental control officer, NGO’s, construction manager, water and Zandspruit River. The relationship between scale and type of water pollution have been determined by the level of water pollution or aspect. The theoretical framework for the Cosmo City low-cost housing development has water pollution from different human made activities practiced. The community in Cosmo City Township were the major contribution to the water pollution and it also affects the human health around Cosmo City development. The research it aims to indicate the problems encountered by the development during operational stage and the scale, types of water pollution.

1.7 Conceptual framework of the study

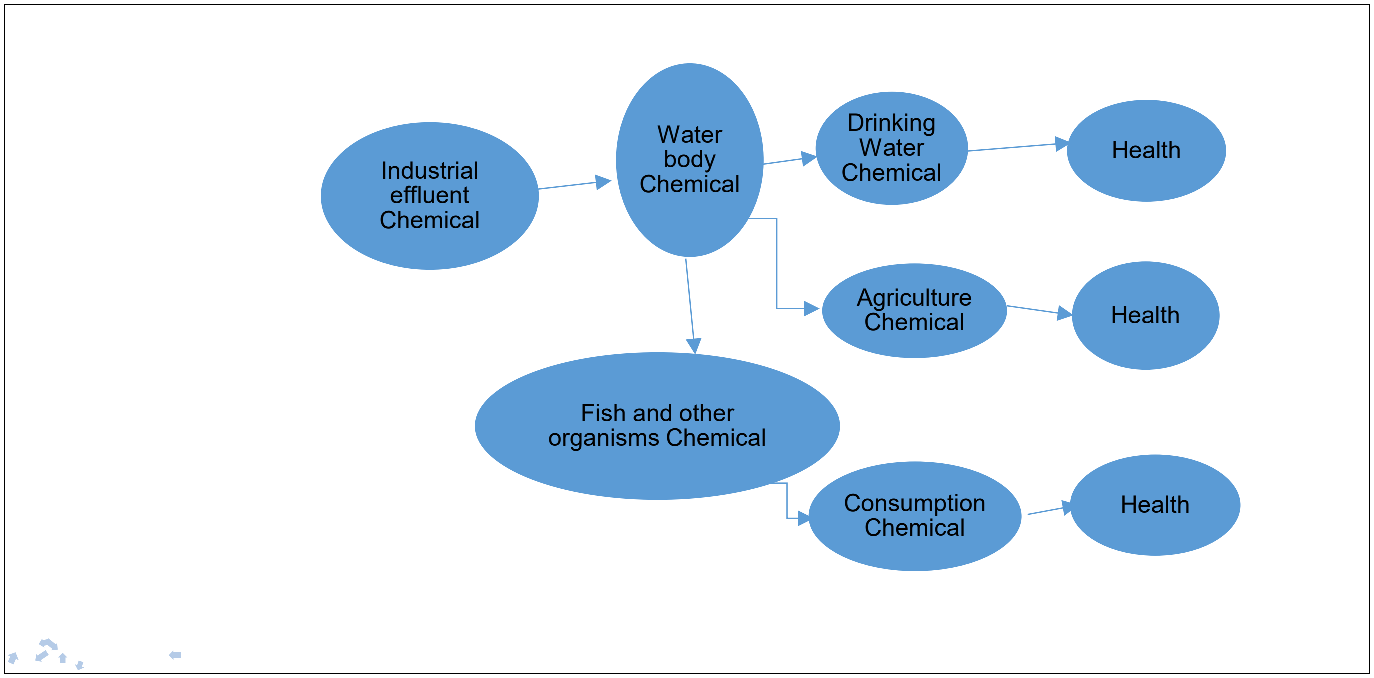


Figure 1.1. Conceptual framework of the study

The conceptual framework of the study involves the process of water pollution from Industrial effluent discharged into the water body which results in drinking water and affect the health of the community. The water pollution from industrial effluent can also contaminate the water body to have an effect on the fish and other organisms and the consumption of water which end up affecting the health of the community.

The proposed intervention will be for government to introduce public awareness, implement water pollution control, cleaning river campaign, proper treatment of hazardous waste and recycling of chemical waste. The regulatory, marked-based, self-regulatory and civil management instruments can be an intervention mechanisms. Another intervention could be to have proposer sanitation to reduce sewage spill, water quality supply to improve drinking water, Hygiene to prevent contamination of human bodies.

1.8 Operational definitions of key terms and concepts

a) **Water pollution** is defined as the contamination of water by chemicals, microbes and other pollutants to make it non-potable (White Paper on Water and Corporate Responsibility: (WPWCR), 2016).

b) **Cosmo City** is an integrated housing project, which makes provision for 11 192 erven, ofwhich 8 288 are for individual housing typologies (Urban Dynamics, 2010 – 2017).

c) **Rural development** is a people centred approach whereby rural residents take control oftheir destiny, thereby dealing effectively with rural poverty through the optimal use and management of natural resources (Gauteng Rural Development Plan, 2014).

d) **Pollution** is the direct or indirect alteration of the physical, chemical or biological properties of a water resource to make it less fit for any beneficial purpose for which it mayreasonably be expected to be used; or harmful or potentially harmful to the welfare, health or safety of human beings; to any aquatic or non-aquatic organisms; to the resourcequality; or to property (National Water Act 36 of 1998).

1.9 Scope and limitations of the study

This study is focused on the contribution of integrated development projects to Zandspruit River water pollution in the area. It focused on the level of pollution by Cosmo City development projects in the Zandspruit River system. It focused on the impact of the Zandspruit River system pollution on the downstream development activities. It focused on the extent of the pollution by Cosmo City development projects in the Zandspruit River system. The results of this study investigation will provide guidance on management water pollution control in the area from human made activities and will add information on proper maintenance of Zandspruit River and policies. The focus on human made activities is crucial on the fact that community residents depended on the Cosmo City economic expansion in the area. Cosmo City are also attracting more community residents to reside on the large population with limited activities.

Due to high large number population, Cosmo City may be forced in future Expansion and economic demand and growth. The study is limited to Cosmo City in South Africa out of all the numerous cities and human made activities that are located along the Zandspruit River and water pollution that are located across the streams are later described in the study. The magnitude of the coverage Cosmo City area, selection of human made activities and respondents and huge financial cost of enumeration also reduced the sample size to selected areas. The study was limited to human made activities within selected areas in selected Johannesburg Metropolitan Municipality Government Authorities within Cosmo City in South Africa.

1.10 Contribution of the study

This study has also contributed to the existing literature review relevant to the study. This study contributes to understanding knowledge of how early water pollution can be effectively managed. The study also added on the analysis of this study to existing research studies by identifying and implementing crucial aspect of water pollution that should be considered of important use in the future research studies. This study contributed to the management of water pollution and awareness. The results showed that water pollution was characterised with the highest importance of human made activities. The study also considered the other existing studies relevant to water pollution often separately conducted qualitative and quantitative studies. The study considered the present research methodologies and case studies. The study contributed to existing case study research by considering management of water pollution cases.

1.11 Outline of the thesis

The dissertation is divided into five chapters. The first chapter consist of the background, problem statement, justification and specific objectives, hypotheses and definition of terms. Chapter two reviews the literature relevant to the study by discussing the concept of water pollution, an overview of currentstatus of water pollution internationally, global perspective of water pollution, status of water quality among the continents, and lastly it covers the legislative framework on water pollution. Chapter three deals with the brief overview of the study area, sampling design, population, sampling, macroinvertebrates sampling, sediment chemistry variables, water chemistry variables,data analysis. Chapter four covers discusses the results of the study focusing on water quality variables, sediment quality variables and macroinvertebrates communities of Zandspruit River system and field survey of community members within the Cosmo City site. Chapter five contain detailed discussion of the study results with a view to proffer concluding remarks and recommendations of the study.

CHAPTER 2: REVIEW OF THE LITERATURE

2.1 Introduction

The literature review was mainly concentrating or based on the utilization of the books; journals: newspapers and internet use. This chapter was also describing the concept of water pollution, an overview or current status of water pollution internationally, global perspective of water pollution, status of water pollution in Africa, water pollution in South Africa and legislative framework of water pollution in South Africa. The consequences caused by human made activities in Cosmo City development project and township project and the impacts on socio-economic or benefits thereof. The research was also discussing the way in which other country or community control water pollution of human made activities development project of township and it was also trying to cover the water pollution assessment done for other rural development project across the entire country. Various researches have also been conducted on water pollution in the entire country with different water pollution problems identified.

2.2 The concept of water pollution

Water pollution is defined as contamination for desecration of dirtying, soiling, spoiling and destruction of water (Karataş, 2016). Water pollution is such a change which adversely affects the aquatic ecosystem in terms of the living organism, oxygen content, the presence of toxins and so on (Pathak, 2013). A body of water, such as a lake, stream, river, pond, ocean and even the water underground in the soil, can become polluted when it's contaminated by sewage leaks, agricultural runoff or chemical spills (Karataş, 2016). Water pollution, though related to the wateraccess issue, is a distinct facet of the overall water crisis (WPWCR, 2016). In legal sense, pollution of water means a departure from normal state of water by human made activities in sucha manner to prevent it from being used for the purposes thought as normal (Pathak, 2013). Unfortunately, this very important source for all living organisms is used unconsciously and contaminated by humans (Karataş, 2016).

2.3 An overview or current status of water pollution internationally

Water pollution occurs when unwanted materials enter into water, changes the quality of water and makes it harmful to the environment and human health. Water is an important natural resource used for drinking and other developmental purposes in our lives (Haseena *et al*., 2017).Conventional or classical pollutants are generally associated with the direct input of waste products (Coker, 2013). Water pollution is a global issue and the world community is facing worstresults of polluted water. Major sources of water pollution are discharge of domestic and agriculture wastes, population growth, excessive use of pesticides and fertilizers and urbanization(Haseena *et al*., 2017). Although essential to the aquatic habitat, nutrients such as nitrogen and phosphorus may also cause over fertilization and accelerate the natural aging process of lakes (Coker, 2013).

Dalu *et al*. (2016) indicated that global water pollution has been demonstrated that human made activities within the rivers catchment across the country impacted on the water pollution and quality, with ammonium, nitrateand phosphate concentrations closely reflecting the industrial, residential and agricultural activities within the catchment. The changes in the physico-chemical parameters of the water column were associated with shifts in the diatom community composition along the length of the rivers in the continent (Dalu *et al*., 2016). Diatom based water pollution and quality indices calculatedduring this investigation were, with few exceptions, not significantly correlated to ambient nutrient concentrations (Dalu *et al*., 2016). The absence of any significant correlations between the diatomindex values and nutrient concentrations may reflect the fact that the diatom indices developed inother regions of the world may not be suitable for temperate African streams (Dalu *et al*., 2016). Because diatoms are very sensitive to environmental change and/or disturbances such as eutrophication, acidification, human made activities and water pollution, they are considered to be powerful indicators of water pollution and quality in freshwater systems (Dalu *et al*., 2016).

Consequently, water pollution globally was regarded as proposed that diatom indices should be developed within the region, after investigations on the diatom nutrient tolerances and preferences have been carried out (Dalu *et al*., 2016). This will greatly improve globally water pollution and quality analysis based on diatom indices (Dalu *et al*., 2016). Distinguishing and managing dynamic environmental conditions in diverse systems requires a cutting-edge approach taking into account ecological principles; an example of such an approach is biological monitoring (Dalu *et al*., 2016). It was hypothesised that changesin water pollution and quality resulting from different land use patterns would be reflected in diatomcommunity structure (Dalu *et al*., 2016). Globally most of the sites along the length of the rivers, both upstream and downstream sampling sites, were subjected to point-source pollution from thecatchment, which resulted in the species distribution being strongly biased towards cosmopolitandiatom species (Dalu *et al*., 2016).

2.4 Global perspective of water pollution

In Bangladesh, untreated wastes of industries, solid wastes of urban and commercial area, wastes of sewerage in municipality, feces of animals, pesticides, fertilizers, radioactive wastes, erosion of lands riverbanks etc., are the main sources of water pollution (Chakraborty *et al*., 2013).Chakraborty *et al*. (2013) maintains that a wide spread of fish deaths has occurred in these areas,and thousands of fishermen have lost their jobs. The industrial areas in Bangladesh are situatedin the midst of densely populated regions (Chakraborty *et al*., 2013). In China, there is a large production and consumption of oil in the world (Seshu & Kumari, 2015). The non-convention In China, there is a large production and consumption of oil in the world (Seshu & Kumari, 2015). The nonconventional pollutants include dissolved and particulate forms of metals, some of themhighly toxic and may accumulate in fish. More than 13,000 oil spills of varying magnitude occur inthe United States each year (Coker, 2013).

Since the pollution disease outbreaks of mercury and cadmium poisoning in Japan, serious mercury pollution situations have been identified in Brazil, China, and the Philippines, and serious cadmium pollution has occurred in Cambodia, China, the Lao People's Democratic Republic, andThailand (Hutton & Haller, 2004). Afroz *et al*. (2014) has commented that an overview of water pollution in Malaysia is a serious problem and impacts negatively on the sustainability of water resources. In addition, it also affects plants and living organisms, people's health and the country'seconomy (Afroz *et al*., 2014). The fact that the Zandspruit River system was dominated by strongpollution-tolerant species reflects that the Zandspruit River quality was in very poor state (Dalu *etal*., 2017). Diatom species richness was low at the first two sites as there were closer to catchmentimpacts i.e., agriculture and urban area (Dalu *et al*., 2017).

According to Dalu *et al*. (2017) the different catchment activities, e.g., agriculture and sewage spillages, had a significant implication to the Zandspruit River state and had a huge impact on the Zandspruit River water pollution and quality, benthic diatom and macroinvertebrate communities. Therefore, it is of paramount importance to understand the catchment processes that cause changes in Zandspruit River ecosystems as a result of human made activities (Dalu *et al*., 2017).This relatively pilot study in an under studied region of the world highlighted that the Zandspruit River state of the Zandspruit River was very poor (Dalu *et al*., 2017). It was advocate for further studies to quantify the impact of the urban area and agriculture on the entire Zandspruit River system catchment through increased sampling sites and assessing nutrient loading over time andspace (Dalu *et al*., 2017). Zandspruit River pollution is a result of several pollutant sources, whichare linked to human made activities discharges such as wastewater discharge and non-point sources, from diffuse sources such as land drainage and agricultural surface runoff (Dalu *et al*., 2017).

Given the long-term threat to the sustainability of deep-groundwater posed by groundwater abstraction, it has been set out primarily to assess the source of recharge to deep aquifers tappedfor domestic supply and for deep groundwater in aquifers used for public supply, to test the potentially adverse effects on water pollution and quality in that aquifer posed by influx of as- polluted groundwater and saline groundwater from adjacent to human made activities (Rotiroti *etal*., 2017). Rotiroti *et al*. (2017) found that it was also examined that sources of recharge to shallowaquifers and evaluate, if any, their degree of anthropogenic contamination and develop a conceptual model of as release in the Po Plain. An important economic activity in the area that could have implications on water quality is livestock farming, in particular, piggery (Rotiroti *et al*.,2017). Pig manure is often used as soil fertilizer, instead of synthetic compounds such as ammonium sulphate, so that this area was classified as nitrate-vulnerable zone (Rotiroti *et al*., 2017).

The sources of water pollution are innumerable. Major sources can be found in practically every variety of industrial, municipal and agricultural operations (Dubos, 1973). Since water pollution has direct consequences on human wellbeing, it is essential, for a better understanding, to develop the right attitude towards water (Owa, 2014). Generally, the pollutants come from three prominent sources: sewage discharged into the river, industrial effluents discharged into the riverwithout any pre-treatment and surface run off from agricultural land (Dwivedi, 2017). About 1500substances have been listed as pollutants in freshwater ecosystems and a generalised list of pollutants (Dwivedi, 2017). The main point sources identified are household sullage, sewage treatment plant and industrial area (Afroz *et al*., 2014).

Most of the inorganic liquid wastes come from industry, and their dilution in large river waters renders them harmless (Chakraborty *et al*., 2013). Highly polluted rivers have obnoxious smell and contain little or no flora or fauna (Owa, 2014). These point sources comprised sewage treatment plants inclusive of 668 network pump stations, manufacturing industries, animal farmsand agro-based industries (Afroz *et al*., 2014). Wastes when disposed of in water, bacteria and other microorganisms combine with oxygen dissolved in water to break them down, can be termedas "oxygen demanding" wastes (Chakraborty *et al*., 2013). A major water pollutant has been oil spilled in large quantities from tankers of broken oil pipes from oil industries which kills sea weeds, mollusks, marine birds, crustaceans, fishes and other sea organisms that serve as food for humans (Owa, 2014).

Origin of water pollution	Comment
Residential and domestic wastes	Organic wastes and sometimes industrial wastes
Industrial wastes	Oil spills from ships
Agricultural wastes and thermal pollution	Formed by combination of SO2 and NO2 with water in the atmosphere
Radioactive materials	Present in wastes, uranium and thorium mining
Untreated wastes of industries	Come from wastes of industries
Sewage leakages	Present in wastes
Sewage discharged into the river	Present in sewage, industrial effluent, fertilizers, chemical fertilizers, pesticides and insecticides

Table 2.1. Common origins of water pollution. **Source: (Kumar, 2011)**

Pathak (2013) states that the effect of any potential pollutant will vary according to the size, temperature, rate of flow and oxygen content of the receiving waters, as well as the local geologyand the presence of other pollutants and any resulting synergistic effects. We must add to thesehuman causes, the poor drainage system of some cities with rather flat relief such as Douala (UNEP, 2006). Pollution of water can take any one or more of physical, chemical, physiological and biological forms (Jivendra, 1995). Other causes of water pollution are linked to the poor management of wastewater in our cities due to uncontrolled urbanisation (UNEP, 2006). Taste and odour, although may not pose public health problems, are considered aesthetic pollutants (Jivendra, 1995). Pollutants of water come in many forms, including Deoxygenating materials, industrial processes, Toxic materials, Disease and Heat (Pathak, 2013). The main manifestationsof water pollution are physico-chemical, bacteriological, biological, and epidemiological. The presence of abnormally high suspended solids such as various debris or dissolved substances (UNEP, 2006).

The causes of water pollution can be divided broadly in two divisions, namely: natural causes such as rain, erosion and siltation andhuman made causes such as industrial activities, residential activities, agricultural activities and commercial activities. Erosion of riverbanks causes siltation, and this silt sometimes hampers aquatic lives (Chakraborty *et al*., 2013). Water pollution leads to damage to human health. Drinking water is affected and health hazardsresult. Direct damage to plants and animal's nutrition also affects human health, globally agriculture and the overexploitation of plants and animal species are significantly greater threats to biodiversity than climate change because nearly three-quarters [about 62%] of the world's threatened species faced these threats, compared to just 19% affected by climate change (Owa, 2014). Water pollution adversely affects the health and life of man, animals and plants, in India polluted water causes some of the deadly diseases like cholera, dysentery, diarrhoea, tuberculosis and jaundice. About 80 per cent of stomach diseases in India are caused by polluted water (Khatun, 2017).

Biomas and diversity of communities are to be expected when large number of toxic materials is released into the streams, lakes and coastal waters in the ocean (Owa, 2014). We could then afford to foul one water source, abandon it, and move on to another. This, however, is no longerpossible since the exponential growth rates of human population have already reduced the availability of water to below its per capita availability (Reddy, 2004). Water pollution leads to damage to human health. Disease carrying agents such as bacteria and viruses are carried into the surface and ground water (Owa, 2014). Most detergents and washing powders contain phosphates, which are used to soften the water among other things (Gambhir *et al*., 2012). Todaya bath in Yamuna and Ganga is a sin against bodily health, not a salvation for the soul, so pollutedand noxious are these holy waters now (Reddy, 2004).

In India, the pollution of water is tortuous act. It is covered by the tort of nuisance as it causes injury to person and property, comfort of health (Pathak, 2013). Although end of pipe approaches has reduced the direct release of some pollutants into surface water, limitations have been encountered (World Health Organization: (WHO) & UNEP, 1997). Changing the pH of wastewater or adding chemicals that flocculate the toxic chemicals so that they settle in sedimentation pondsare common methods (Kinniburgh & Smedley, 2001). Another way to join or get involved with pollution prevention is to practice efforts on your own or join projects or programme (Owa, 2014).Water pollution control requires action at all levels and the ideal method to abate diffuse chemicalpollution of waterways is to minimize or avoid the use of chemicals for industrial, agricultural, anddomestic purposes (Scheierling, 1995). With regard to the generation of wastewater, pollution prevention and minimisation technologies are mainly implemented in the industrial sector (WHO& UNEP, 1997).

Other interventions include proper treatment of hazardous waste and recycling of chemical containers and discarded products containing chemicals to reduce solid waste buildup and leaching of toxic chemicals into waterways (Kinniburgh & Smedley, 2001). There is also a need to institute a regulatory framework for management of e-waste and compel industries that generate waste to put measures in place to reduce pollution (Failler *et al*., 2016). The main formsof land and sea use are fisheries, tourism, agriculture, industry, forestry, shipping/ports, mining, conservation, housing and infrastructure (Failler *et al*., 2016). Sewage is first passed through series of steps: screens, comminutor, grit chamber, and settling tanks (Coker, 2013). In the past, pollution prevention and minimisation were an indirect, although beneficial, result of the implementation of water conservation measures (WHO & UNEP, 1997). There are many approaches that could be adopted in water pollution control and management (Owa, 2014).

2.5 Status of water pollution in Africa

Water pollution occurs when unwanted materials enter into water, changes the quality of water and make it harmful to environment and human health. Water is an important natural resource used for drinking and other developmental purposes in our lives (Haseena *et al*., 2017). Conventional or classical pollutants are generally associated with the direct input of waste products (Coker, 2013). The nonconventional pollutants include dissolved and particulate forms of metals, some of them highly toxic and may accumulate in fish. Coker (2013) maintained that more than 13,000 litres oil spills of varying magnitude occur in the United States each year. Waterpollution is a global issue, and the world community is facing worst results of polluted water. Major sources of water pollution are discharge of domestic and agriculture wastes, population growth, excessive use of pesticides and fertilizers and urbanization (Haseena *et al*., 2017). According toGarcia *et al*. (2017) agriculture is regarded as one of the main sources of surface and groundwaterpollution. It increases suspended solids and organic matter concentration with the subsequent eutrophication. In addition, there is a differential impact in river water quality that depends on theproportion of altered basins, riparian forest and kind of crop (Garcia *et al.,* 2017).

Africa’s expanding economies are resulting in greater demand for freshwater, but its quantity is decreasing, and quality is deteriorating as a result of over exploitation, climate change and pollution (UNEP, 2012). The impact of pollution has been widespread in all aspects of the villagelife. However, here we focus on three important impacts for an in-depth analysis. These are impacton water resources, Impact on employment, livestock, health, and impact on crop production and other agricultural activities, and impact on livestock (Reddy & Behera, 2005). Some water pollution effects are recognized immediately, whereas others do not show up for months or years(Afroz *et al*., 2014). As more people move into towns and cities in Africa, they contribute to a number of factors that lead to water pollution (UNEP, 2012). Chemicals from industries in urban areas also cause water pollution (UNEP, 2012). Before going into the details of analysing the impacts of pollution on various aspects, it would be pertinent to examine the impact of industrial pollution on water sources or bodies. For that reason, the impact on village community is routed through water bodies (Reddy & Behera, 2005).

Water pollution in the continent is naturally influenced by the climatological and geochemical location of the water body through temperature, rainfall, leaching, and runoff of elements from the Earth's crust (UNEP,2016). The increase in the number of extreme precipitation events and other unusual weather events in Southern African countries strongly suggest that weather conditions are changing. Moreover, the availability of sediment increased with the increasing soil moisture content in the area (Bhuiyan *et al*., 2013). During the rainy season, there is adequate seepage of water into the ground, the indicative organisms or other pathogenic microorganisms thereby find their way into the well. This case occurs when or where the well is so close to a septic tank and so on (Taofeek *et al.,* 2014). UNEP (2016) has commented on the typical water pollution problems, causes and impacts over the last 50 years and an intense urbanisation process has taken place in Southern Africa region. Bhuiyan *et al*. (2013) point out that due to increase of the number of populations diversity in the earth every day have caused of rapidly increased in demand for water resources needs and increase in occurrences of pollution density of numerous water sources, environmental risks to humans andother life beings are enhanced.

In view of population increase, demand for freshwater for all the uses will be unmanageable (Mali*et al*., 2015). Suspended sediment resulting from agricultural fields impairs aquatic life by reducingsunlight, damaging spawning grounds and becoming toxic to aquatic organisms (Mali *et al*., 2015). These collectively exert enormous pressure on the country's natural resources and triggera breakdown of the water, sewerage, waste disposal and transport infrastructure, leading to higher levels of water-borne and respiratory illnesses (Failler *et al*., 2016). In Kenya, water pollution is considered to be a fatal main source of pollution. Every human being needs water ona daily basis, and there is a high chance of being affected by water pollution (Failler *et al*., 2016).Intensification of agricultural activities with increasing use of fertilizers and pesticides and allied livestock activities have an adverse impact on water quality (Mali *et al*., 2015). With rising levels of water pollution, surface water bodies as well as groundwater in certain parts of India are becoming unsuitable for agricultural use (Mali *et al*., 2015).

It also varies unpredictably over timeand space and is governed by rainfall patterns, land slope, soil characteristics, land use and cropchoices, production techniques and the intensity of fertilizer and pesticide use (Mali *et al*., 2015).

2.6 Water pollution in South Africa

In South Africa WHO has analyzed control strategies for biological water pollution and water and sanitation improvements in relation to the Millennium Development Goals (Hutton & Haller, 2004). The analysis demonstrated the considerable benefits of water and sanitation improvements for a number of intervention options. Careful analysis of the same type is required for populations particularly vulnerable to chemical water pollution to assess whether control of chemical pollution can also yield significant benefits (Hutton & Haller, 2004).

Musingafi and Tom (2014) confirmed that the contamination of the Gauteng Province's groundwater and surface water is considered detrimental for future plans to access groundwaterto cope with the growing demand for water in the province. Musingafi and Tom (2014) suggest that in Gauteng Province during rainy seasons, the resulting floods carry all the pollutants from human made activities and disposals into catchment water systems resulting in disasters if water treatment and reticulation is below standard. Many industrial processes in South Africa produce waste products that contain hazardous chemicals, and these are sometimes discharged directly into sewers, rivers orwetlands (Musingafi & Tom, 2014). It was noted that pollution of water sources is a major threat to the scarce water resources in the province. This severely affects water pollution and quality and impacts negatively on public health, particularly in remote rural communities that are rarely supplied with treated municipal water. In Limpopo Province such communities rely on directly abstracted untreated water from rivers, boreholes, springs and rainwater harvesting (Odiyo & Makungo, 2012). Odiyo and Makungo (2012) however, discovered that human made activities such as effluent released by the growing industrial sectors, domestic (residential) and commercial sewage, acid mine drainage, faecal contamination (agricultural sector) linked to insufficient infrastructure and leakingsewers, improperly sited sanitation systems, domesticated animals grazing too close to water sources, agricultural runoff, and litter and natural sources such as geology contribute to water pollution.

Karataş (2016) have shown that in South Africa the rainwater or melted snow can transfer materials such as oil,litter, fertilizers, and salt down storm sewer inlets found on the streets. In some South Africa areas, the storm sewer transports this polluted water to a water treatment facility. Different types of pollutants affecthuman health in different ways (Karataş, 2016). Several attempts have been made to group water pollutants into classes or categories. Pollutants have been classified according to their mode of occurrence into physical, chemical and biological pollutants (Agarwal, 2009). Karataş (2016) argued that these pollutants can come from a specific source such as a pipe that discharges used water or other material from a factory into a water body. South Africa pollutants can also come from large areas such as agricultural fields that have been covered with fertilizer or pesticides.

Occurrence	Nature	Examples
Physical water pollutants	Water pollutants of temperature and turbidity	Wood chips
Chemical water pollutants	Water pollutants of Inorganic and Organic	Nitrites
Biological water pollutants	Water pollutants of pathogenic and nuisance organisms	Viruses
		Slime

Table 2.2. Different types of water pollutants. **Source: (Agarwal, 2009)**

2.7 Legislative framework of water pollution in South Africa

At present, there are numerous existing national water legislations and policies to prevent water pollution in our country. The Constitution under Chapter 2 provides environmental right for everyone to have the environment protected for wellbeing for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation; promote conservation; and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development. (Chapter 2 of Bill of Rights and Section 24 of the Constitution of South Africa Act 108 0f 1996). NHA, section 21, makes provision for environmental health standards and practitioners (NHA, 2003). The WPIPWM makes provision under key issues for water pollution control and prevention(WPIPWM, 2000). Section 19 under Part four of NWA makes provision for prevention of pollution by the owner of land conducting activities (NWA, 1998). NEMA principle 4 (ii), gives mandate and provision for prevention of environmental degradation and pollution (NEMA, 1998). However, neither these legislations nor policies tend to adequately address the problems of water quality in our country. Therefore, there must be a requirement for more effort to protect water and the lack of implementation of water legislations, policies have subsequently created a gap of pollutionand water quality. Pollution can be managed by relevant legislations and policies to handle scarcity of quality water in South Africa.

Relevant legislation	Relevant provision	Provision description	Relevant authority
Constitution 108 of 1996	It makes provision under 24 act	It makes provision, and prevention of pollution	Justice and Constitutional
NWA 36 of 1998	The provision is in Chapter 3, Section 19 part 4 of act	It gives provision to prevent pollution	Water and Sanitation
NEMA 107 of 1998	It makes provision in (i) and (ii)	Pollution and environmental degradation should be avoided and minimised	Environmental Affairs
White Paper on Integrated Pollution and Waste Management, 2000	It makes provision in Chapter 3 and Section 3.1 of the white paper	It makes provision under key issues for water pollution control and prevention	Environmental Affairs
National Health Act, 61 of 2003	The provision is in Chapter 3, Act	It makes provision for National Environmental Health Norms and for implementation	Health

Table 2.3. South Africa water pollution related legislations and provisions.

2.8 Conclusion

Based on the review of the literature, there was a gap in terms of the enforcing legislation around water pollution and activities that contribute to water pollution in South Africa.Furthermore, there are no proper strategies to prevent water pollution from occurrence. The literature review was done to identify the water pollution from human made activities to show the gaps that were currently existing. A discussion around ways of managing water pollution was also presented in the Chapter. Based on the review of the literature, there was a gap in terms of enforcing legislation that prevents water pollution in South Africa Rivers systems and there were no proper strategies to prevent water pollution from occurrence. The literature review was done to identify the water pollution human made activities to show the gaps that were currently existing in the study. Lastly, legislations that were referred to in the study were considered as the most important factors in the management of water pollution and quality.

CHAPTER 3: MATERIALS AND METHODS

3.1 Introduction

This chapter was mainly focusing on the research materials and methods that was employed in this study. The description of the study area, research design, population and sampling, data collection and data analysis. Both qualitative and quantitative research designs was considered and described in more detail. The chapter was also look into how the study area coordinates was identified and how the location of the site was identified as well as described. Lastly, the chapter was also focus on the water chemistry sampling, sediment chemistry sampling, field survey and macroinvertebrate sampling that was identified and described in detail. There was a need to maintain the different results and analysis in this chapter. The aspect of the sampling was considered in this chapter even look into the research materials, methods and there was a need to discuss the role to design the reach based on the evidence obtained.

3.2 Description of the study area

The research was conducted at Zandspruit system around Cosmo City within the Johannesburg Metropolitan Municipality (JMM), which falls under Ward 100 in the Johannesburg area. Zandspruit is 25 km away from Central Business District. The study was conducted in MalibongweDrive between Randburg and Lanseria Airport in Zandspruit River system (Figure 3.1). The sitescoordinates from site one to site five area are site one – 26°2.721'S 27°54.966'E, site two – 26°1.608'S 27°55.175'E, site three – 26°0.595'S 27°56.156'E, site four – 26°0.828'S 27°56.015'E and site five – 26°0.961'S 27°55.937'E. Zandspruit River system flows through Cosmo City development activities. The study area which was a Greenfield Project was located in the northwest of Johannesburg's City Centre (Figure 3.1). Cosmo City was established in 2004. Thearea has become a welcoming haven for people of all social and financial backgrounds.Zandspruit River system is characterized by human made activities from domestic activities at different locations across Cosmo City.

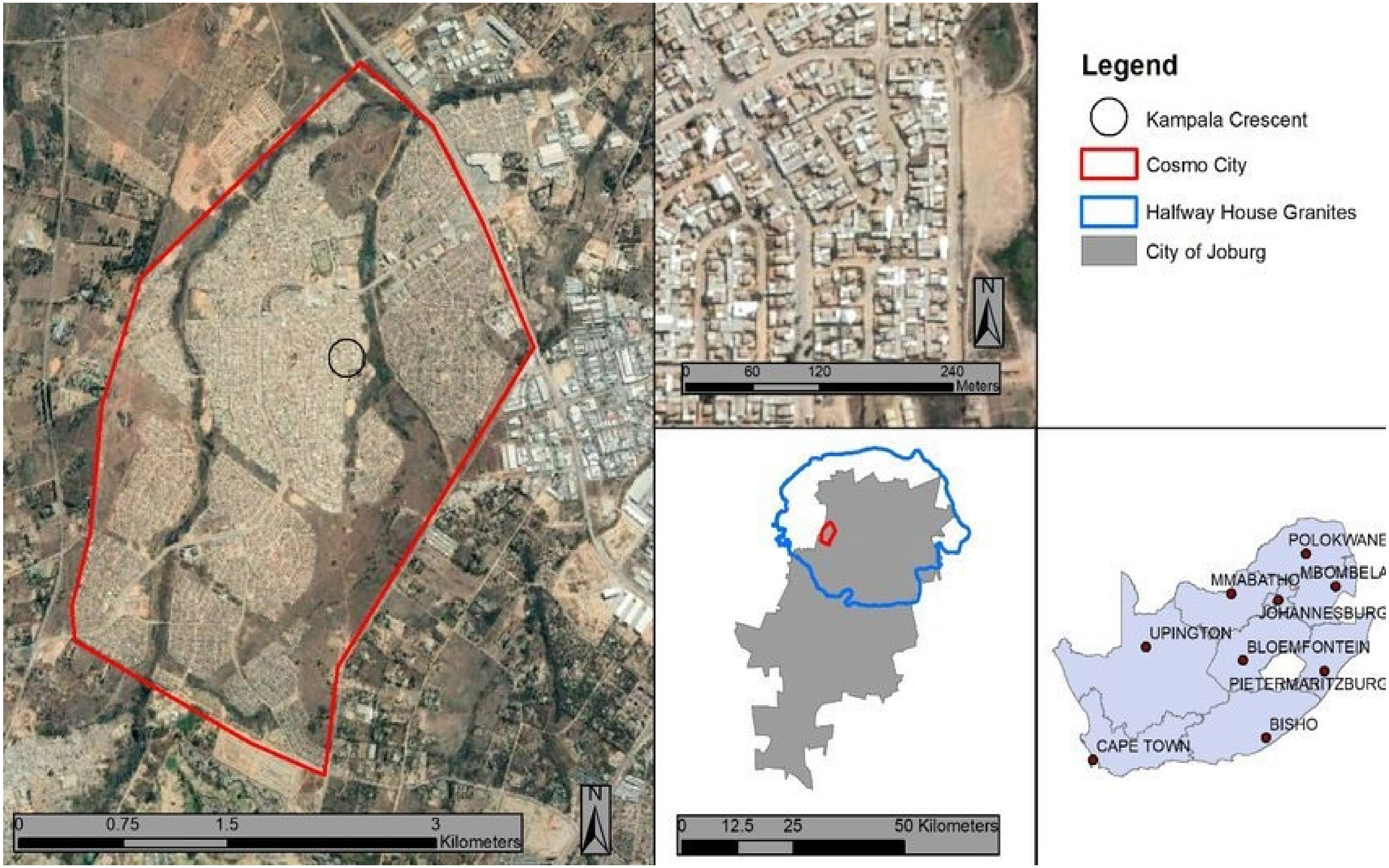


Figure 3.1. Study area, Cosmo City. **Source: Zijl *et al.*, 2020**

3.2.1 *Vegetation cover*

The Cosmo City is characterised by both flora and fauna species from protected conservation area in Cosmo City's natural environment. The Zandspruit River system is also characterised byriparian vegetation along the Zandspruit River system and is rich in reeds, the area also has alienvegetation in the bush while some species are dependent on the vegetation for habitat in the area.The area has natural fauna, flora, wetlands, and streams surrounding the Zandspruit River system. The area is also rich in forest in the conservation area and there is also indigenous vegetation planted across the area, especially in the parks, open spaces and green belts as wellin tree parks along the streams and Zandspruit River system. Indigenous and alien plants contribute significant biodiversity and natural spaces of streams or natural wetland areas aroundCosmo City Zandspruit River system.

3.2.2 *Rainfall*

The study is characterized by humidity during the day with temperature ranging between 16.3 °C in June to 26.1 °C in January. Cosmo City area temperature humidity weather throughout July with decreased to 0.5 °C on mean during the night. The annual average rainfall experienced in Cosmo City is 607mm, more rainfall experienced in summer. The development and subsequent surface sealing of the area caused an increase in runoff and stream flow, but reduced the evapotranspiration, lateral flow, and deep percolation (Zijl *et al*., 2020).

3.2.3 *Geology*

Cosmo city is characterised by rocky outcrop area as well as the hillslope and clustered geological types in the area. The area is rich in flora as well as fauna for the forest mainly from natural geological features and natural terrain. The area is considered to have landscape which includes:slope, profile curvature, planform curvature, aspect, topographic wetness index, flow accumulation, altitude above channel network, relative slope position, and multi resolution indexof valley bottom flatness (Zijl *et al*., 2020). The geological features in the area are typically used to simulate the quality and quantity of surface and ground water and to predict the environmentalimpact of land use, land management practices, and climate change (Zijl *et al*., 2020). The terrainis hilly, with slopes of up to 12%, but with the majority of hillslopes having an average slope of below 5% (Zijl *et al*., 2020).

3.2.4 Land use activities

Current activities in Cosmo City are characterized by rural development project that has three main activities namely commercial, residential and industrial that are next to the Zandspruit Riversystem. However, some potential activities were agricultural irrigation, fishing, recreation, water extraction and habitat for aquatic ecosystem. There are natural conservation activities characterized of conservation area as well as nature reserve preserved forecosystem environmental species diversity

3.2.5 Socio-economic activities

Study area located near Randburg around Johannesburg in Gauteng Province which representsan intertwining of the socio-economic activities and environmental problems of urbanisation. It is characterised by many economic factors which contribute to the increase in the economy aroundthe area creating small scale jobs for local dwellers. Farming is recognised in the area as another economic activity in the community small scale farmer such as cropping. There are establishments such as development activities which contribute to the improvement and increasein local economy in the area. The area is characterized with many human made activities of residents and property owners.

3.3 Research design

In this study a sequential research design was adopted, identified and developed. A developed sequential mixed methods exploratory research design was used for this study. The study utilizedboth quantitative and qualitative design. The Zandspruit River system was divided into blocks andthis was done through identifying possible water pollution entry into the Zandspruit River system.Sequential research design was used whereby the first sequence was experimental design to collect samples from the identified study areas over a series of times. In the sequential researchdesign, a researcher typically connects the two phases while selecting the participants for the qualitative follow-up analysis based on the quantitative results from the first phase (Creswell *et al.,* 2003). Sequential research designs include elements of both longitudinal and cross-sectionalresearch designs (Schaie & Baltes, 1975).

3.4 Sampling

The water chemistry, sediment chemistry and macroinvertebrate samples were collected in the five selected sites points along the Zandspruit River system for the entire identified sites for the sampling days. The sampling was identified based on the site receiving pollutants from different activities including agriculture, industrial effluent, and domestic waste. The sampling was considered based on the level of pollution from community activities along the Zandspruit River system and the sampling point was identified based on the impacts of activities in the area. The sample was divided into blocks and spread across the Cosmo City site but mainly along the Zandspruit River system in order to ensure that the targeted respondents have enough knowledgeabout water pollution to help achieve research objectives. Sampling was looking at the downstream users as well as the upstream and to select or pick some few people from the proposed interest group. The sampling upstream and downstream was to check water pollution level in the region before the river cross Cosmo City and the region is not influenced by development of Cosmo City and downstream region influenced by Cosmo City Development. It was also prudent to sample a region of the river within the Cosmo City (middle of Cosmo City) where the development of the Cosmo City may have significant effect to water pollution since on the downstream other activities such as agriculture may also have an effect.

The sampling was done in four consecutive days on Tuesdays and Wednesdays, respectively forboth downstream and upstream for water quality. Sediment quality and macroinvertebrates, andfield survey to check water pollution and the quality of water thereof. During the sampling some of the sites were accessible while other sites were not accessible and inclement weather contributed to inaccessibility to the site. There were a few areas of research study which consist of very dry sampling days among Zandspruit system. Five sampling sites were identified in Zandspruit River system, and all sampling sites were checked. Two sampling points were in the northern side of Zandspruit River system while three sites were on the southern side of the Zandspruit River system. All five sampling sites include inlets flow of discharge and outlets flow of discharge around the Zandspruit River system which were identified and selected, as well as sampled. Site one and site two were identified in the downstream of the Zandspruit River systemand sites three, four and five were identified in the upstream of the Zandspruit River system.

The total number of samples collected was five and water chemistry variables were collected during the end of April and early June in hot and sunnyfour days: from 6 April 2021 to 7 April 2021 and 1 June 2021 to 2 June 2021 and April and June was selected because was the best dry months to collect samples to avoid rainy months. The times of collection were from 9h00 to 16h00 during the sunny hot dry month. The total suspended solids and pH were measured using a HACH DR/2010 spectrophotometer, based on standard methods from Environmental Protection Agency (EPA), and Standard Methods (Nhiwatiwa *et al.,* 2017a). The water was collected from Zandspruit River from upstream to downstream using plastic containers, and the containers were labelled for all five sites and the samples were stored in 500mL containers. The samples were sealed and immediately sent to the BEMLAB laboratory, and the water samples were filtered onto filter paper before being stored into the deep freezer for threedays. The water was stored in the fridge at the University of Venda in the 10 ˚C stores for one week and then sent to the BEMLAB laboratory for analysis.

The first samples collection was done during the end of April dry month and the second samples collected in early June wet month. The five sites weredetermined for both macroinvertebrates, sediment chemistry and water chemistry of which out offive sites visited, two (site one to site two) were from downstream Zandspruit River system whilesites (three to site five) where mainly from the upstream Zandspruit River system. Zandspruit River system in Cosmo City is exposed to numerous water pollution sources from activities practiced along the streams. In this study, only five sites were selected and sampled for determination of water chemistry, sediment chemistry and macroinvertebrates.

3.5 Determination of environmental variables

3.5.1 In-situ measurements

Five sampling sites for water chemistry (n = 5) acquired in 500 mL plastic bottles among sampledarea included Zandspruit River, inflows, outflows including streams water chemistry. The water chemistry included pH, alkalinity, electrical conductivity, langelier index, saturation pH, sodium adsorption ratio (SAR), chloride (Cl), sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), sulphur (S), sulphate (SO_4), iron (Fe) and manganese (Mn). Five sampling sites for sediment chemistry (n = 5) acquired in 500 mL plastic bottles among sampled area included Zandspruit River, inflows, outflows including streams sediment chemistry. The sediment chemistry included pH, electrical resistance (EC), p bray i (P), sodium (Na), potassium (K), calcium (Ca), magnesium(Mg), sulphur (S), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), organic carbon (OC). During the sampling of all five sites, the sediment chemistry was measured for parametersof pH, temperature (°C), conductivity (mS/m) and alkalinity (mg/L).

3.5.2 Water chemistry variables

The water chemistry variable was at least collected from five sites points from Zandspruit River system of Cosmo City for BEMLAB laboratory analysis. During data collection, the water from samples was collected in stopper fitted polyethylene or polypropylene bottles which were labelledfor all sites from site one to site five, the bottles were cleaned with water by removing duty materials before being filled with water samples. All the water bottles were put in the freezer at 4 ˚C before the analysis at the BEMLAB laboratory. The BEMLAB is a certified laboratory according to South African National Accreditation System (SANAS). The BEMLAB conducted the metal analysis. Thebottles were kept in an upright position to prevent water entering into or leaking from the container.

The water from samples was collected in the mornings and afternoons. Collected data was stored using ice for few hours, to be analysed later. Living organisms were separated from water sample and were taken back to the Zandspruit River system. The water pH and temperature were measured in all five sites of the Zandspruit River system using portable measuring device and thelevels of pollution were measured. However, in Zandspruit River system, the inlet flow dischargefrom Cosmo City development and outlet flow discharges out of Zandspruit system sites were measured among five sampling site across stream. Water samples (500 mL, n = 5) were collectedin 500 mL plastic bottles from all sampled sites such as river, inlets, outlets including streams, forfurther chemical analysis and were analysed.

3.5.3 Sediment chemistry variables

The sediment chemistry variables were conducted in Zandspruit River system sites and were collected at the upstream and downstream of the Zandspruit River system for all five sites visited. Monthly changes were also identified for April and June for all sites. The sediment was collectedfrom Zandspruit River water utilizing hand shovel plastic. Chemistry variables were collected andstored in 500 mL glass bottles from all five sites from downstream to upstream and the bottles were labelled. Sediment chemistry sampling bottles were washed before use and then placed inthe plastics containers. Water was immediately separated from the sediment to remove moistureduring sediment sampling collection. During the sediment chemistry sampling collection, the remaining water was removed from sediment samples and roots and other debris were also removed from the sediment chemistry samples. The sediment chemistry samples were stored inthe fridge at the University of Venda in the 18 ˚C stores for one week and then sent to BEMLAB.

Integrated sediment samples (1.5 kg, n = 5) were collected at the centre and littoral zones of eachsite using a plastic hand shovel after the removal of the overlaying debris to a depth of about 5 –10 cm into the sediment layer (Dalu *et al*., 2017). Samples were then stored in polyethylene 500mL glass bottles (Dalu *et al*., 2017). The study, however, considered the following metals EC, P,Na, K, Ca, Mg, S, Fe, Zn, Mn, Cu, B and Cl were analysed and determined from site one to site five in Zandspruit River system for both April and June months including sediment organic matteras well as organic carbon were determined using the modified Walkley–Blackmethod (Chan *et al*., 2001). The sediment quality guidelines for freshwater (MacDonald *et al.,* 2000) were used todetermine organic matter. Sampling sediment for heavy metals were determined and analysed inthe laboratory.

3.6 Population

The estimated population for the survey in Cosmo City was 44,295(4,476.06 per km^2) which were households in Cosmo City area (Census, 2011). The activities tobe sampled included residential, commercial, fishing, farming and industrial.

3.7 Field survey

The sample collection was followed by a survey where data was collected from sampled community members within the site. The field survey was conducted with community members living around Cosmo City in the study area next to the Zandspruit River system. Field survey wasdesigned to collect data from the randomly selected people downstream as well as in the upstream of the Zandspruit River system to confirm or give their view about the possible impact of water pollution. The survey used interviews with some residents (including residential, commercial and industrial), farmers and fishermen, downstream. The field survey was mainly focusing on the selected people especially those living along the Zandspruit River system. The survey intended to engage with at least twenty respondents among community members, including fishermen, farmers, residents (including residential, commercial and industrial) who lived next to Zandspruit River system. Subsequently, twenty people who live along the ZandspruitRiver system was selected to participate in the survey.

3.8 Macroinvertebrate sampling

Macroinvertebrate's sampling was collected using the kick sampling method (Dickens & Graham, 2002). The kick sampling method involves the collection of sediment and rocks from the water which were kicked with feet while sweeping the net in a zig-zag manner to dislodge any attached macroinvertebrates using a hand-held kick net. In each of the sampling site, approximately six minutes were spent sampling all aquatic habitats and the samples were combined to form one composite sample. During the laboratory process, all macroinvertebrates were counted, recordedand selected. In this study, macroinvertebrates were sampled from the Zandspruit River system sites from one to five river sites using a nylon hand net (mesh size 500 µm, dimension 30 × 30 cm), with an aluminium rim handle which was extended to allow sampling distance of up to 1.5 mradius (Dalu *et al*., 2012).

The study considered the kick sampling which was followed by performing the South African Scoring System guidelines (Dickens & Graham, 2002). Macroinvertebrate samples were placedin 500 mL plastic sampling containers kept in 70% ethanol mixture. At University of Venda lab, macroinvertebrate selected where recorded as well as counted using macroinvertebrate identification guidelines (Gerber & Gabriel, 2002; Gooderham & Tsyrlin, 2002; Stals & Moor, 2008). In this study, sampling collected utilizing hand net by kicking samples and were collectedfrom river water from all five sites from upstream to downstream. The South African Scoring System version 5 (SASS 5) score, which is the sum of all macroinvertebrates pre-determined taxatolerance values to pollution within a sample, and the average score per taxon (ASPT), calculatedby dividing the SASS 5 score by the sample taxa number (Dickens & Graham, 2002). In this study,macroinvertebrates were stored in the 500L bottles and labelled, and stored in the fridge at the University of Venda in the 18 ˚C stores for one week and were then counted and recorded using Aquatic Invertebrates of South African Rivers Field Guide (Gerber & Gabriel, 2002). The followingmacroinvertebrates family were counted and recorded from site one to site five in Zandspruit Riversystem for both April and June: Dytiscidae, Gerridae, Hydrometridae, Aeshnidae, Chlorolestidaeand Lymnaeidae this were only macroinvertebrates identified out of other macroinvertebrates families.

3.9 Data analysis

The data that was collected during April and June sought to identify macroinvertebrates taxa, determine water chemistry and sediment chemistry as well as significant impact of the human made activities in Zandspruit River system across the sampled sites. All quantitative data analyses were carried out and analysed using Statistical Package for Social Sciences (SPSS) version sixteen (16) for both survey and samples (SPSS Inc., 2007). The two-way ANOVA quantitative data was used to check the relationship between the sediment chemistry and water chemistry variables in the Zandspruit River system streams between two months using the Statistical Package for Social Sciences (SPSS) version sixteen (16) (SPSS Inc., 2007). The biological water chemistry along the selected Zandspruit River system was assessed, macroinvertebrate community structure patterns were also evaluated using SASS score, ASPT score, Taxa richness and Shannon–Weiner (Shannon & Weaver, 1949; Margalef, 1958). The macroinvertebrate taxa among different species diversity were also grouped based on the upstream and downstream for Zandspruit River based on human made activities and were also assessed across two study months for all five sampled sites.

The South African Scoring System version 5 (SASS 5) score, which was the sum of all macroinvertebrates pre-determined taxa tolerance values to pollution within a sample, and the Average Score Per Taxon (ASPT), calculated by dividing the SASS5 score by the sample numberof macroinvertebrates taxa identified, recorded and counted across sampling sites (Dickens & Graham, 2002) for water pollution quality on the Zandspruit River system. The Average Score per Taxon (ASPT) index was also calculated, which indicates the average tolerance score of all identified macroinvertebrate taxa per site (Dalu *et al*., 2017). The variables for water chemistry metals were analysed using parameters such as temperature, pH, alkalinity, electrical conductivity, langelier index, saturation, sodium adsorption ratio as SAR, chloride as Cl, sodium as Na, calcium as Ca, potassium as K, sulphur as S, sulphate as SO_4, iron as Fe total and manganese as Mn total was analysed and identified.

The ASPT was calculated by dividing the SASS5 score by the number of families present at eachsite (Dalu *et al*., 2017). The variables for macroinvertebrates families Dytiscidae, Gerridae, Hydrometridae, Aeshnidae, Chlorolestidae and Lymnaeidae were recorded and counted for all five sampled sites across the Zandspruit River streams for two months. The variables for sediment chemistry were analysed and identified using parameters such as pH, electrical resistance as EC,p bray i as P, sodium as Na, potassium as K, calcium as Ca, magnesium as Mg, sulphur as S, iron as Fe, zinc as Zn, manganese as Mn, copper as Cu, boron as B and organic carbon as OC for all five sites and for both April and June months at Zandspruit River system, for both downstream and upstream activities to measure water quality pollution. In terms of the qualitativedata collected from the respondents the analysis was more on perceptions especially from thosepeople living along the Zandspruit River system.

The water chemistry variables and sediment chemistry variables were compared for all five sites visited, for both April and June on the river system. Macroinvertebrates were also recorded and counted which were compared with the different types of months for both April and June. The macroinvertebrate was scored using the South African Scoring System (SASS) score, ASPT score, Taxa richness and Shannon–Weiner conducted family. The score range include five sampling sites per six macroinvertebrates and the higher the score the lower the macroinvertebrates and the lower the score the higher the macroinvertebrates. The macroinvertebrate taxa data were log transformed to reduce the effects of extreme values, with exception of pH permutation tests which were used to test the significance of the index results (Dalu *et al*., 2017). The macroinvertebrate variables were used to analyses whether macroinvertebrate abundance and environmental variables differed between river sections (main river, streams) and months (April, June) (Anderson *et al*., 2008). The water metals and sediment metals were evaluated and determined among sampling sites across Zandspruit River as well as stream.

The quantitative data was also analysed using SPSS version 16 with the residents, farmers and fishermen who were interviewed, and it was then recorded by hand and captured on the computer software using Microsoft Excel 2013 spreadsheet and Canoco version 5.1, and this was considered data assess results. Quantitative data were also analysed using the DS analysis system to evaluate data utilizing the tables and graphs analysed to calculate data index. The quantitative data was also analysed using two-way ANOVA which was also considered and used to check thelevel of the relationship between the variables and the difference between the variables for residents, farmers and fishermen. The two-way ANOVA technique was used to check if there wasa mean of groups of activities and if they were significantly different among each other and also utilized to examine impact of activities on the Zandspruit River system streams. The quantitativedata was analysed using Chi-Square test and to calculate the difference in the residents, farmersand fishermen living along the Zandspruit River system streams water quality pollution from different activities. The macroinvertebrate abundance and macroinvertebrates taxa richness were also calculated on counting the most dominant and abundance of the macroinvertebrates.

Objectives	**Data source**	**Data analysis**	**Questions**	**Data analysis techniques**	**Types of data**
Evaluate the contribution of integrated development project activities to Zandspruit River systempollution in Cosmo City	Water quality test and review of relevant documents	Arc Explorer	What is thelevel of pollution by Cosmo City development on the ZandspruitRiver system?	Two-way ANOVA, Descriptive Statistics and Chi - Square	Quantitative

Characterize and measurethe major pollutant sources on Zandspruit River system associated with Cosmo City	Water quality test, focus group and relevant documents	Quantitative data analysis (Arc Explorer and GIS)	What is the extent of the pollution by Cosmo City development on the ZandspruitRiver system?	Descriptive Statistics	Quantitativeand qualitative data
Analyse the potential impact of thepollutants associated with the Cosmo City development on the downstream	Water quality test, focus group and documents	Qualitative and Quantitative data analysis	What is the impact of the Zandspruit River system pollution on the downstream development activities?	The SASS score, Shannon-Weiner diversity index, the macroinvertebrate taxa richness, Two-wayANOVA, Descriptive Statistics	Quantitativedata
Recommend strategies to minimize the level of pollution by integrated development activities on adjacent river	Focus group and relevant documents	Qualitative data analysis	Which strategies can be implemented to minimize the level of pollution by Cosmo City development on the ZandspruitRiver	Descriptive Statistics	Qualitative data

			system?		

Table 3.1. Data collection and analysis process

3.10 Conclusion

The conclusion of the research materials and methods considered that the materials and methods of the study was well evaluated and described. All aspect of the methodology was also identified including design of the research population, sampling and results was also discussed in this chapter identify all gaps to be followed. Lastly the most important aspect of the study was the use of both qualitative and quantitative questionnaires of the study. The water chemistry variables, sediment chemistry variables, field survey and macroinvertebrate variables were also described in detail in this chapter. The relationship between the water chemistry variables, sediment chemistry variables and macroinvertebrate variables were of importance in this chapter and very well relevant to the discussion of the study methodology. The overall research methodology was discussed in this chapter in full detail considering the facts observed in the other research methodology and compared. Lastly, sampling protocol was also presented in this chapter in detail and how they were importance in the study.

CHAPTER 4: RESULTS AND DISCUSION

4.1 Introduction

This chapter mainly focusses on the research results and discussion that was being employed in this study. The main identification and discussion of the water pollution of Zandspruit River system as well as the description of the sediment quality and macroinvertebrate communities. The relationship between water quality, sediment quality and macroinvertebrate communities has been discussed in detail on the research study. The results of the research were crucial, and it shows the different types of water pollution results from community contribution to the Zandspruit River system pollution from upstream to downstream human made activities near by the river. This chapter has to lastly check into considering the way study results and discussion to be presented and described in full detail and any kind of the gap thereof identified in the study area in Cosmo City and Zandspruit River system that pollution impacted the water quality. The research results and discussion were considered in this chapter based on the observation from field visit and other method of reporting study results.

4.2 Results

4.2.1 Respondents' view on water pollution in Zandspruit River system in Cosmo City

The respondents who participated in the interview are fishermen, farmers, residents who are contributing to human made activities adjacent to the Zandspruit River system downstream. The respondents commented on the major pollutants along the Zanspruit Rivers system, and this is what they said:

*"The main water pollutants in our area are from residential, commercial and industrial activities."*The residents on the downstream mentioned that integrated development project activities can be regarded as the major pollutant. Another source of pollution is from illegal dumping of waste, overflow of raw sewage, siltation and erosion on the streams. Over population can also be regarded as another source and this was a view from one of the respondents. Poor and lack of waste management, raw sewage management and maintenance of the stormwater channels arealso the causes of the pollution in the area. Proper implementation of by-laws on the prevention of illegal dumping on streams mainly from residential activities is lacking. There is also a need forinstallation of signage for dumping prohibition, continuous fixing of the main holes and proper management of stormwater channels.

The major pollutants are from illegal dumping into the water and littering along the streams. Thisview was expressed by one of the residents in the area.

"The main pollutants in our area are mainly illegal dumping into the water and littering along the streams."

The major pollutants are mainly from residential activities, especially illegal dumping and litteringalong the streams perpetrated mostly by fisherman, farmers and residents, according to one respondent. There is a need for the fisherman, farmers and residents to refrain from dumping waste and littering into the streams, because it is contributing to pollution in the area. One respondent confirmed that Cosmo City development has the potential to contribute to the pollutionof the area and the river:

"*The overflow of raw sewage on continuous basis in my area is the other pollutant that has impacted negatively on water quality*."

The continuous overflow of raw sewage contributes to pollution of water, and it affects species diversity in the area on the downstream, through soil erosion and sedimentation. The main problem is that the municipality is not attending to the raw sewage in time and the raw sewage continues to pollute the water. There is a need for the municipality to attend to management of erosion. Some respondents' view is that there are no strategies from municipality to minimize thelevel of pollution from development activities in the area, where some respondents said:

"There are currently no strategies from municipality to minimize the level of pollution caused by development activities in our area."

In relation to the above challenge, there is no sustainable strategy to minimize the level of pollution caused by development activities adjacent to the Zandspruit River system. The municipality must continuously implement strategies that curb pollution. Other respondents indicated that the main source of pollution is from natural causes which affect the quality of water in Zandspruit River:

"There are currently lack of management of water pollution and poor control of water pollution inthe area."

The main challenge is that there are no water pollution management and control being implemented by the municipality. The municipality must continue to implement water pollution management and control in Cosmo City, and this will help in mitigating and reducing the water pollution in the study area significantly. The municipality must also implement the continuous water pollution management and control on a regularly basis across Cosmo City area. Another respondent shared the following view:

"There are sources and causes of water pollution in our area."

The major sources and causes of pollution are mainly from garbage discharged as well as waste, including littering, which affect species diversity by causing poor water quality. The main sourcesof pollution were heavy materials during heavy rains which come from upstream and stormwater channels from commercial and industrial activities as well as lack of proper management of garbage and waste by the municipality. The municipal must continue to implement proper management of garbage and waste, including littering throughout Cosmo City. The other respondent indicated that current status of water pollution in Cosmo City is regarded as significantly bad because of the activities along the streams which are detrimental to species diversity, and this view was confirmed by the following statement:

"Currently there is water pollution and pollutants in our area." (sic)

The current status of water pollution and pollutants in the area is affected by activities practiced along the streams, and this was confirmed by one respondent. The status of water pollution andpollutants is exacerbated by lack of knowledge on water pollution among the community members. There is a need for the community to be educated about water pollution and pollutants.One of the respondents indicated the following:

"There are many challenges and impacts of water pollution facing the community in our area". Some of these challenges and impacts of water pollution are mostly from residents than otheractivities such as fishing and farming. This view was confirmed by one respondent. There iscurrently a need to educate, provide knowledge and conduct workshops on the activities causingwater pollution. There is also a need to teach residents to refrain from polluting the streams.

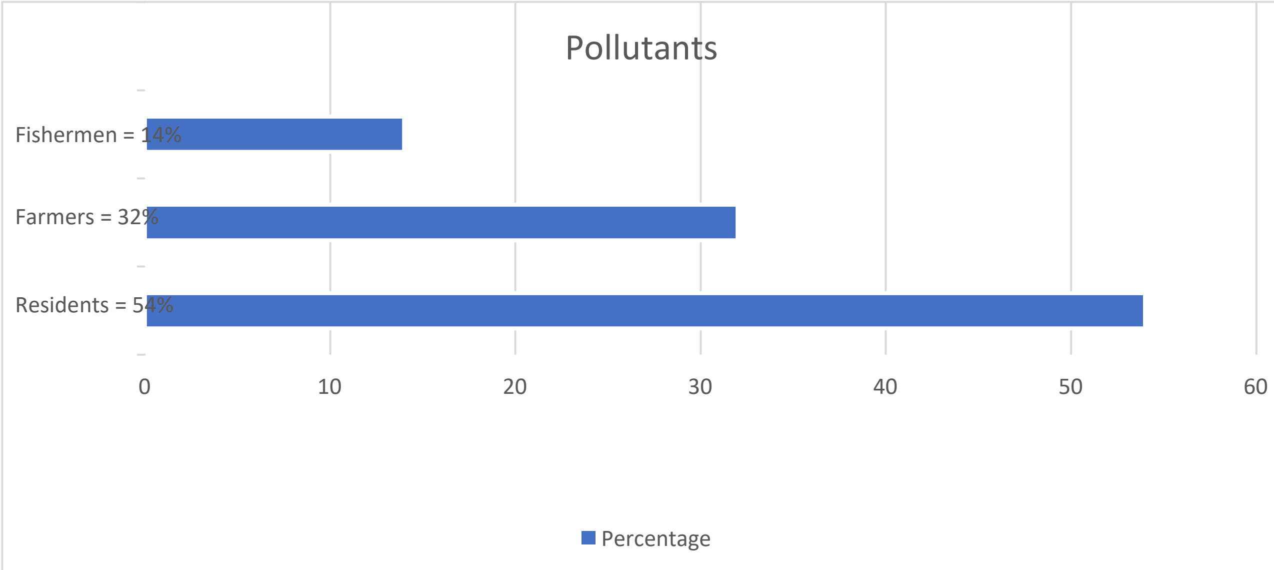


Figure 4.1. Pollutants in Zandspruit River system of Cosmo City

The study found that water pollutants from illegal dumping of waste, overflow of raw sewage, siltation and erosion in the Zandspruit River system were from residents. Residents contributed 54 % of the total water pollutants on the downstream activities and are generally high among thewater pollutants. The water pollutants from soil erosion and sedimentation from farming activitiesconstitute 32 % on the downstream activities. The contribution of fishing to water pollution was generally low at 14 % of the total water pollutants through garbage discharge and littering on thedownstream.

Respondents	Percent	Pollutants	Sources / causes	Solutions	Challenges
Residents (Residential, industrial and commercial)	54	Illegal dumping of waste, overflow of raw sewage, siltation and erosion	Population growth, unattended raw sewage and heavy materials	Signage of waste prohibition, continuous fixing the main holes and proper management of stormwater channels	Poor and lack of waste, raw sewage management and maintenance of the stormwater channels
Farmers	32	Soil erosion and sedimentation	Contaminated water	Proper management of erosion and siltation	Poor and lack of erosion and siltation management
Fishermen	14	Garbage and waste	Discharge of garbage and waste	Proper management of garbage and waste	Poor or lack of proper management of garbage and waste
Total	100				

Table 4.1. Pollutants, sources / causes, solutions and changes in Zandspruit River system

4.2.2 Zandspruit River assessment

The Zandspruit River system was polluted mostly due to human development causing environmental degradation such as siltation and erosion. Raw sewage pollution from overflow ofunattended burst sewage pipes which take time to be fixed or attended to by the Johannesburg Metropolitan Municipality results in pollution of Zandspruit River system. The community causespollution and continues illegal dumping of waste along the Zandspruit River system banks. This was observed during the field visits in April and June which occurred continuously, causing deterioration of macroinvertebrates (Figure 4.2).

There was significant impact of macroinvertebrates due to poor water management control measures which was also noticed during the field visits in April and June both from downstream and upstream. Due to human made activities practiced along the Zandspruit River system and disturbing the river flow as well as the quality of the water, sediment and macroinvertebrates. Thepoor drainage line was also observed as another factor that contributes to water pollution, and sediment pollution which were not being maintained regularly. However, human made activities along the Zandspruit River system were also observed during the field survey in April and June and human made factors from the community living nearby the Zandspruit River system affectedthe water quality, sediment quality and macroinvertebrates. Evidence showing water pollution from raw sewage overflow resulting in the pollution of Zandspruit River system of Cosmo City impacted on the river system. The temperature and pH measurement indicated the quality of Zandspruit system water, sediment and macroinvertebrates; a resulting pollution of human madeactivities (Figure 4.2).

The evidence of overflowing and leaking raw sewers was noticed in some area that were exposedto the pollution and there was also an observation showing compromised pollution of water in Zandspruit River system. The sewage was observed as a crisis because some poor sewage management resulted pollution of streams. The field visits showed that the major contributor to pollution was human activities, and the human population density was also observed as another major contributor to pollution resulting in poor Zandspruit River system water quality.

Figure 4.2. Water pollution observed within the Zandspruit River system: **1** sewage overflow (site1), **2** illegal dumping of waste (site 2), **3** erosion (site 3), siltation (site 4), **4** human activities (site 5)

Raw sewage and damaged main holes causing continuous pollution from upstream Zandspruit River system to downstream Zandspruit River system, entering the Zandspruit River system wereobserved from the overflow. This was noticed as a continuous practice in the community, which on a daily basis, affects the water quality, sediment quality and macroinvertebrates. Erosion andsiltation were observed from evidence of heavy rain entering the Zandspruit River system from residential area into the water, polluting the river. Poor drainage channel was also observed as another main challenge causing poor water and sediment quality as well as affecting macroinvertebrates. These were noticed on numerous occasions including lack of maintenance and management of drainage channel. Some variables such as water quality, sediment quality and macroinvertebrates communities have influence on the Zandspruit River system from blockage of some of few drainages channels that need continuous maintenance. Water from residential area goes straight into the Zandspruit River system. Similarities were observed in the sites and there were no differences when measured against each other for both streams of Zandspruit River system (Figure 4.2). The level of water pollution was observed as not improvingfrom upstream to downstream, producing similar results at all times, mainly from human made activities.

Raw sewage overflow was observed during the site visits in April and June. Raw sewage resultsin Zandspruit River system polluting the water pH, temperature and affecting water quality, sediment quality as well as macroinvertebrates. Continued illegal dumping of waste on the riverbank was observed and the wastes result in water and sediment pollution. Macroinvertebrates are affected along the ecological ecosystem and species living in the Zandspruit River system. Evidence of erosion and siltation were also observed to be occurring ondaily basis especially during rainy months. Siltation and erosion activities result in Zandspruit River system pollution on the downstream (Figure 4.2). All these human made activities were observed at the upstream of the Zandspruit River system and they end up affecting the downstream water, sediment and macroinvertebrates.

There was observation that site one to site two for both April and June in downstream water quality, sediment quality and macroinvertebrates affected by pollution were very much similar withsite three to site five in upstream pollution of water quality and sediment quality. Human made activities in all sites in April and June were seen to have similar impact on the water quality, sediment quality and macroinvertebrates on both downstream and upstream. However, raw sewage gushing through a school to the nearby Zandspruit River system was an ongoing problem (Eco Culture Sechaba Foundation, 2018). Therefore, the sources of water pollution from upstream and downstream levels of pollution were similar across caused the same significant impact on the Zandspruit River system quality. Development of Cosmo City have insignificant effect on water pollution along the river.

During field visits, there were pollutants observed for pollution on water quality, sediment and macroinvertebrates with evidence of pollution also affecting Zandspruit River system. It was also observed that Johannesburg Metropolitan Municipality was committed to the management of the environmental issues facing the area, including water quality, sediment quality and macroinvertebrates pollution control through engaging with the community. It was also noticed that during the two field visits in April and June, some of the issues such as environmental awareness and education were addressed by continued campaigns and workshops conducted with the community, especially in the schools to educate teachers and learners about the importance of preserving water and sediment quality as well as the significance of macroinvertebrates. Catchments along the Zandspruit River that were vulnerable to human activities were also observed.

4.2.3 Water and sediment quality variables

The water quality variables considered in this study of the Zandspruit River system were temperature, pH, alkalinity, electrical conductivity, saturation pH, chloride (Cl), sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), sulphur (S), sulphate (SO_4), iron (Fe) and manganese (Mn). Furthermore, the langelier index and sodium adsorption ratio (SAR) were calculated for water quality variables. The sediment quality variables were pH, electrical resistance (EC), phosphates(P), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), zinc (Zn),manganese (Mn), copper (Cu), boron (B) and organic carbon (OC).

4.2.3.1 Water quality

A similar trend for most of the water variables such as water total Fe (<0.08 mg/L) and water totalMn (<0.04 mg/L) concentration were observed to be below detection limit across all sites for bothstudy months. The water pH values for both sites were ranging between 7.6 to 8 for both the studymonths and the pH values were similar in April across all study sites (mean 7.6) and in June it increased slightly to 8 (Table 4.2; Figure 4.3.1). However, water electricity conductivity (mean range 101 – 114 mS/m) and water alkalinity (mean range 470 – 521 mg/L) were generally high between two study months across all sites (Table 4.2; Figure 4.3.2,3). A similar trend was observed for water potassium (K) with the lowest concentration (mean 5 mg/L) and highest concentration (mean 5.8 mg/L) for both sites across two months (Table 4.2; Figure 4.3.12).

The water chlorine (Cl) (mean range 46.7 – 52.3 mg/L) and water sulphate (SO_4) (mean range 29.3 – 61.5 mg/L) concentration was observed to be high in June and low in April across all sites(Table 4.2). The significant differences were observed for pH, alkalinity, Cl, Na, Ca, Mg and SO4 for both months in the study sites across the river upstream (Table 4.2; Figure 4.3). The water temperature (mean range 16.5 – 19.5 ˚C) was significant and water sodium (Na) was also significant (mean range 26.5 – 31.4 mg/L) for both study months across all sites downstream (Table 4.2;Figure 4.3.10). Low concentration of water sulphur (S) (mean range 9.8 – 20.5 mg/L) was observed to be high in June and low in April for all sites upstream (Table 4.2; Figure 4.3.9). The water calcium (Ca) (mean range 64.9 – 89.2 mg/L) and water magnesium (Mg) (mean range 71.7 – 79.5 mg/L) concentrations were high in June and low in April across all sites downstream.

Parameter	Unit	April					June				
WATER											
Temperature	˚C	19.5	18.9	19.2	19.2	19.5	17.1	16.9	16.7	16.5	16.5
pH		7.6	7.6	7.6	7.6	7.6	8	8	7.9	7.8	7.8
Alkalinity	mg/L	470	476	472	470	485	516	511	510	517	521
Electrical Conductivity	mS/m	101	102	101	101	101	113	112	111	114	110
Langelier Index		0.4	0.4	0.4	0.4	0.4	1	0.9	0.8	0.8	0.8
Saturation		7.2	7.2	7.2	7.2	7.2	7	7.1	7.1	7	7
SAR		0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
Cl	mg/L	47.1	47.4	46.7	47.6	46.8	52.1	51	50.7	52.3	51.1
Na	mg/L	31.2	30.3	30.8	31.4	30.9	27.7	26.8	26.5	27.2	26.6
Ca	mg/L	65.6	64.9	66	67.2	66.4	89.2	87.1	87	88.6	89.2
Mg	mg/L	72.3	71.7	72.9	74.3	73.1	79.5	77	75.4	78.8	75
K	mg/L	5.5	5.4	5.5	5.6	5.4	5.1	5	5.3	5	5.8
S	mg/L	9.9	9.8	9.9	10.1	10	20.5	19	16.9	20.2	14.4
SO_4	mg/L	29.6	29.3	29.6	30.2	30	61.5	57	50.6	60.7	43.1
Total Fe	mg/L	0.15	0.08	0.14	0.22	0.23	0.31	0.64	0.85	0.44	0.64
Total Mn	mg/L	0.06	<0.04	0.04	0.08	0.08	0.09	0.14	0.23	0.12	0.25

Table 4.2. Water quality parameters recorded in April and June 2021 in Zandspruit River system

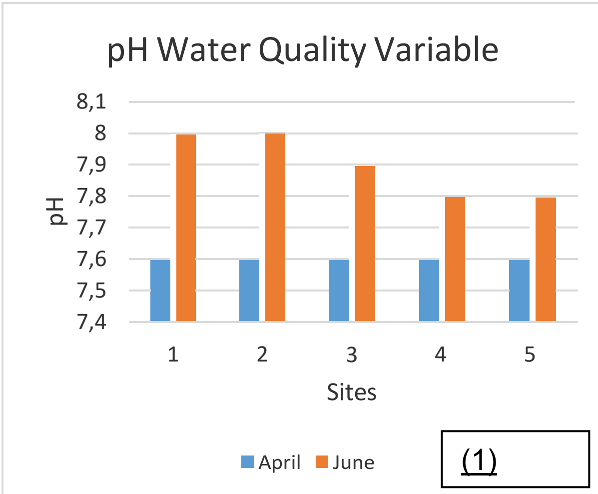
Variable	Zandspruit River				Zandspruit River x Month	
	F	*p*	F	*p*	F	*p*
WATER						
Temperature	19.5	0.195	16.9	0.169	16,5	0.165
pH	7.6	0.076	8	0.008	7,8	0.078
Alkalinity	**470**	**<0.001**	**511**	**<0.001**	**521**	0.052
Electrical Conductivity	**101**	**<0.001**	**112**	**<0.001**	**110**	0.011
Langelier Index	**0.4**	**<0.004**	0.9	0.009	0,8	0.008
Saturation	7.2	0.072	7.1	0.071	7	0.007
SAR	0.6	0.006	0.5	0.005	0,5	**<0.005**
Cl	47.1	0.471	51	0.045	51,1	0.511
Na	31.2	0.321	26.8	0.268	26,6	0.266
Ca	65.6	0.659	87.1	0.875	89,2	0.892
Mg	72.3	0.072	77	0.007	75	0.075
K	5.5	0.055	5	0.005	5,8	0.058
S	9.9	0.099	19	0.009	14,4	0.144
SO_4	29.6	0.296	57	0.057	43,1	0.431
Total Fe	**0.15**	**<0.001**	0.64	0.006	0,64	0.006
Total Mn	0.06	0.006	**0.14**	**<0.001**	0,25	**<0.002**

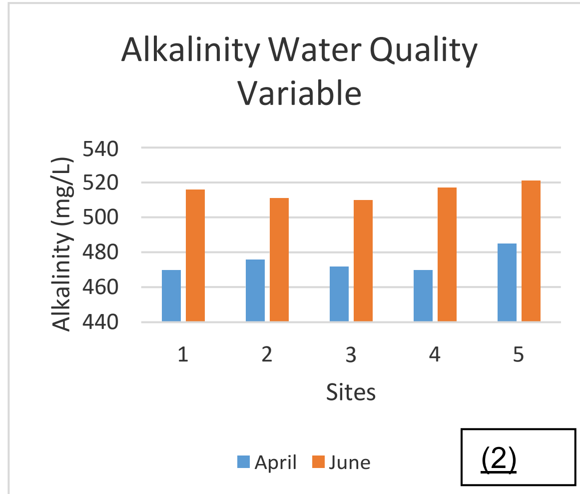
F-statistic ANOVA and **p-value ANOVA**

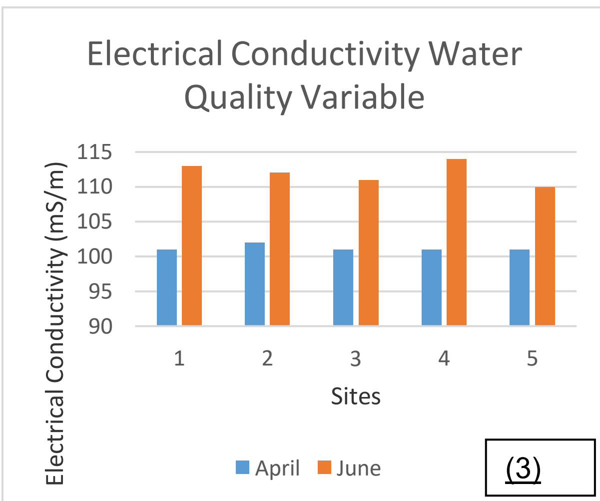
Table 4.3. Two-way ANOVA for water quality parameters environmental variables for five sites in April and June 2021 inZandspruit River system downstream and downstream. Significant variables highlighted in Bold ($p < 0.05$)

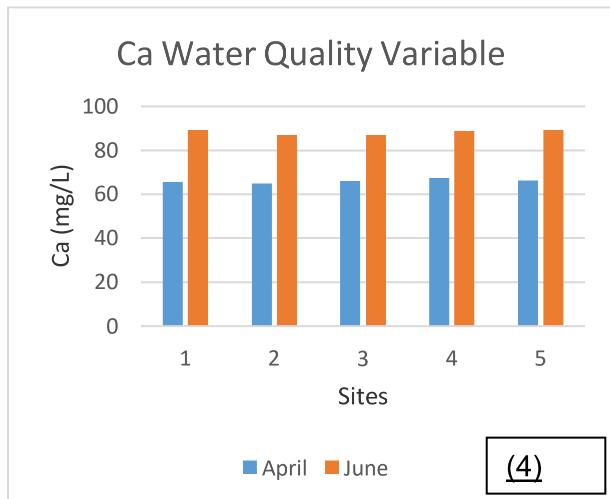
Variable	**$\lambda 1$**	**λ_2**	**λ_1/λ_2**	***P***
WATER				
Temperature	0.19	0.16	0.18	0.16
pH	0.07	0.07	0.01	0.08
Alkalinity	**0.47**	**0.52**	**0.90**	**0.01**
Electrical Conductivity	**0.10**	**0.11**	**0.90**	**0.01**
Langelier Index	0.04	0.08	0.05	0.09
Saturation	0.07	0.07	0.01	0.07
SAR	**0.06**	**0.05**	**0.11**	**0.05**
Cl	0.47	0.51	0.92	0.45
Na	0.32	0.26	0.23	0.26
Ca	0.65	0.89	0.73	0.87
Mg	0.07	0.75	0.09	0.07
K	**0.05**	**0.05**	**0.01**	**0.05**
S	0.09	0.14	0.64	0.09
SO_4	**0.29**	**0.43**	**0.67**	**0.05**
Total Fe	0.01	0.06	0.16	0.06
Total Mn	**0.06**	**0.02**	**0.03**	**0.01**

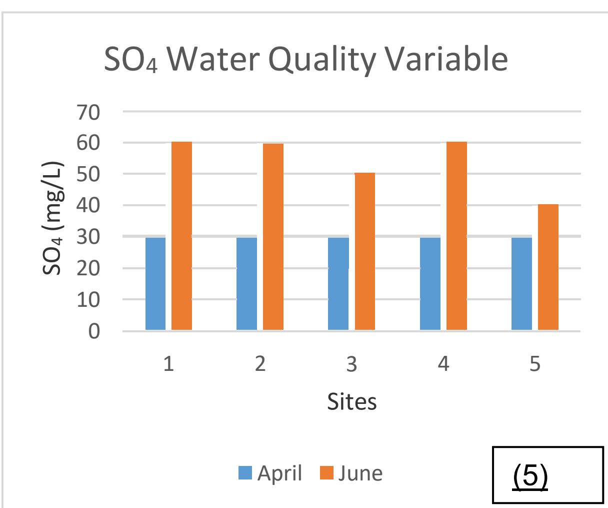
Table 4.4. Redundancy analysis showing important influence for the water parameters variables. Values in bold highlighted significant variables ($p < 0.05$)

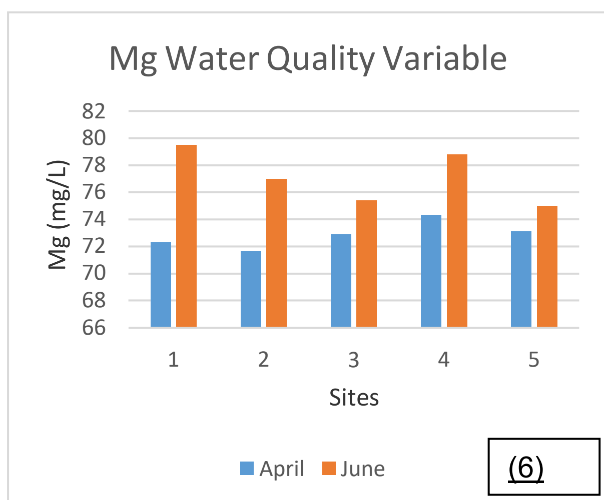

pH Water Quality Variable
pH
8,1
8
7,9
7,8
7,7
7,6
7,5
7,4
1
2
3
4
5
Sites
April
June
(1)


Alkalinity Water Quality Variable
Alkalinity (mg/L)
540
520
500
480
460
440
1
2
3
4
5
Sites
April
June
(2)


Electrical Conductivity Water Quality Variable
Electrical Conductivity (mS/m)
115
110
105
100
95
90
1
2
3
4
5
Sites
April
June
(3)


Ca Water Quality Variable
Ca (mg/L)
100
80
60
40
20
0
1
2
3
4
5
Sites
April
June
(4)


SO₄ Water Quality Variable
SO₄ (mg/L)
70
60
50
40
30
20
10
0
1
2
3
4
5
Sites
April
June
(5)


Mg Water Quality Variable
Mg (mg/L)
82
80
78
76
74
72
70
68
66
1
2
3
4
5
Sites
April
June
(6)

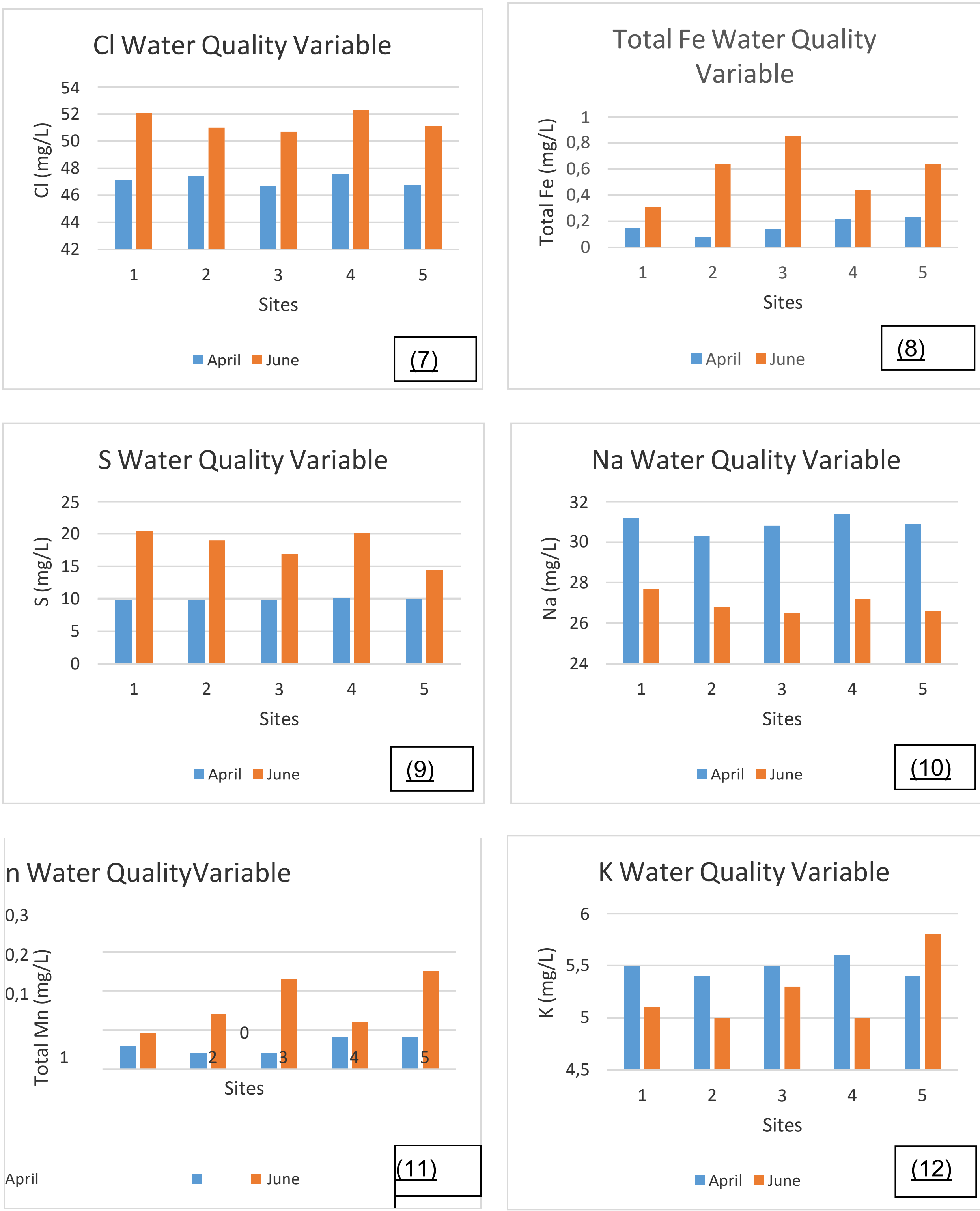


Figure 4.3. Variation in water quality variables values recorded across the two study months and5 sites in Zandspruit River system

4.2.3.2 Sediment quality

A similar trend for most of the sediment variables were observed across the five study sites acrossthe two study months (Table 4.5; Figure 4.4). The sediment sulphur (S) and sediment magnesium(Mg) were significant for both study months across the Zandspruit River system sites. However, sediment sodium (Na) was significant (mean range 13.3 – 21.4 mg/kg) only in June across the sites (Table 4.5; Figure 4.4.10). The sediment magnesium (Mg) concentrations were significantlydifferent for both study months across all Zandspruit River system sites (mean range 22.8 – 48.2mg/kg).

However, downstream during the month of April, the concentration was low at 22.8 mg/kg and increased significantly in the month of June to 34.3 mg/kg for all sites (Table 4.5; Figure 4.4.3). Upstream the sedimentsulphur (S) concentrations were high in April at 104 mg/kg and decreased significantly in June to 39.8 mg/kg across all sites (mean range 39.8 – 104 mg/kg). Sediment sulphur (S) concentrationwas much high and differs between the two study months across the sites (Table 4.5; Figure 4.4.12). Similar trend in concentration was observed for sediment magnesium (Mg) and sedimentsodium (Na) between the two study months and across the Zandspruit River system sites.

Parameter	Unit	April					June				
SEDIMENT											
pH		7.6	7.7	7.7	7.6	7.6	7.4	7.5	7	6.1	5.8
EC	mS/m	37.1	43.7	26.2	25	29	26	23.9	21.2	20.6	24.3
P	mg/kg	0.35	0.16	0.36	0.28	0.22	0.26	0.28	0.35	0.28	0.44
Na	mg/kg	18.1	19.7	13.3	14.6	13.5	21.4	20.2	16.2	17.2	21.4
K	mg/kg	8	10.9	13.8	11	10.6	13.9	14	16	14	18.5
Ca	mg/kg	68.5	72.7	46.4	47.4	48.5	54.2	48.3	46.8	38.7	61.4
Mg	mg/kg	38.3	48.2	22.8	25.6	25.6	34.3	32.3	24.3	23.6	29.2
S	mg/kg	86.7	104	40.6	50.8	54.2	74	62.6	46.5	39.8	57.2
Fe	mg/kg	0.15	0.03	9.6	0.82	0.67	0.21	0.21	2.2	0.49	7.2
Zn	mg/kg	0.02	0.01	0.03	0.01	0.01	0	0	0.02	0	0.02
Mn	mg/kg	0.1	0.11	0.17	0.1	0.11	0.16	0.11	0.1	0.09	0.22
Cu	mg/kg	0.02	0.02	0.04	0.02	0.03	0.03	0.03	0.03	0.03	0.04
B	mg/kg	0.16	0.11	0.14	0.12	0.1	0.05	0.06	0.09	0.06	0.09
OC	mg/kg	0.01	0.01	0.01	0.01	0.01	0.16	0.12	0.1	0.14	0.12

Table 4.5. Sediment quality parameters recorded across the five sites for April and June 2021 inZandspruit River system

Variable	Zandspruit River		Month		Zandspruit River x Month	
	F	*p*	F	*p*	F	*p*
SEDIMENT						
pH	7.6	0.076	7.4	0.074	5,8	0.058
EC	37.1	0.371	26	0.267	24,3	0.243
P	**0.35**	**<0.003**	**0.26**	**<0.002**	**0,44**	**<0.004**
Na	18.1	0.181	21.4	0.214	21,4	0.243
K	8	0.088	13.9	0.139	18,5	0.185
Ca	68.5	0.645	54.2	0.542	61,4	0.614
Mg	38.3	0.383	34.3	0.343	29,2	0.292
S	86.7	0.867	74	0.074	57,2	0.572
Fe	**0.15**	**<0.001**	**0.21**	**<0.002**	**7,2**	**0.072**
Zn	**0.02**	**<0.002**	**0**	**<0.001**	**0,02**	**<0.002**
Mn	**0.1**	**<0.001**	0.16	0.006	0,22	**0.002**
Cu	**0.02**	**<0.002**	**0.03**	**<0.001**	**0,04**	**<0.004**
B	0.16	0.006	0.05	0.005	0,09	0.009
OC	**0.01**	**<0.001**	0.16	0.006	0,12	0.006

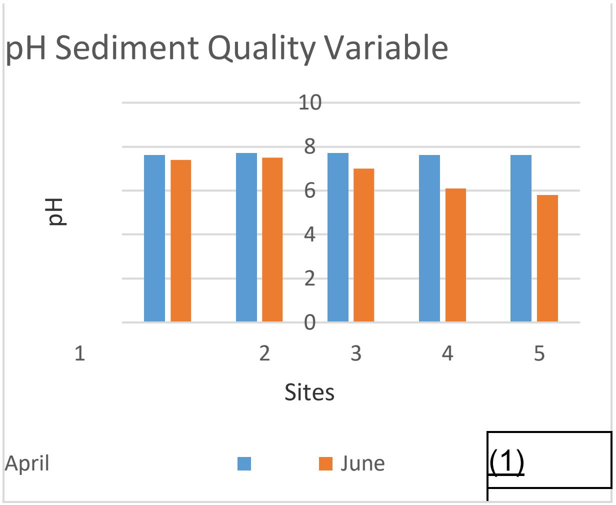
F-statistic ANOVA and **p-value ANOVA**

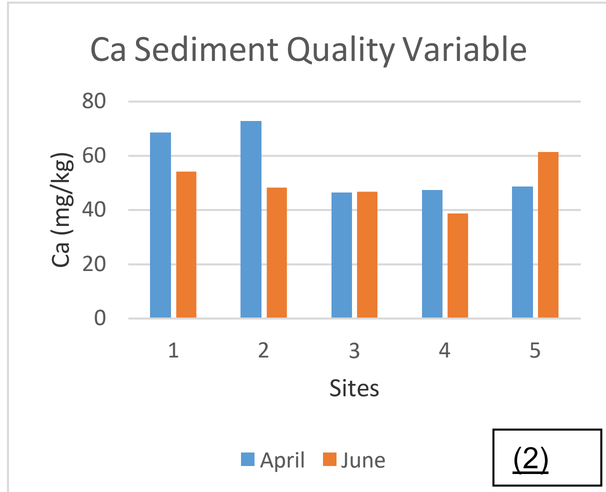
Table 4.6. Two-way ANOVA for sediment quality parameters environmental variables for five sites in April and June 2021 inZandspruit River system downstream and downstream. Significant variables highlighted in Bold ($p < 0.05$)

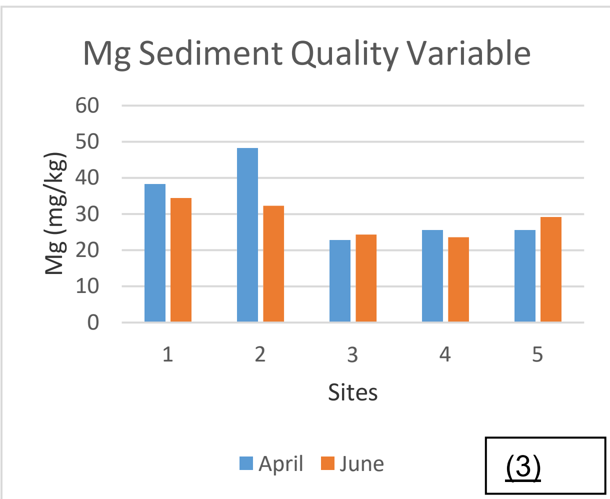
Variable	λ_1	λ_2	λ_1/λ_2	*p*
SEDIMENT				
pH	0.07	0.05	0.04	0.07
EC	0.37	0.24	0.54	0.26
P	**0.03**	**0.01**	**0.03**	**0.02**
Na	0.18	0.21	0.85	0.21
K	0.08	0.18	0.44	0.13
Ca	0.64	0.61	0.49	0.54
Mg	0.38	0.29	0.31	0.34
S	0.86	0.57	0.50	0.07
Fe	**0.01**	**0.07**	**0.14**	**0.02**
Zn	**0.02**	**0.02**	**0.01**	**0.01**
Mn	0.01	0.02	0.05	0.06
Cu	**0.02**	**0.04**	**0.05**	**0.01**
B	**0.06**	**0.09**	**0.66**	**0.05**
OC	0.01	0.01	0.01	0.06

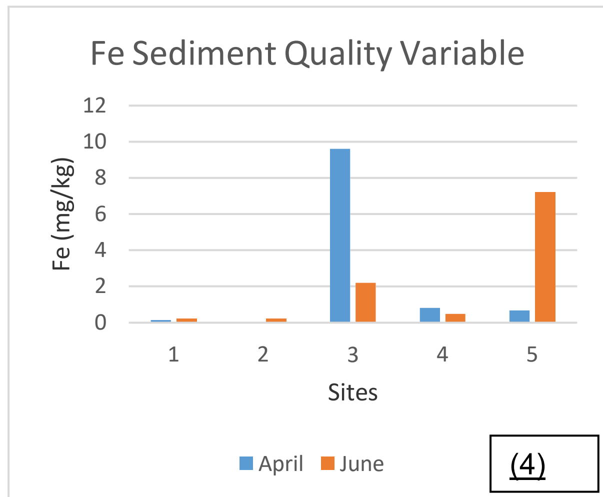
Table 4.7. Redundancy analysis showing important influence for the sediment parameters. Values in bold highlighted significant variables ($p < 0.05$)

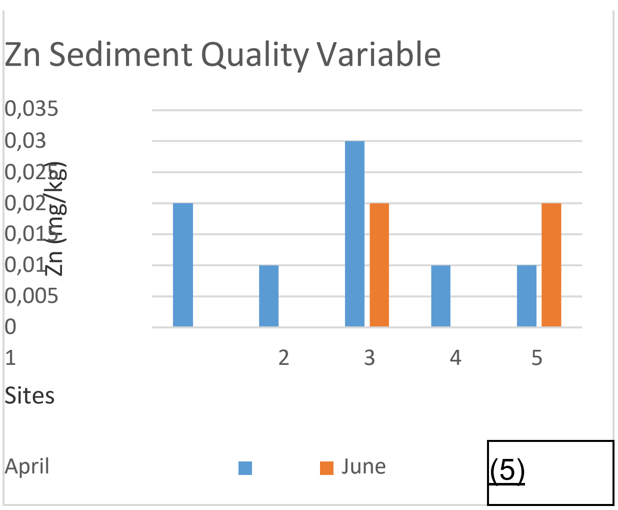
The environmental variables for water chemistry and sediment chemistry were analysed showingthe difference in ratio between the study months across all sites. The environmental variables showed that difference among environmental values ($p < 0.05$) across all study sites and the study months. There was no significant difference among the environmental variable for water chemistry alkalinity for (p = 0.01) and there was no significant change for water chemistry electrical conductivity (p = 0.01) between the study months across the sites. The environmental variable for water chemistry SAR (p = 0.05) was also significant among the environmental variables and the water chemistry K (p = 0.05) variable showed important change across all sites.The water chemistry SO4 (p = 0.05) variable was not changing among environmental variables and the water chemistry total Mn (p = 0.01) variable was also not changing between study monthsacross all sites. The sediment variable for P (p = 0.02) showed important difference among environmental variables and the environmental sediment chemistry for Fe (p = 0.02) was not changing across sites. The environmental variables for sediment chemistry Zn (p = 0.01) were not changing across all sites and the sediment chemistry for Cu (p = 0.01) was not changing acrossall sites. The environmental variable for sediment chemistry B (p = 0.05) was also significant for both study months across all sites (Table 4.7).

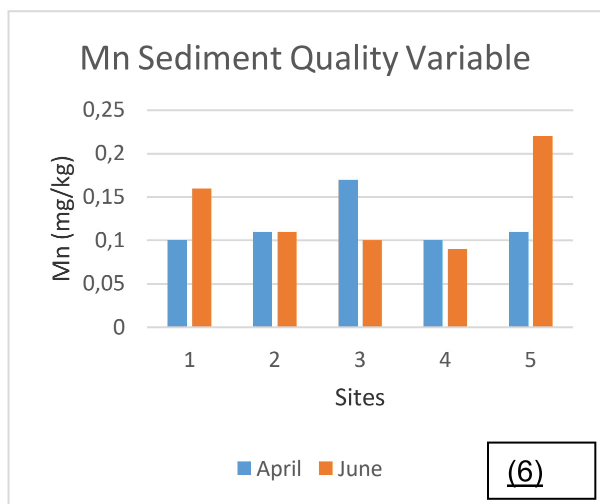

pH Sediment Quality Variable
10
8
6
4
2
0
pH
1
2
3
4
5
Sites
April
June
(1)

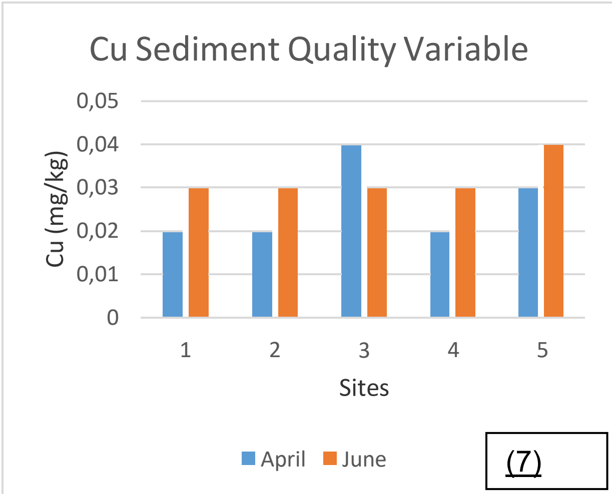

Ca Sediment Quality Variable
80
60
40
20
0
Ca (mg/kg)
1
2
3
4
5
Sites
April
June
(2)


Mg Sediment Quality Variable
60
50
40
30
20
10
0
Mg (mg/kg)
1
2
3
4
5
Sites
April
June
(3)

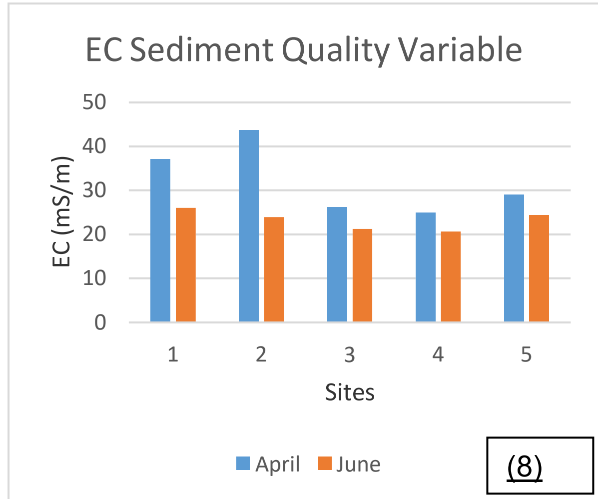

Fe Sediment Quality Variable
12
10
8
6
4
2
0
Fe (mg/kg)
1
2
3
4
5
Sites
April
June
(4)


Zn Sediment Quality Variable
0,035
0,03
0,005
0
Zn (mg/kg)
1
2
3
4
5
Sites
April
June
(5)

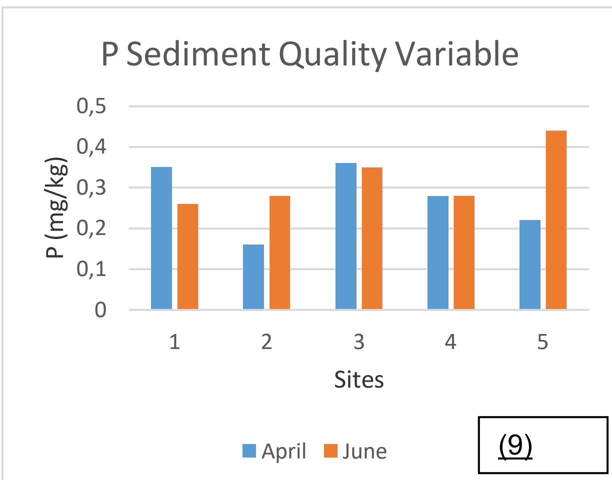

Mn Sediment Quality Variable
0,25
0,2
0,15
0,1
0,05
0
Mn (mg/kg)
1
2
3
4
5
Sites
April
June
(6)


Cu Sediment Quality Variable
Cu (mg/kg)
0,05
0,04
0,03
0,02
0,01
0
1
2
3
4
5
Sites
April
June

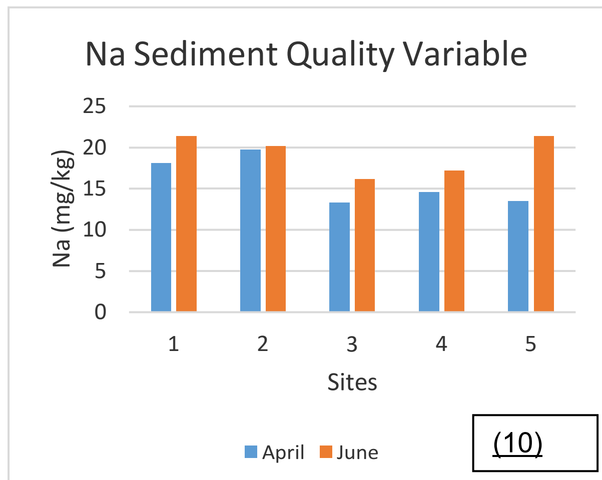
(7)


EC Sediment Quality Variable
EC (mS/m)
50
40
30
20
10
0
1
2
3
4
5
Sites
April
June

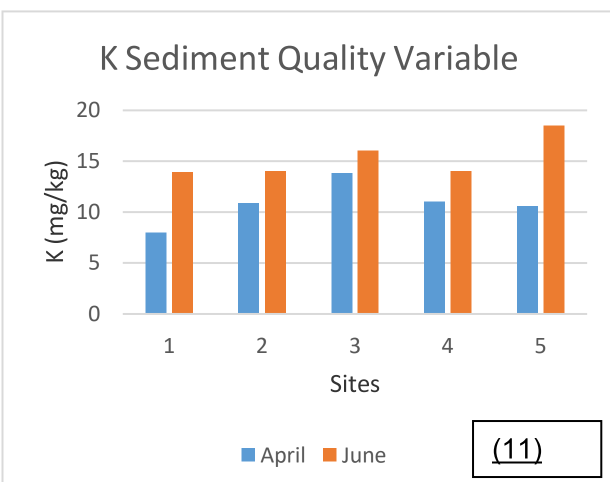
(8)


P Sediment Quality Variable
P (mg/kg)
0,5
0,4
0,3
0,2
0,1
0
1
2
3
4
5
Sites
April
June

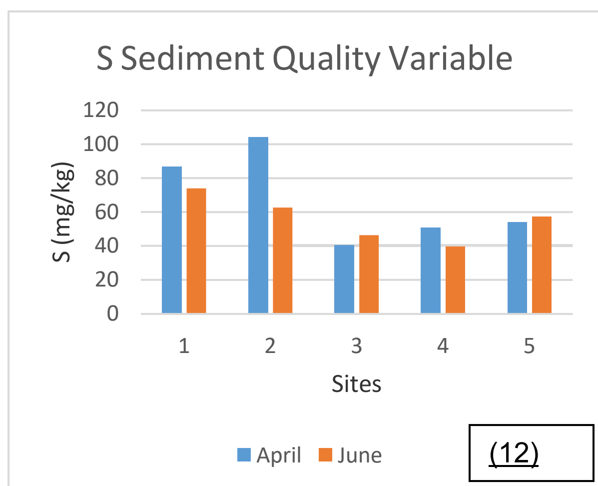
(9)


Na Sediment Quality Variable
Na (mg/kg)
25
20
15
10
5
0
1
2
3
4
5
Sites
April
June

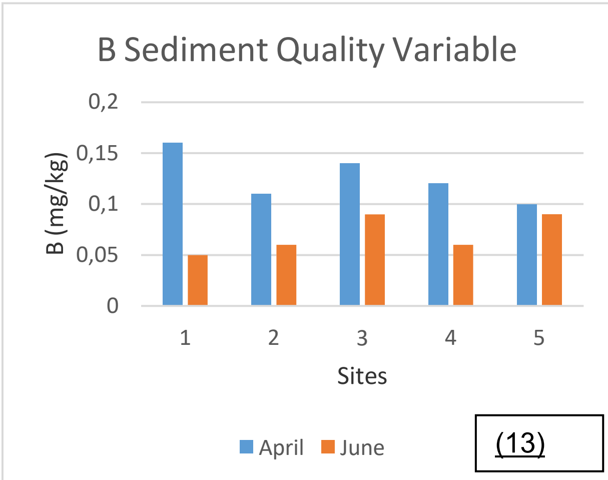
(10)


K Sediment Quality Variable
K (mg/kg)
20
15
10
5
0
1
2
3
4
5
Sites
April
June

(11)


S Sediment Quality Variable
S (mg/kg)
120
100
80
60
40
20
0
1
2
3
4
5
Sites
April
June

(12)



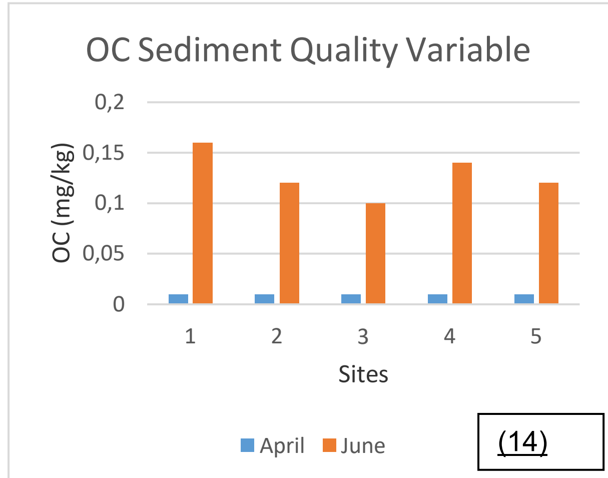


Figure 4.4. Variation in sediment quality variables recorded for five sites in April and June 2021in Zandspruit River system

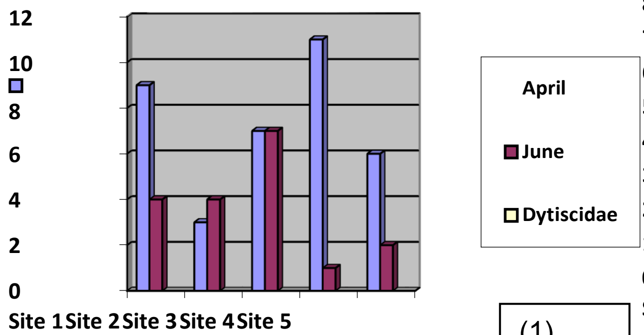
4.2.4 Macroinvertebrate community structure

Fourteen macroinvertebrate taxa were identified across two months during the study (Table 4.8; Figure 4.5). The most dominant taxa were Gerridae, Chlorolestidae and Lymnaeidae. The least dominant taxa were Hydrometridae, Dytiscidae and Aeshnidae. The SASS score was significantlyhigh in April, whereas, in June it was slightly low (mean range 6 – 43), with site 4 in April and site5 in June having high SASS scores of 43. The low SASS score was for site 5 at SASS score of 6in April. The SASS5 scores was observed to be generally high in April but low in June among sites 1 to site 5, and the Zandspruit River system was identified to be very poor to fair in water quality along the system (Table 4.8; Figure 4.5.7). However, Shannon-Weiner diversity index (mean range 0.05 -1.56) was 0.05 for site 1 in April to 1.56 for site 4 in April, which had a fair andgood water quality across the study sites. The Shannon–Wiener diversity index was observed tobe low in April, whereas it was high in June across all sites (Table 4.8; Figure 4.5.10). The macroinvertebrate taxa richness (mean range 4 – 6) across the study sites was observed to be similar for the two months and for all sites. Macroinvertebrate taxa richness was observed to differ between the two months indicating importance among Zandspruit River system sites. Low macroinvertebrate taxa richness was observed in April but increased slightly in June across studysites (Table 4.8; Figure 4.5.9). The study results showed the macroinvertebrate community structure similar for both April and June throughout the Zandspruit River system.

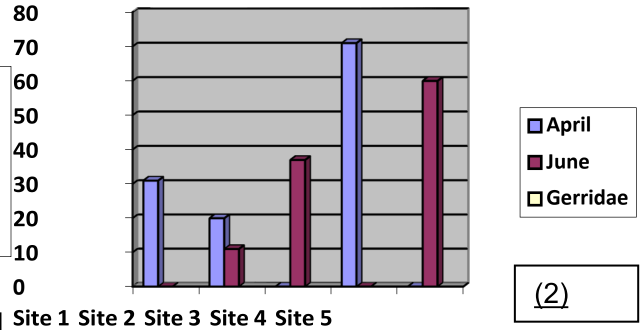
However, poor water quality level was recorded across the two months in Zandspruit River system. The ASPT scores (mean range 4.4 – 7.4) showed that the water quality level was normaland different throughout the sites, while site 1 in June had a high ASPT score and for site 5 a lowASPT score of 4.4 in June across all sites. The ASPT score was observed to be slightly high in June and low in April indicating that most sites had very poor water quality-based macroinvertebrate taxa assessment (Table 4.8; Figure 4.5.8). The Chlorolestidae family was the most abundant and dominant macroinvertebrate family and Dytiscidae were the least dominant macroinvertebrate family in the Zandspruit River system across all sites. The taxa identified washigh in April, however, was low in June, and macroinvertebrates taxa were observed to deceasesignificantly among sites across months. In April macroinvertebrates taxa characterised by fair water quality for both site 1 to site 2, while the water quality condition for site 3 to site 5 was considered to fair. However, the water quality condition in June was poor for sites 4 and site 5, while sites 1 to site 3 had very fair water quality condition.

Taxa	April					June				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5
ColeopteraDytiscidae										
	9	3	7	11	6	4	4	7	1	2
Hydraenidae										
Ephemeroptera										
Baetidae										
Prosopistomatidae										
Gastropoda										
Lymnaeidae	34	50	10	54			23		17	70
Hemiptera										
Gerridae	31	20		71			11	37		60
Hydrometridae	10	6	5	29	6	9	1	7	7	6
Nepidae Hydracarina										
Hydrachnellae										
Odonata Aeshnidae										
	7	16	34	9	11	27	7	3	12	21
Chlorolestidae	44	69	60	24	18	34	58	27	20	29
Lestidae										
Plecoptera										
Notonemouridae										
Trichoptera										
Psychomyiidae										
SASS score	**27**	**33**	**17**	**43**	**6**	**10**	**19**	**14**	**11**	**43**
ASPT score	**5**	**4.9**	**6.8**	**4.6**	**6.8**	**7.4**	**5.5**	**5.8**	**5.2**	**4.4**
Taxa richness	**6**	**6**	**5**	**6**	**4**	**4**	**6**	**5**	**5**	**6**
Shannon–Weiner	**0.05**	**1.31**	**0.22**	**1.56**	**0.17**	**0.26**	**0.99**	**0.78**	**0.99**	**1.56**

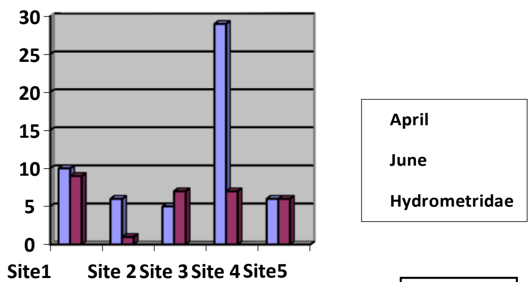
Table 4.8. Macroinvertebrates community's taxa recorded at five sites for April and June 2021 inZandspruit River system


12
10
8
6
4
2
0
Site 1 Site 2 Site 3 Site 4 Site 5
April
June
Dytiscidae

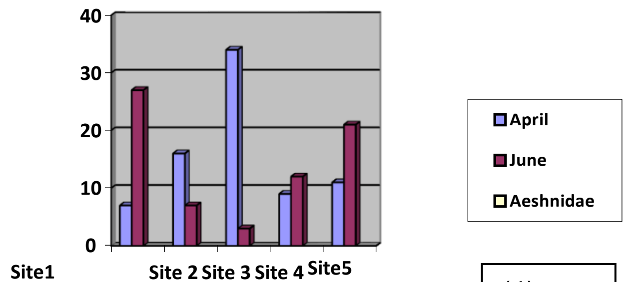
(1)


80
70
60
50
40
30
20
10
0
Site 1 Site 2 Site 3 Site 4 Site 5
April
June
Gerridae

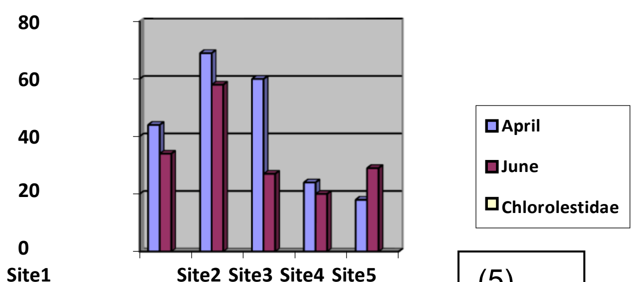
(2)


30
25
20
15
10
5
0
Site1 Site 2 Site 3 Site 4 Site5
April
June
Hydrometridae

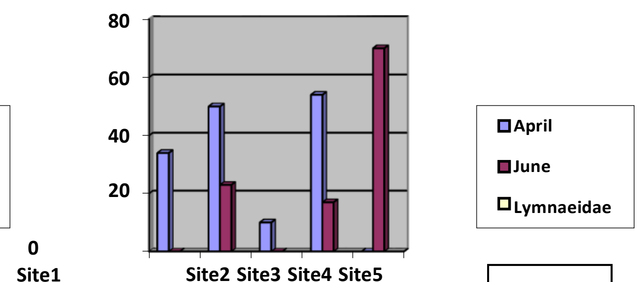
(3)


40
30
20
10
0
Site1 Site 2 Site 3 Site 4 Site5
April
June
Aeshnidae

(4)


80
60
40
20
0
Site1 Site2 Site3 Site4 Site5
April
June
Chlorolestidae

(5)


80
60
40
20
0
Site1 Site2 Site3 Site4 Site5
April
June
Lymnaeidae

(6)

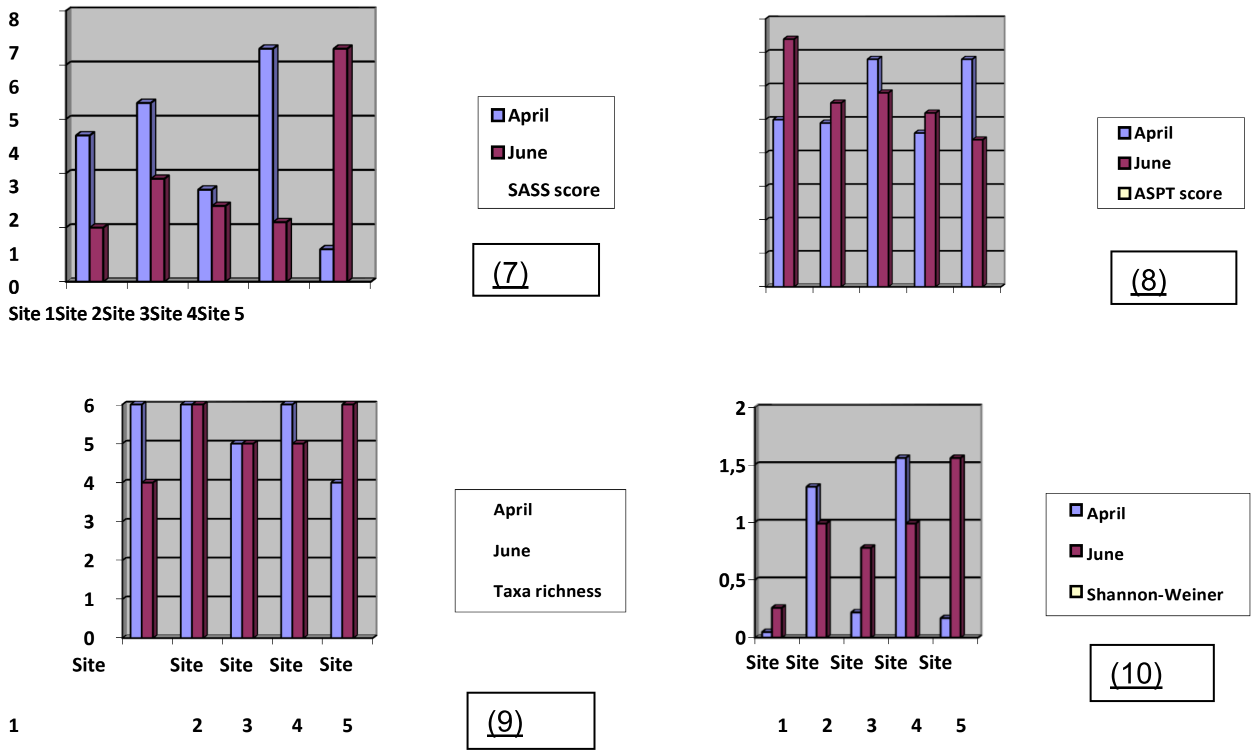


Figure 4.5. Macroinvertebrate's taxa diversity index evaluated from five sites for April and June 2021 in Zandspruit River system

Taxa	**April**					**June**				
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**
ColeopteraDytiscidae										
	1.8	0.6	1.4	2.2	1.2	0.8	0.8	1.4	0.2	0.4
Hydraenidae										
Ephemeroptera										
Baetidae										
Prosopistomatidae										
Gastropoda										
Lymnaeidae	11.3	16.7	3.3	18			7.7		5.7	23.3
Hemiptera										
Gerridae	6.2	4		14.2			2.2	7.4		12
Hydrometridae	1.7	1	0.8	4.8	1	1.5	0.2	1.2	1.2	1
Nepidae Hydracarina										
Hydrachnellae										
Odonata Aeshnidae										
	0.9	2	4.3	1.1	1.4	3.4	0.9	0.4	1.5	2.7
Chlorolestidae	5.5	8.6	7.5	3	2.3	4.3	7.3	3.4	2.5	3.6
Lestidae										
Plecoptera										
Notonemouridae										
Trichoptera										
Psychomyiidae										
SASS score	**27**	**33**	**17**	**43**	**6**	**10**	**19**	**14**	**11**	**43**
ASPT score	**5**	**4.9**	**6.8**	**4.6**	**6.8**	**7.4**	**5.5**	**5.8**	**5.2**	**4.4**
Taxa richness	**6**	**6**	**5**	**6**	**4**	**4**	**6**	**5**	**5**	**6**
Shannon–Weiner	**0.05**	**1.31**	**0.22**	**1.56**	**0.17**	**0.26**	**0.99**	**0.78**	**0.99**	**1.56**

Table 4.9. Relative abundance of macroinvertebrates occurring across the five sites for April andJune 2021 in Zandspruit River system

The macroinvertebrate taxa were identified and highlighted indicating abundant dominant among study months and across the five study sites. The macroinvertebrate taxa indicating strong abundance dominant and showed similarities in the macroinvertebrate taxa observed across all the study months and all five sites (Figure 4.6).

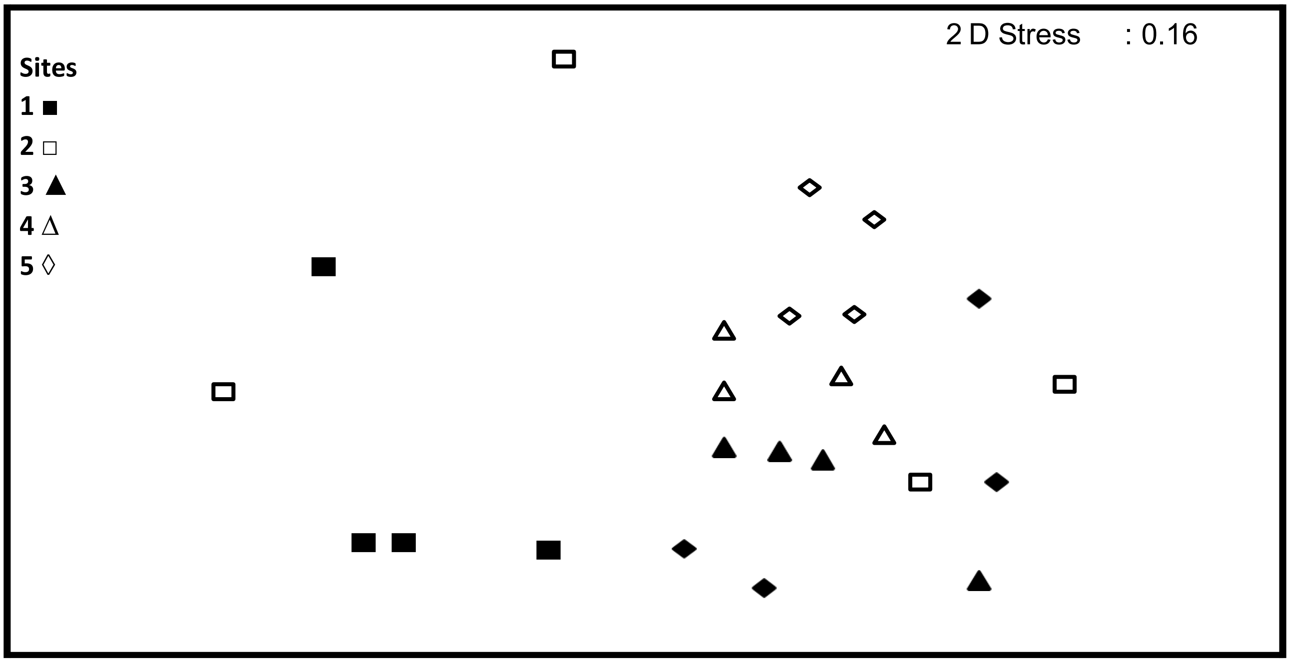
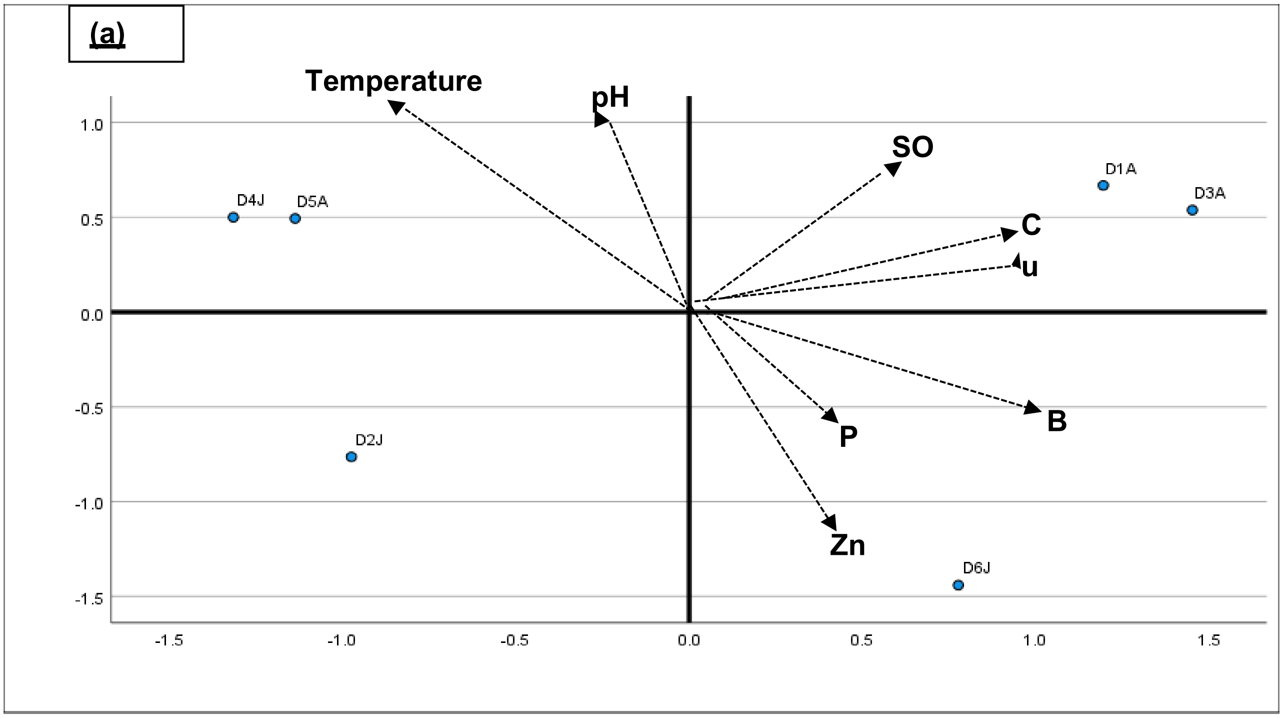


Figure 4.6. The non-numerical distances between plot for macroinvertebrate communities at fivesites for April and June 2021 in Zandspruit River system

4.2.5 Influence of environmental factors on macroinvertebrate communities

The environmental factors influencing macroinvertebrate communities were presented showing the results for the relationship between significant environmental variables for both the study months and across all sites. There was high significant dominance of macroinvertebrates taxa for Gerridae, Chlorolestidae and Lymnaeidae for both the study months among sampled sites. The macroinvertebrates taxa for Hydrometridae, Dytiscidae and Aeshnidae were significantly least dominant for both study moths and across the sampled sites (Figure 4.7.b). The environmental variable for water chemistry for temperature was associated with significant changes and the environmental variable for pH was significant for the two the study months and across all sampledsites. There was significant change for SO_4 water chemistry variables among environmental variables across study sites and study months. The environmental sediment variables for B and for P were significantly changing for both study months and across all the sampled sites. The sediment variables for Zn and Cu were also significantly changing among the environmental variable for both study months and across the sampled sites (Figure 4.7.a).



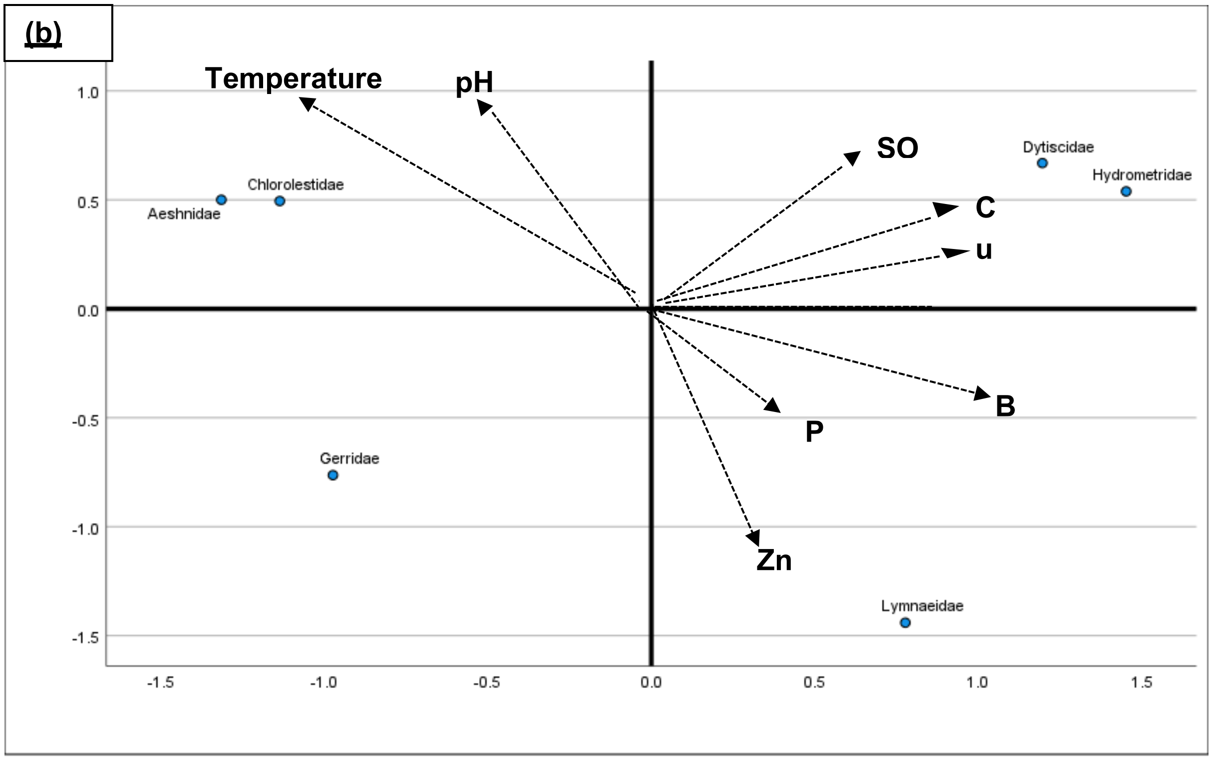


Figure 4.7. Redundancy analysis indicating affiliation among important sampled sites

The analysis of relative variation among macroinvertebrate community structures was described across study sites. Analysis results showed that environmental variables for water chemistry was associated with 51.5 % of the total macroinvertebrate community structures and were high amongthe macroinvertebrate community structures. The environmental variables for sediment chemistrywere analysed and associated with 30.2 % of the total macroinvertebrate for both study months.The shared environmental variables between the water chemistry and sediment chemistry were associated with 18.3 % of the total macroinvertebrate which were the less among the macroinvertebrate community (Figure 4.8).

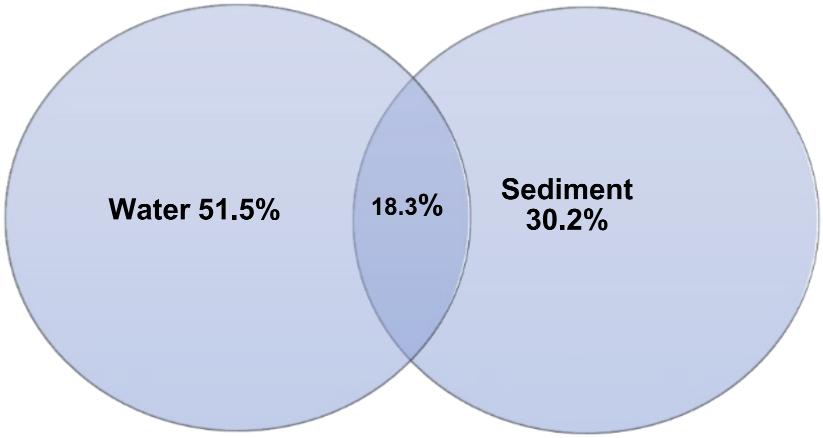


Figure 4.8. Partitioning analysis of comparative difference among the macroinvertebrate community structures

4.2.6 Macroinvertebrate taxa richness

The Dytiscidae taxa were accounted for 54 of the total macroinvertebrate families recorded as well as counted with less taxa richness among families and the macroinvertebrate taxa richnessfor Gerridae were accounted for 230 of the macroinvertebrate families recorded as well as counted for all five sampled sites. The macroinvertebrates taxa richness for taxa of Hydrometridaewere accounted for 86 of the total macroinvertebrate families recorded as well as counted and Aeshnidae taxa richness was accounted for 147 of the total macroinvertebrate families grouped for all five sites sampled. The taxa richness for Chlorolestidae was grouped as well as recorded and counted and was accounted for 383 of the total macroinvertebrate families with high taxa richness among families and Lymnaeidae taxa were also accounted for 258 of the total macroinvertebrate families recorded as well as counted for all five sampled sites.

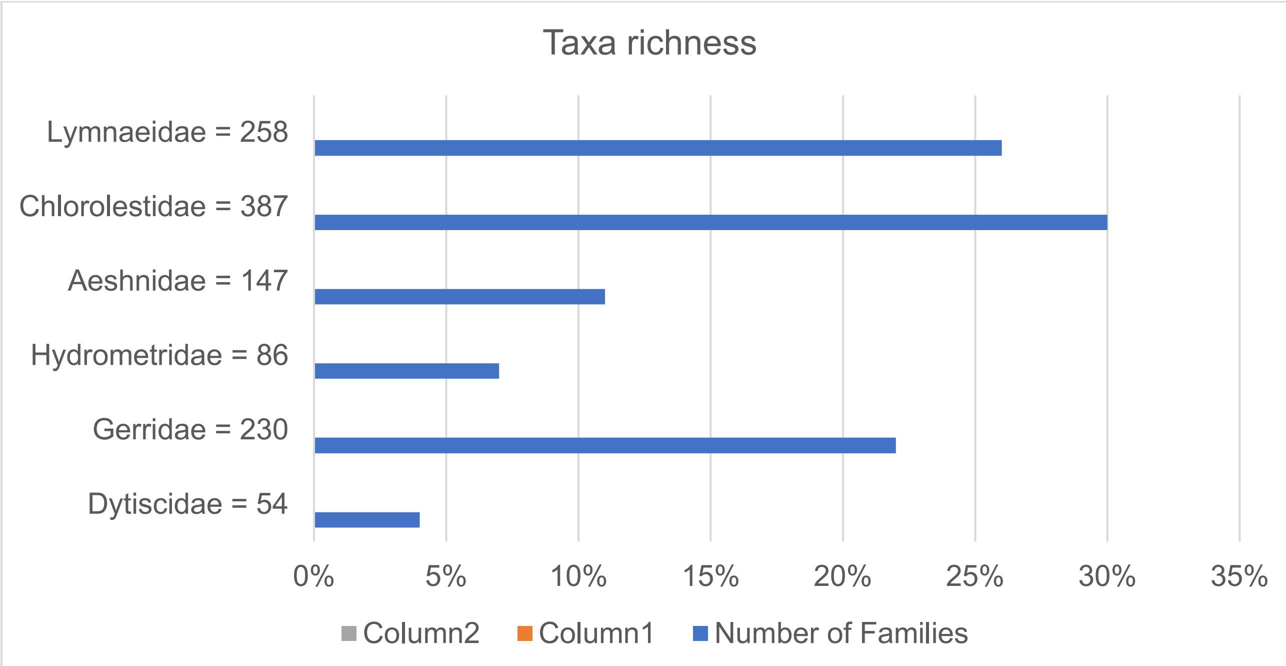


Figure 4.9. Macroinvertebrate taxa richness at five sites for April and June 2021 in ZandspruitRiver system

4.2.7 Macroinvertebrate relative abundance

The relative distribution of Dytiscidae was found to be 4 %, which is generally low among the macroinvertebrate families and Gerridae were constituted 22 % of the community distribution. Hydrometridae constituted 7 % and the distribution of grouped families and Aeshnidae were 11 % of the distribution. The distribution of Chlorolestidae was 30 %, which is generally high among the macroinvertebrate families and Lymnaeidae constituted 26 % of the community distribution.

Taxa	Percentage
Dytiscidae	4
Gerridae	22
Hydrometridae	7
Aeshnidae	11
Chlorolestidae	30
Lymnaeidae	26

Table 4.10. Macroinvertebrate relative abundance at five sites for April and June 2021 in Zandspruit River system

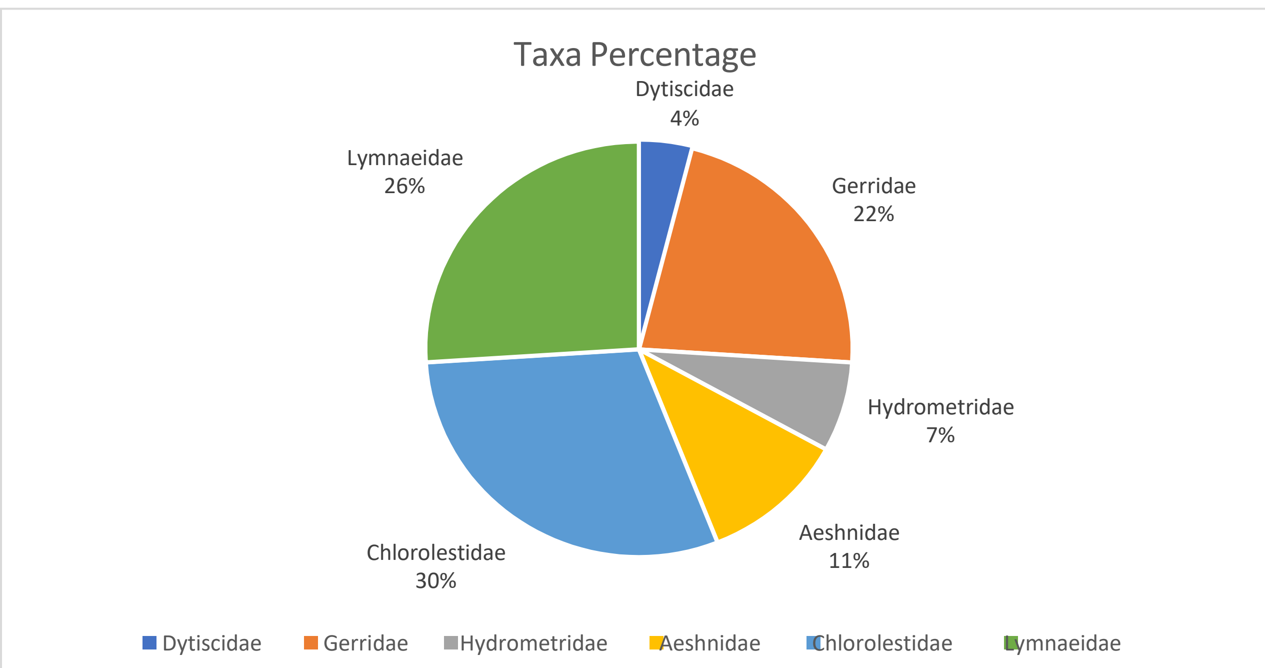


Figure 4.10. Macroinvertebrate relative abundance at five sites for April and June 2021 in Zandspruit River system

4.2.8 Macroinvertebrates distribution

The macroinvertebrates families were grouped as Ephemeroptera (Baetidae and Prosopistomatidae), Trichoptera (Psychomyiidae), Coleoptera (Dytiscidae and Hydraenidae), Hemiptera (Gerridae, Hydrometridae and Nepidae), Odonata (Aeshnidae, Chlorolestidae (Synlestidae) and Lestidae), Plecoptera (Notonemouridae), Hydracarina (Hydracarina (Hydrachnellae)) and Mollusca (Gastropoda) (Lymnaeidae). The macroinvertebrate group of Odonata and Hemiptera is the most diverse group consisting of three families each in the five sites. The macroinvertebrate group of Trichoptera, Hydracarina and Plecoptera were the least diverse groups consisting of one family each in the five sites. The macroinvertebrates group Chlorolestidae had the highest number of macroinvertebrates families recorded. The Dytiscidae had the lowest number of macroinvertebrate families recorded. The total number of six groups ofmacroinvertebrates were recorded, which included Dytiscidae, Gerridae, Hydrometridae, Aeshnidae, Chlorolestidae and Lymnaeidae.

The distribution of taxa families at the upstream and downstream was similar throughout. The macroinvertebrate families that were distributed indicated significantdifference across the sites and the difference between the months. The different families were distributed based on their natural ecosystem diversity across the streams and natural Zandspruit River. The upstream was characterised by high number of family groups and downstream was characterised by low number of family groups. The family's group for upstream was characterisedby much diversity of groupings and downstream was characterised by less diversity in groupingsacross the sites and between the two months.

4.2.9 Discussion

The study focused mainly on the quality of water, sediment quality and macroinvertebrate structures in Zandspruit river system of Cosmo City. It also looked into factors such as human made activities that contribute to water pollution in Zandspruit River system. Literature review hasshowed that the impact of water quality, sediment quality and macroinvertebrates communities were regarded as significant contributions from human made activities for both streams' diversity.The study by Masese *et al*. (2014) revealed that difference in stream size as determined by discharge, width, and depth were a reflection of human made activities both at the reach and catchment scales (Masese *et al.,* 2014) producing the same study results. This study did providethat Zandspruit River system water was regarded as an important ecological aspect of living in our communities across the country for different needs such as drinking, fishing, agricultural irrigation, washing, recreation, water extraction and habitat for aquatic ecosystem, as well as species diversity. Nhiwatiwa *et al*., (2017b) study suggested that diatom species richness can below at some sites as there were closer to catchment impacts i.e., agriculture and urban area. Theresults in some factors showed that human made activities along the Zandspruit River system were the cause of pollution.

The study findings have shown the potential impact of the pollutants associated with the Cosmo City development. The number of macroinvertebrates communities, water quality and sediment quality compared with upstream zone before Cosmo City development compared with downstream zone affected by the development project is not different, it therefore means the development of the Cosmo City had minimum effects. The study discovered that the water pH level was also drastically changing among months for all sites impacting on thespecies diversity by the different human made activities across the streams. However, populationdensity was identified as another factor in the community that contributes to poor management ofsediment and macroinvertebrates as well as pollution. This analysis showed some of water qualitypH, alkalinity, conductivity and temperature were affected as a result of parameters of water quality, sediment quality and macroinvertebrates communities. Dalu and Chauke (2020) highlighted that water depth, conductivity, ammonium, conductivity, pH, phosphates and macrophyte cover were significant variables affecting macroinvertebrate community structuring as highlighted by the CCA analysis.

The study suggested that continuous environmental degradation, erosion, siltation from heavy rain and drainage line happening in the Zandspruit River system have contributed significantly tothe pH, conductivity, alkalinity and temperature of water and pollution. This study showed that Zandspruit River system of Cosmo City has primary hazards which were identified, including long term sewerage leaks, massive illegal dumping, deforestation and gully erosion (Eco Culture Sechaba Foundation, 2018). The study indicated that raw sewage overflow was resulting in the impact of Zandspruit River system quality across Zandspruit River system and Cosmo City at large. The study results found it to be important that the phenomenon of pollution was an indirectmeasure of total dissolved salts and high conductivity which may arise through natural weatheringof certain sedimentary rocks or may have an anthropogenic source, e.g., industrial and sewage effluent (Hameed *et al*., 2010), which could result in negative environmental impact on macroinvertebrates, sediment and water in Zandspruit River system.

The results showed that the raw sewages that was observed has resulted in the pollution of Zandspruit River system causing poor water quality and pollution on macroinvertebrates from upstream Zandspruit River system sites to downstream Zandspruit sites. This results also indicated level of water pollution has increased significantly day by day because of community involvement in the pollution and there was no positive change in water quality, sediment quality and macroinvertebrates. While monthly changes can play an important and act as key driver for macroinvertebrate community dynamics, its effect was regulated by the predictability of its recurrence (Tonkin *et al.,* 2017). The study by Tanaka and Santos (2017) showed that the hydrological variation can strongly influence the stability and structure of stream macroinvertebrate communities, and that this effect can override water chemistry differences suchas dissolved oxygen concentrations and electric conductivity.

On the other hand, the upstream Zandspruit River system was characterized by mainly high levelof water pollution than the downstream Zandspruit River system, this was because the upstream Zandspruit River system has numerous human made activities as compared to the downstream Zandspruit River system. Nevertheless, the study results indicated that the water pollution in Zandspruit River system was of concern with some problems emanating from poor decision making and unattended issues, which need urgent attention and intervention from main role players, to resolve the issue of water pollution. However, the pollution has much significant impacton the water values, needs from community and water was seen as an important aspect of humanlife.

Therefore, the macroinvertebrate taxa for Dytiscidae were the lowest among the macroinvertebrate taxa and the macroinvertebrate taxa for Chlorolestidae were the highest among the macroinvertebrate taxa community structures. Dalila *et al*. (2014) found that macroinvertebrate community composition did not differ significantly between the two sampling months, but the corresponding quality metrics were slightly better in April than in June, associated with higher Zandspruit River flows. However, complete knowledge of the exact causalrelationships between specific environmental variables and macroinvertebrate community structure may be unnecessary to identify community metrics that were diagnostic of these multiple-scale environmental stressors, because of the interrelations in the resulting alterations inthe environmental variables (Griffith *et al.,* 2001).

The results indicated that there was much higher macroinvertebrate taxon richness, and this was observed to be higher in the downstream than in the upstream because of activities practiced along the Zandspruit River system, which result in poor water pollution in the downstream than inthe upstream Zandspruit River system. Nevertheless, the combined effect created a gradient of water quality, sediment quality conditions that led to a reduction in macroinvertebrate taxa richness by exclusion of sensitive species and increase in tolerant taxa, causing a decline in macroinvertebrate community diversity indices (Nhiwatiwa *et al*., 2017a). However, the macroinvertebrates were affected by the activities and found to be tolerant to poor water pollutionand sediment pollution because of the species diversity found across the sites. Furthermore, drymonth was characterized by the impact different from the wet month, and hot months bring different front.

Furthermore, Johannesburg Metropolitan Municipality also introduced some mitigation initiative used for eliminate water pollution in the area including environmental awareness campaign, educating, teaching and workshopping the community in Cosmo City. However, some of the factors contributing to the pollution of water, sediment and macroinvertebrates included raw sewage, and that there were no differences between all the five sites visited. The study results showed that poverty also contributed significantly in terms of the community practice of continuous illegal dumping of wastes on the water. This causes pollution and poor water quality on sediment hence macroinvertebrates species depended on clear Zandspruit River system. Lastly, some important information for the promotion or implementation of environmental education and awareness in the community which could be studied further by other researchers in relation to impact of Zandspruit River water system pollution, to improve the water quality, sediment quality as well as macroinvertebrates in the Zandspruit River system. Therefore, the results suggest that the community must adopt polluter pay principle to prevent community members from polluting the Zandspruit River system water such that this would result in minimisedor reduced pollution in Zandspruit River system water. In this way pollution can be avoided from sources such as the industrial, residential and commercial activities practiced along the Zandspruit River system.

The study further concluded that the effects of water pollution in Zandspruit River system result affecting the macroinvertebrate species diversity and different species diversity dependent on clean water. The study showed that the entire evaluation of macroinvertebrate species is very crucial to identify, determine and check the level of water pollution in Zandspruit River system. The findings were crucial because water quality pH, alkalinity, conductivity and temperature for sediment quality and macroinvertebrate communities were assessed and compared with their available standard values to determine the water quality. This study showed that different humanmade activities along the Zandspruit River system affects sediment quality and macroinvertebrates species. According to a study by Superada and Tampus (2015) the streams in Zandspruit River system have poor macroinvertebrates taxa richness as a results of poor quality of water. However, there was taxa for Dytiscidae which have the lowest abundance of macroinvertebrates than others because they are less adapted to dry seasons. Chlorolestidae were the ones with highest macroinvertebrates taxa richness than others for all five sites because they are adapted to dry seasons.

The study reveals that water quality, sediment quality and macroinvertebrate communities were used to indicate that there was significant water pollution from human made activities nearby or across Zandspruit River system and the level of water quality and sediment quality. However, therelationship between water quality, sediment quality and macroinvertebrate communities were used to determine the increase in water pollution from human made activities. Nhiwatiwa *et al.* (2017a)'s study showed that the indices adopted from the South African Scoring System version5 proved to be applicable to the study area as the macroinvertebrate taxa revealed similar response patterns to those recorded in South Africa. This findings showed the different impacts of water pollution in urban areas than in rural areas, because in urban areas there were numeroushuman made activities such as industrial, commercial, residential and agriculture being practicedthan in rural areas, which contribute to the increase in water pollution.

The findings demonstrate that community engagement by community leaders is crucial to make the community understand the impact of water pollution from different community activities in thearea around the Zandspruit River system. The study suggests that the involvement of the political leadership is also important in the Cosmo City community as well as the involvement and engagement of the relevant municipality officials of Johannesburg Metropolitan Municipality responsible for protection of water pollution in the study area. It was further concluded that water pollution from residential activities has been seen as the major pollutant and this needs urgent attention and should be addressed by the relevant municipal authority responsible for the management of illegal dumping of waste in the Zandspruit River in Cosmo City. However, other activities such as fishing, commercial, industrial and farming do not have much significant impacton water pollution downstream. It was important to note that all identified human made activities including residential, commercial, industrial, farming and fishing were polluting the water significantly, resulting in poor water quality and affecting the species diversity. The study results emphasised that residential activities were observed as the most human made activities that cause poor water quality in the Zandspruit River system.

The results further indicated that the main human made activities which are contributing factors to water quality pollution downstream were industrial, commercial, fishing, farming and residential activities in Cosmo City. According to Dalu *et al*. (2017) most of the stream sites were in urban areas, while most of the Zandspruit River system sites were downstream of the urban area and located mostly in agricultural areas. Some of human made activities such as commercial and industrial activities cause pollution from poor stormwater channels only during rainy seasons andthis also affects the water quality significantly. However, residential activities were regarded as the major significant type of water pollution causing significant impact on the streams including species diversity and the other human made activities such as fishing, and farming were regardedas having lesser impact on water pollution.

4.2.10 Conclusion

In conclusion, based on the results and discussion been discussed there was still more contribution to be delivered and the results of the study findings was discussed and their observations. The results and discussion have showed that there was significant impact of the water pollution on the human made activities across Zandspruit River system as a results of Cosmo City development project. Based on the results and discussion above there was much water pollution on the river and the water quality was very significant affected. This normally happens on a daily basis and the results shows the importance of the water quality on the species that depends on the water for usage. Some of the illustration has showed that the result of the pH, temperature, macroinvertebrate was contributed by pollution from river water. The pollution on water river system was seen in the area with high value and the value for the water was of importance in the area. There was significant pollution from different human made activities causing pollution on water was discussed in this chapter and their impact on the river quality based on the sampling results. Lastly, some of the factors contributing to the water pollution were considered in this chapter and water was found been polluted significantly with poor quality.

CHAPTER 5: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

This chapter make focusses on the research summary, conclusion and recommendations that was used in this study base on the results and discussion of the study. The description of the study area has an important role to play in this chapter thereby identifying and any important gaps to be identified and discussed in detail on the study area. The chapter has to look into the summary, conclusion and recommendations of the results and discussion to be implemented and proposed mainly from the water pollution in the area and trying to identify other means of resolving water pollution issue across Cosmo City along Zandspruit River system. Recommendations for future use was also look into in this chapter including any kind of management implementation strategies to be used to maintain the clear water in the Zandspruit River system. The proposed importance of recommendations was considered in this chapter in detail and the recommendations were identified and outlined for the current study discussion and results. The last thing to be considered in this chapter must be to discuss how the research come up with any means of promoting water pollution and environmental awareness in the area.

5.2 Conclusion

In conclusion, the study results indicated that water quality, sediment quality and macroinvertebrate communities showed that there was water pollution in Zandspruit River systemin Cosmo City in all sites. The results also showed that human made activities such as industrialactivities, residential activities and commercial activities along the Zandspruit River system indicated that there was potential water pollution in the Cosmo City area. This study concluded that the water parameters such as temperature, alkalinity, pH and conductivity conducted from allfive sample sites collected from upstream and downstream in different sites were found to be within the recommended limits. The study showed that water pollution was a serious environmental problem in in Cosmo City. Therefore, there is a need for government to intervene to prevent and protect pollution of rivers. The study results also concluded that water pollution in Zandspruit River system was mostly from human made activitiesincluding agriculture, industrial, residential and commercial than the natural activities such as erosion and siltation. On the other hand, Zandspruit River system water was also crucial for the community living in the area for different purposes such as drinking, washing, farming irrigation and fishing. Therefore, people cannot live or survive without this essential element.

In conclusion, the study was conducted focusing on water pollution among months, across sampling sites stream and also considered the factors that contribute to pollution in the ZandspruitRiver in Cosmo City. The study highlights that community upstream as well as downstream of theZandspruit River system use water for different purposes and water, sediment as well as macroinvertebrates were important in the study in identifying sources of water pollution in the study area. Anthropogenic impacts such as sewage leakages resulted in increased nutrient concentrations, which might have had a significant effect on the macroinvertebrate communities. The results showed there is a needfor future research focusing on the effects of pollution on health among communities living around the Zandspruit River system, who use Zandspruit River system water for drinking. Therefore, there is also a need for future studies on the effects of pollution on macroinvertebratesfrom downstream activities and how to improve the water quality around Cosmo City for future use. Lastly, other factors to be considered for further studies are strategies and policies that the municipality should implement to reduce different kinds of pollution and prohibit different human made activities that cause pollution in Cosmo City.

5.3 Recommendations

This study recommends the following on pollution in Cosmo City: There is a need for continuous implementation of the policies that are relevant to water pollution by the Johannesburg Metropolitan Municipality in managing pollution, and prohibiting human activities that cause pollution. The study further suggests that future leaders should value water quality, sediment quality as well as to control and protection of water in the Zandspruit River from impact of humanmade activities around Cosmo City and stream. The study highlights the detrimental effects of poor management of raw sewage gushing in the Zandspruit River system and how this contributes to water pollution, among other human made activities in the area. The JohannesburgMetropolitan Municipality should in future priorities this problem when planning for Cosmo City area. The study also highlighted that lack of financial support from government has also contributed to the poor management of water pollution and therefore, there was a need for proper commitment from the community, community leaders and the municipality in order to reduce the impact of water pollution. As the study highlighted, it was further supported that the main strategyto be used in the Zandspruit River system water pollution was the control of activities around theZandspruit River system, to reduce and mitigate the impact of water pollution and improve the water quality in the Zandspruit River system. It is further recommended that human made activities that are contributing to pollution of Zandspruit River system should be minimized and mitigated by introducing a proper management of water pollution. Therefore, environmental management control strategies are important in controlling and managing water pollution.

The study results suggest that continuous cleaning as well as maintenance of the water to improveits quality as well as sediment was needed in the Zandspruit River system and this needs to be conducted on a regular basis by the Johannesburg Metropolitan Municipality officials. The resultsalso suggest that the fencing along the riverbank where human made activities were take place should be fixed. Raw sewage overflow that takes time to be attended to by the Johannesburg Metropolitan Municipality must be prioritised and dealt with as soon as it starts to avoid water pollution in the Zandspruit River system. Additionally, existing water pollution control measures should be put in place in the Cosmo City. Furthermore, existing pollution control management systems in the Cosmo City were also evaluated as well as policy options and a variety of pollution control options were recommended, and these included pollution permits, self-regulation, economic incentives and pollution penalties (Lynzaad, 2018). The study further emphasizes thatthe sustainable strategies to minimize the level of water pollution in development activities on adjacent rivers was also seen as an important factor to be implemented to prevent, protect, maintain and restore water quality. The study further suggested that regulation and monitoring were an effective way of pollution management (Owa, 2014). Lastly, there is a need to preserve and maintain the quality of water parameters, sediment parameters and macroinvertebrates community structures, and protect them from different kinds of pollution that result from human made activities around the Zandspruit River system in the Cosmo City. Theseresults further indicate that because of lack of knowledge by the community living near the Zandspruit River system, there is a need for education in the community in Cosmo City about theimpact of water pollution caused by people near the Zandspruit River system on water quality.

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APPENDICES

Appendix 1: Ethical clearanceConsent letter

I am Nemalili AY, a Masters students in IRD. Topic for the contribution of integrated development projects to Zandspruit River water pollution, Gauteng Province. With this letter, I am inviting you to participate in this study. Please note that any information you will provide will be treated as confidential and therefore will not be disclosed to anyone without your consent. Your participationis also voluntary, meaning that you are free to pull out at any time should you feel uncomfortableduring the course of the study.

Signature of researcher_____________________ Date _________________________

I………………………………………………………………………………………. have read and understood the contents and terms of this invitation to participate in this study. I hereby declare that I am voluntarily participating in this research.

Signature of respondent_____________________ Date ______________________

Request to conduct research

Dr. Ndivhoniswani Lukhwareni
Municipal Manager
Johannesburg Metropolitan Municipality
PO Box 1049
Johannesburg
2000

Councillor Ward 100
Johannesburg Metropolitan Municipality
Cosmo City
PO Box 1049
Johannesburg
2000

Dear sir/Madam

Subject: Permission to conduct research

This communication refers:

I am Nemalili AY, master's for student in IRD. I write this communique to request for permission to conduct research. The topic for the contribution of integrated development projects to Zandspruit River water pollution, Gauteng Province, which falls under your jurisdiction. Specifically, the research will be conducted amongst communities, councillors and administratorsof the municipality.

Your favourable response in this matter will be highly appreciated.Sincerely,

Signature ....Date: …………………………

Appendix 2: Data collection instrument

Questionnaire quantitative data collection Sample questionnaire on river water pollution

Name of researcher:___________________Starting time: _____________________________

Date:________________on Tuesday to________________on Wednesday and ______________ on Tuesday to_________________on Wednesday: ______________

Researcher beginning:

I am conducting research at Cosmo City, student from university regarding acquiring knowledgeon river quality pollution for Zandspruit River.

Section I. Water pollution generalQuestion 1

Do you think integrated development project activities contribute to Zandspruit River water pollution in Cosmo City (yes or no)?

Answer: ____

Question 2

Are there any major pollutants sources on Zandspruit River water associated with Cosmo City (yes or no)?

Answer: ____

Question 3

Does the Cosmo City development association have the potential effects and impact of the pollutants on the downstream (yes or no)?

Answer: ____

Question 4

Do you think the sustainable strategies can minimize the level of pollution in development activities on adjacent river (yes or no)?

Answer: ____

Question 5

Are there origin and effect for quality water of Zandspruit River (yes / no)?

Answer: ____

Question 6

Are there current status of water pollution and pollutants in Zandspruit River (yes or no)?

Answer: ____

Question 7

Are there any challenges and impacts of water pollution (yes or no)?

Answer: ____

Question 8

Has the water pollution management and control been implemented (yes or no)?

Answer: ____

Thank you