

Assessment of the extent of the impact of agricultural activities on different water uses in the Mooi River

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Dissertation accepted in partial fulfilment of the requirements
for the degree *Master of Environmental Management with
Ecological Water Requirements* at the North-West University

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Graduation July 2023

30375150

ACKNOWLEDGEMENTS

I would like to thank God the Almighty for giving me strength and wisdom to be able to conclude this dissertation. I would also like to express my deepest gratitude to my family especially my mom for words of encouragement and prayers and also to my last born Rhandzu for allowing me to sacrifice and dedicate the time I should have spent with him to my school work. I am deeply indebted to my supervisor Professor V. Wepener and my co-supervisor Dr J.H. Erasmus for supervising my work and for assistance with software and statistical analysis. My gratitude also goes to Mr J.C Maluleke for assistance with real and descriptive statistics and also for holding my hand throughout the entire process.

Last but not least, I would like to thank the Department of Water and Sanitation for funding my Masters' studies, I could not have undertaken this journey without the funding from the Department.

Lastly, I am extremely grateful to myself for the sleepless nights I have spent working on this documents, for keeping myself sane when I felt like I was losing it and for enduring until the end, Glory be to God.

ABSTRACT

The quality of water in the Mooi River is deteriorating due to anthropogenic activities practiced in the catchment area. The most practiced activities in the catchment include amongst others mining which is dominating the upper catchment (Wonderfontein Spruit), urban and industrial activities, agricultural activities such as crop and cattle farming and chicken breeding, as well as abattoirs. The Mooi River is used for domestic water supply, crop irrigation, livestock watering and recreational use. Anthropogenic activities are having a serious impact on the quality of water and makes it less fit for the intended water uses. Several studies were conducted in the catchment to identify and quantify pollution emanating from mining activities and urban pollution but a little has been done to determine the extent of agricultural pollution in the area. The main aim of this research is the assessment of the extent of the impact of agricultural activities on different water uses in the Mooi River.

The objectives of the study were achieved by sourcing data for two time periods (2014 – 2015) and (2018 – 2019) from the Department of Water and Sanitation's water quality management system, the data was therefore plotted on line graphs to determine the trends and changes that occurred between the study period. The data was analysed and compared with water quality guidelines for domestic, agricultural and aquatic ecosystem use. The data was also compared with the resource quality objectives for the Mooi River catchment. The degree of change in the water quality and the relationship between the agricultural related measured parameters were determined using analysis of variance (ANOVA) and principal component analysis biplots (PCA) methods. With the aid of the land-use map seven water quality monitoring points located within the Mooi River and its tributaries were selected from the existing DWS monitoring programme and used for the present study.

Analysis of the results demonstrated that the upper parts of the Mooi River just below the Klerkskraal Dam is still complying with the water quality guidelines, however, trend analysis demonstrated that the lower catchment is mostly affected by agricultural activities, this is based on the increasing trends in phosphate (PO_4^{3-}), magnesium (Mg^{2+}), chloride (Cl^-), potassium (K^+) and nitrate-nitrite ($\text{NO}_3\text{-NO}_2$). The other sites along the Mooi River demonstrated an increase in Mg^{2+} and Cl^- , electrical conductivity (EC), PO_4^{3-} and sulphates (SO_4^{2-}). An increase in Cl^- , Mg^{2+} and SO_4^{2-} were also noted for the Mooi River tributaries (Loop Spruit and Wasgoed Spruit). For the sites located on the Mooi River after confluence with the Wonderfontein Spruit trend analysis have also shown some increase in EC and SO_4^{2-} , which is an indication of the acid mine water release from the west basin mines. Based on this study the agricultural water use has an impact in the water quality of the Mooi River, however, it is recommended that further studies be conducted to determine the impacts of pesticides and metals, as well as other parameters such as sodium, calcium and pathogens, which did not form part of this study.

Keywords: Mooi River, water quality, impacts, land-use, agriculture, surface water, pollution

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ABBREVIATIONS

BMP	Best Practice Management
Ca ²⁺	Calcium
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
EPA	United States Environmental Protection Agency
EU	European Union
GDP	Growth Development Plan
K ⁺	Potassium
Mg ²⁺	Magnesium
NH ₃	Ammonia
NO ₂ -NO ₃	Nitrate-Nitrite
NWA	National Water Act
NWDACERD	Northwest Department of Agriculture, Conservation, Environment and Rural Development
OECD	Organisation for Economic Co-Operation and Development
PFMA	Public Finance Management Act
PO ₄	Phosphate
READ	Department of Rural, Environment and Agricultural Development
RQO	Resource Quality Objectives
SO ₄	Sulphate
SWAT	Soil and Water Assessment Tool
WMS	Water Management systems
WRC	Water Research Commission
WSA	Water Services Act

CHAPTER 1: INTRODUCTION

1.1 Background

Agricultural water pollution has been identified as a major environmental impact by the Organisation for Economic Co-operation and Development (OECD) (Parris, 2011). Globally, 70% of the available water has been allocated to the agricultural sector and this sector is highly contributing to the pollution of water resources since it generates fuzzy nitrates, phosphates and salts. The pollution is generated from the disposal of large quantities of agrochemicals, organic matter, drug residues, sediments and saline drainage from crops and livestock farming activities. The resultant water pollution poses a serious threat to aquatic ecosystems and human health (Mateo Sagasta *et al.*, 2017). Methemoglobinemia (blue baby syndrome) is an example of disease acquired through drinking of water containing high concentrations of nitrates (DWAF, 1996a).

According to Pimentel *et al.* (2004), 40% of the United States (US) freshwater is no longer suitable for drinking or recreational use due to contamination by dangerous microorganisms, pesticides and fertilizers. The same authors have also articulated that application of sludge to agricultural land in the US has resulted in the contamination of land and water bodies with metals and toxic material. It is estimated that three billion kg pesticides are applied worldwide in agriculture each year and that this alone contribute to 26 million human poisoning and 220,000 deaths each year (Richter *et al.*, 2002; Mateo Sagasta *et al.*, 2017). The treatment of water containing agricultural pollutants is very costly. Agricultural pollutants are also affecting activities such as the commercial fishing, recreational, and cultural values of water resources (Parris, 2011).

Apart from agricultural pollution, the Mooi River and its tributaries receive contamination from different types of point and diffuse sources of pollution (Labuschagne, 2017). Mine residue deposits of old and abandoned mines are located in the headwaters of the Wonderfontein Spruit (Potgieter, 2019; Coetzee *et al.*, 2006). These mine tailings dams, sand dumps and rock dumps are potentially significant contributors to diffuse pollution (Coetzee *et al.*, 2006). Furthermore, a few active gold mines situated in the same area are discharging fissure and process water into the water environment. Most of the areas in this sub-catchment are underlain by dolomite of which three of the dolomite compartments are dewatered by the gold mines (Institute for Water Quality Services, 1999).

The Institute for Water Quality Services (1999) further explains that water in the Wonderfontein Spruit is diverted into a one metre diameter pipeline, which transports the water over two of

the dewatered compartments to avoid pollution from seeping through in to the dolomitic compartment. A number of growing communities are located downstream of the pipeline in the catchment which includes amongst others Kagiso, Mohlakeng, Toekomsrus, Rietvallei and Bekkersdal and they are also playing a major role in diffuse source pollution (van der Walt *et al.*, 2002).

In the North West Region where the Mooi River is situated, agriculture is known as the second contributor in the growth development plan (GDP) of the province. It contributes 13% of Growth Development plan and it also provides 18% of the work labour force in the area (WRC, 2011). Two major irrigation schemes (Mooi River and Klipdrift) are located in this area (DWA, 2012). The agricultural activities that are dominating in the Mooi River include amongst others planting of mealies, sunflower, sorghum, ground nuts, as well as cattle and sheep farming (READ, 2015).

Worldwide, the area equipped for agriculture is estimated to be around 320 million hectares (Mateo Sagasta *et al.*, 2017). In the Mooi River catchment, 35.25 million cubic meters of water has been allocated to irrigate a total area of 4 578.11 hectares (DWA, 2012). The Mooi River catchment consist of three sub catchments namely the Wonderfontein Spruit (north eastern reach), Mooi River proper (northern reach) and Loop Spruit (eastern reach). Farming activities are recorded to be taking place in all the mentioned sub-catchments and the Mooi River system which is the main water resource in the area currently faces a serious challenge due to these anthropogenic activities (Barnard *et al.*, 2013).

1.2 Problem statement

The Mooi River system currently faces a serious challenge due to anthropogenic activities such as agricultural activities and others (Barnard *et al.*, 2013). In the North West region where the Mooi River is located, approximately 62% which is equivalent to 35.25 million cubic meters of surface water has been allocated to the agricultural sector, this water use generates surface runoff which contains pollutants such as manure, pesticides, herbicides and other chemicals. These pollutants find its way into ground and surface water resources through point source and diffuse source discharges (Pelser, 2015; DWA, 2012). The headwaters of the Mooi River is at the northern parts of Potchefstroom in close proximity of the town of Koster and then flows southerly where it confluences with the Vaal River. The Mooi River runs through the towns of Potchefstroom, Westonaria, Oberholzer, Fochville and Carletonville until it confluences with the Vaal River near the border of Free State, approximately 15 km from Stilfontein.

The Mooi River catchment consist of three sub catchments namely the Wonderfontein Spruit (north-eastern reach), Mooi River proper (northern reach) and Loop Spruit (eastern reach). There are various dams along Mooi River and these include Donaldson, Klipdrift, Boskop and Potchefstroom dams. The Mooi River Catchment borders Gauteng Province in the upper section of West Rand and the lower part of the catchment is within the North West Province. According to the Van der Walt et al. (2002), the upper reaches of the Mooi River Catchment is dominated by gold mining activities, comprising tailing dams, mine dumps, sand dumps and rock dumps which together contribute significantly to the poor water quality of this river system. Farming activities dominates the lower Wonderfontein Spruit, while the Northern sub-catchment is dominated by crop farming and cattle grazing, and the eastern sub-catchment (Loop Spruit) is dominated by crop farming and grazing lands.

Since the year 1842, the Mooi River has been the sole supply of water for Potchefstroom. From the late 1950's and early 1960's the quality of water has gradually deteriorated in the Boskop and Potchefstroom dams, which are known as the reservoirs for drinking water supply for Potchefstroom and both dams are located within the Mooi River system (Van der Walt *et al.*, 2002).

The citizens of Potchefstroom are faced with a serious problem of bad taste in the water and most of them are resorting to buying bottled water and others are even installing water purification systems in their homes (Manyatshe, 2017; Mulovhedzi, 2016). Several studies were conducted in the Mooi River and most of them are focusing on the impact of mining activities that are occurring in the area. Agriculture is one of the anthropogenic activity that is contributing to the deterioration of water quality in the Mooi River, however, there is not enough evidence to support this allegation (Barnard *et al.*, 2013). According to Labuschagne (2017), agricultural activity run-offs and abattoir wastewater are some of the main sources of organic pollution within the catchments of the Mooi River. A study by van der Walt *et al.* (2002) proposed a development of an integrated management plan that will assist in the filling of gaps in the knowledge and understanding of different pollution sources in the Mooi River. Furthermore, this authors recommended further studies which will gather more information on the Mooi River to assist in the quantification of pollution sources.

In the Mooi River catchment, the Boskop Dam is known to be used for recreational and conservation activities by the surrounding communities, however, due to the thick reeds that are growing along the banks of the dam shoreline angling is currently restricted (DWS, 2015). Although the situation has a potential to restrict other secondary uses of the dam to a point that the economic potential of the dam and access by the users may be compromised, Boskop Dam remain a well-known destination for recreational activities. Also, within the Mooi River

itself, Taruza (2016) reports that secondary activities such as angling and general recreational activities are widely undertaken by users. The aim of this study is therefore to provide insight into the extent of the impacts of agricultural activities on both domestic and agricultural water uses in the Mooi River system and the environment.

1.3 Research justification

The Water Research Commission (2011) concluded that surface and ground water in the Mooi River catchment is poor and recommended that a large scale water quality study be conducted to determine the contributing factors. The research seeks to identify and quantify the impact and contribution of the agricultural sector to the pollution in the Mooi River. The present study will benefit the local JB Marks Municipality in a sense that the quality of water to be treated for drinking purpose will be known and proper treatment facilities will be used to obtain the desired drinking water quality. The local water users will also know whether the surface water in the area is safe for agricultural and recreational activities and other uses. The regulatory authorities will also be aware of the contribution of the agricultural water use to the deterioration of the river, this will assist in the development of strategies and regulation to mitigate impacts of agricultural activities.

1.4 Hypothesis

The below hypothesis statements will be tested during the study:

- H0: Agricultural practices will not impact the water quality in the Mooi River and will not have a negative effect on different water use sectors.
- H1: Agricultural practices will impact the water quality in the Mooi River and will have a negative effect on different water use sectors.

1.5. Aims and objectives

The main aim of this research is to determine and quantify the extent of water quality impacts caused by poorly managed agricultural activities within the Mooi River Catchment, with specific reference to domestic, agricultural and aquatic ecosystem water user groups.

This research has the following objectives:

- Determine the water quality and trends in the Mooi River catchment for the period 2014-2019.
- Analyse water quality data (2014/2015; 2018/2019) and compare with target water quality guidelines for domestic, agricultural and aquatic ecosystem water users.

- Analyse the water quality data (2014/2015; 2018/2019) and determine its compliance to resource quality objectives (RQO's) with relevance to the aquatic ecosystem quality requirements.
- Identify/ locate different agricultural activities and their sources which may impact water quality in the Mooi River.
- Recommend best practices for agricultural activities based on water quality guidelines.

1.6 Dissertation layout

Chapter 1: General introduction.

This chapter introduces the research. The chapter lays the foundation by addressing the research problem, aims and hypothesis. The background information to the impacts of agricultural activities on domestic and recreational water uses is introduced. The chapter also provide a general overview on the research methodologies, design and ethical considerations.

Chapter 2: Literature review

This chapter address literature review by deliberating the findings of other studies on the impact of agricultural activities on domestic water, agricultural and recreational water uses. Literature survey on water quality on a global and local scale, the different types of agricultural activities and the associated impacts are comprehensibly discussed in line with the research questions.

Chapter 3: Research design and methodology

This chapter discusses the research design, approach and methodologies used in data collection, water quality data analysis, tables and graphs interpretation and discussion. This part will consist of the historical and present water quality status, data analysis and interpretation of the data in relation to the applicable legislation and standards.

Chapter 4: Presentation of results.

The section contains line trend analysis graphs for all selected parameters for both study periods 2014-2015 and 2018-2019. Each graph will present results for each parameter for all sampling sites. The graphs will also depict the changes that took place during the study period.

Chapter 5 & 6: Discussion and Conclusion

The findings of the study in accordance with the set objectives will be discussed in this section and the summary of the findings and recommendations on the practices and or mitigation measures to be implemented to improve the Mooi River system will also be covered under this topic.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The protection of water resources in South Africa is regulated through the Constitution, the National Water Act (NWA) and the Water Services Act. According to section 24 of the Republic of South Africa Constitution (1996) every South African citizen is entitled to a harmful free environment and an environment that is protected for the benefit of current and future generations. Section 3 of the Water Services Act 108 of 1997 (WSA) promotes equal access to clean water and sanitation. Chapter 3 of the NWA gives the Minister of Water and Sanitation a mandate to develop water resource protection measures (classification of the water resources, reserve determination and development of resource quality objectives).

In South Africa the National Water Act, 36 of 1998 (NWA) (1998) is regarded as the legal tool for protection, use, management and conservation of the Nations water resources. Section 21 of the NWA defines water use as “ *taking water from a water resource, storing water, impeding or diverting the flow of water from the water course, altering the bed banks and characteristics of the water resource, engaging in a controlled activity, discharging of water through a pipe or canal into the water resource, disposing of waste in a manner which may have detrimental impact into the water resource, disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation processing, removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people, and using water for recreational purpose*”.

According to the NWA (1998), it is the responsibility of the Minister of the Department of Water and Sanitation to fulfil the purpose of the Act to ensure that water resources are protected in a manner in which it will remain fit for the above-mentioned water uses through establishment of policies, strategies and regulations. This study focused on the impact of agricultural water use in the Mooi River catchment and its impact on other water uses (domestic, recreational, agricultural and aquatic ecosystems). In terms of section 21 of NWA the below listed five water uses are relevant or associated with agricultural water uses:

- Section 21 (a) - taking of water from water resource for livestock watering, and irrigation of crops. The resource could be either surface or ground water.
- Section 21 (b) - storing of water in dams for crop irrigation or any other agricultural use.
- Section 21 (e) – engaging in a controlled activity (irrigating with waste water generated from the agricultural activities).

- Section 21 (g) - disposing of waste or water containing waste in a manner which may be detrimental to a water resource e.g., disposal of wastewater generated from chicken houses, piggery or abattoir and storage of manure.
- Section 21 (f) – discharging of waste water generated from agricultural activities into the water resource through a pipe or a canal.

For the purpose of the present study the extent of the agricultural impact will be assessed against four selected water uses: domestic, recreation and aquatic ecosystems. The impact will also be assessed against the agricultural water use. Domestic water is described as water that is set aside for drinking purpose, food preparation and personal hygiene e.g. bathing, washing and transporting of waste and in order for the water to be fit for this use it must meet a certain criteria or standards (DWAF, 1996a). The National Sport and Recreation Act (1998) define recreation as “*a process of voluntary participation in a wide variety of activities that are undertaken during leisure times and contributes to the improvement of general health, well-being and skills of both the individual and society*”. DWAF (1996e) categorizes recreational water use activities into three categories as described below:

- Primary contact recreation, where you are in direct contact with the water, where the body can be fully immersed in water. This includes surfing, water skiing, diving and swimming.
- Secondary contact recreation, where you have direct contact with the water but are unlikely to swallow it. This includes paddling, wading, boating and fishing.
- Passive recreation, where there is no contact with the water. This includes scenic appreciation, walking and picnicking.

Aquatic ecosystems as defined by DWAF (1996b) are “*the abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones, reservoirs lakes and wetlands and their fringing vegetation*”. The terrestrial biota and human beings depend on aquatic ecosystems for survival hence a water quality guide line for aquatic ecosystems was developed by the DWAF to provide the required level of protection for aquatic ecosystems. Agricultural water use is the use of water for crop irrigation, livestock watering and aquaculture. Water quality guideline or standards to regulate the agricultural water use are discussed under section 2.8.

2.2 General chemistry

2.2.1 Introduction

Both surface and ground water contain elements or compounds which occur naturally as part of geology or through catchment activities such as mining, industry, and agriculture. The presence of elements and compounds in water have a serious impact on the quality of water. As stated in the water quality guidelines (1996e) the physical, chemical, and biological characteristics of water is influenced by elements/ constituents contained in water. Significant amount of dissolved minerals makes the water to be hard. According to Michaux et al. (2018), the following are the elements that are relevant when surface/drinking water quality is under consideration.

- Calcium,
- Magnesium,
- Sodium,
- Potassium,
- Aluminium,
- Iron,
- Manganese,
- Fluoride,
- Chloride,
- Oxygen,
- Nitrogen (nitrate, nitrite and ammonia),
- Sulphur/ sulphate
- Carbon.

The study only focused on parameters that are associated with agricultural activities and the basic chemistry of those parameters are further discussed below.

2.2.2 Basic chemistry of parameters/ constituents selected for the study

2.2.2.1 pH

According to Omer (2019), pH is defined as the negative logarithm of the hydrogen ion concentration. pH measures the acidic or basic strength of water. Acidic water contains extra hydrogen ions (H^+) and basic water contains extra hydroxyl (OH^-) ions.

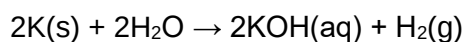
Values for pH ranges from 0 to 14, with 7 being neutral, pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base solution. Pure water is neutral, with a pH close to 7.0 at 25°C. Normal rainfall has a pH of approximately 5.6 (slightly acidic) due to atmospheric carbon dioxide gas. As per DWAF (1996) safe ranges of pH for drinking water are from 6.5 to 8.5 for domestic use and livestock watering. The geology or geochemistry of rocks in a particular area has a major influence on the pH and alkalinity of water. In catchment area industrial and agricultural effluents also have an influence on the pH of water. Unionised NH_3 is influenced by pH, as the pH increases NH_3 toxicity also increases (Wurts, 2003).

2.2.2.2 Electrical Conductivity

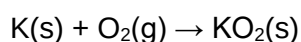
Salinity is a build-up or accumulation of salt compounds made up of Na^+ , Mg^{2+} , Cl^- , SO_4 and bicarbonate in soil or water and it is measured as total suspended solids or total dissolved solids (Platform, 2010). Salinity occurs naturally as result of weathering of rocks or as a result of anthropogenic activities (Corwin and Yemoto, 2017). Dissolved salts conduct electricity and EC is a measure of the ability of water to conduct an electrical current (DWAF, 1996C). According to Corwin and Yemoto (2017), EC salinity has a negative impact on crop yield due to the fact that it is toxic, reduces plant permeability and water absorption hence it is used to determine the suitability of water for irrigation. High levels of salts in water cause a bitter taste in drinking water and health effects such as kidney failure, they also have an impact in terms of corrosion and scaling of plumbing and electrical appliances (DWAF, 1996a).

2.2.2.3 Potassium

As defined by Arega (2020), K^+ is known as a silver white alkali metal which is highly reactive in water and is a very good dietary constituent required by living organisms (human and animals). Below is the chemical reaction equation of K^+ in water when the solid K^+ reacts with water it forms aqueous potassium hydroxide and hydrogen gas:



Potassium metal reacts rapidly with atmospheric oxygen to form flaky white potassium peroxide within seconds of exposure. K^+ also reacts with water to form K^+ ions. It is highly soluble in water but also difficult to remove through precipitation (DWAF, 1996a). The chemical reaction of K^+ with air is as follows:



Potassium is also known as good oxidant used for removal of manganese in water treatment process (Zhang *et al.*, 2021).

Approximately 95% of commercially produced K^+ compounds are used as fertilizer and it is estimated that roughly 25 million tons of K_2O and KCl are supplied worldwide as fertilizer (Gandebe *et al.*, 2017). Potassium is applied on soil or crops to increase crop yields. Crop plants require nitrogen, phosphorous and K^+ to maintain the normal physiological function of the cell. Potassium iodide is used as table salt and animal feed (DWAF, 1996a).

As recommended by the WHO (2009), K^+ is good for heart functioning, however, if taken in high quantities K^+ could result in significant health effects in people with kidney disease or other conditions, such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia, it can also affect older individuals with reduced physiological reserves in their renal function and/or individuals who are taking medications that interfere with the normal handling of K^+ in the body.

2.2.2.4 Magnesium

Magnesium as described by DWAF (1996a) is an alkaline earth metal which burns with brilliant light to form magnesium oxide. Mg^{2+} is a nutritional element useful for muscle functioning. High intake can result in suppression of central nervous system.

Calcium and magnesium naturally occur in soil as cations, Ca^{2+} and Mg^{2+} these two cations are attracted to anions found on clays and organic matter (cation exchange complex of the soil). They are both used as secondary micronutrients and are easily taken by plants when they are in ionic format (Chapman, 1996).

According to Chandini *et al.* (2019), Mg^{2+} , in plant nutrition, is as a constituent of the chlorophyll molecule and as a carrier, it is also involved in enzyme reactions as an effective activator. The most common magnesium minerals are magnesium carbonate and silicate. Magnesium silicate is used as an animal feed and as a fertilizer (Chandini *et al.*, 2019).

2.2.2.5 Chloride

Kaushal *et al.* (2005) defined chloride as an anion which is negatively charged and this writer further explains that chloride exist as Cl^- . It is formed when the element chlorine gains an electron, or it can be formed when hydrogen chloride dissolves in water. Chloride can impact freshwater organisms including plants by changing their reproductive rate and increasing their mortality. Chloride concentration of 1 200 mg/l in water causes nausea and vomiting and high concentration of chloride also accelerates corrosion of metals (DWAF, 1996a).

Based on McDowell (2019) chloride is an important micronutrient during oxidation of water in photosynthesis and it serves as a charge balance during cation transport and also assist with

cell hydration. The same writer also mentioned that potassium chloride and ammonium chloride are the most commonly used fertilisers, however, it was discovered in certain studies that chloride can solubilise and increase the plant uptake of cadmium which is toxic for human consumption.

2.2.2.6 Sulphate

Sulphate naturally occurs as a result of dissolution of calcium sulphate (gypsum) (moreno *et al.*, 2009). However, acid mine water and leachates and other industrial processes such as tanneries, textile mills are also known as major sources of SO_4 (Luptakova *et al.*, 2016). Sulphate is an oxy-anion of sulphur in the +VI oxidation state and it reacts with various cations such as K^+ , Na^+ , Ca^{2+} , Mg^{2+} , barium, lead and ammonium to form salts. Potassium, Na^+ , Mg^{2+} and ammonium sulphates are highly soluble, whereas calcium sulphate is partially soluble and barium and lead sulphates are insoluble (Singh and Turner, 1965). Sulphur dioxide, which is released into the atmosphere, during combustion of fossil fuels is another source of SO_4 and it is discharged back into the environment as sulphuric acid in rainwater (acid-rain) (Sporl *et al.*, 2013). Drinking water with high concentration of SO_4 has bitter taste and it also causes diarrhoea. Elevated concentration also increase the rate of corrosion on metal fittings and water distribution pipelines. Sulphate can be removed or treated through ion exchange, distillation, demineralisation, reverse osmosis, and precipitation (DWAF, 1996a).

In the agricultural sector sulphur or SO_4 is essential for growth of corn and soybean. The most common sulphur compounds used for soil supplement include amongst others, ammonium sulphate, ammonium thiosulphate, calcium sulphate, magnesium sulphate, polysulphate and potassium sulphate (Sawyer, 2020).

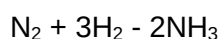
2.2.2.7 Nitrogen (nitrate - nitrite)

According to Yuan *et al.* (2021), nitrate is a plant nutrient which is derived from the oxidation of ammonia (NH_3) through the nitrification process, the Nitrobacter bacteria found in aerobic condition converts organic nitrogen (NH_3) to nitrate and nitrite. DWAF(1996e) stipulates that nitrates occur in natural water due to the oxidation of plant and animal debris and from the decomposition of animal and human excrement. The same writer further narrates that nitrate if consumed through drinking water at levels higher than the recommended limits, has the potential to cause tiredness and failure to thrive. The study done by Ward *et al.* (2018) revealed that in addition to the hemoglobinemia a condition that occurs due to reduction of nitrate to nitrite, which then combines with the red blood pigment, haemoglobin to form methaemoglobin in the presence of an abnormal gut flora, high nitrate intake can also cause colorectal cancer, thyroid disease, and neural tube defects.

Nitrogen in agricultural areas reach the water environment by three ways: Drainage, leaching and runoff and the majority of nitrogenous fertilizers are not easily absorbed products as a result they interfere with both underground and surface waters (Gandebe *et al.*, 2017).

2.2.2.8 Ammonia

The Prevention (2007) describes ammonia as a gas that exist in two forms, unionised (NH_3) and ionised (NH_4) formed naturally through degradation of nitrogenous matter. As shown on the below chemical reaction NH_3 is a compound of nitrogen and hydrogen gas which can be easily converted into liquid.



Based on DWAF (1996b) unionised NH_3 is toxic to aquatic biota while the ionised form is responsible for causing eutrophication in lakes, dams and other impoundments (DWAF, 1996b). According to DWAF (1996a), NH_3 is not toxic to human beings at the concentrations likely to be found in drinking water, however, elevated concentrations of NH_3 can jeopardize the disinfection of water and result in conversion of NH_3 to NO_2 in the distribution systems, which may result in taste and odour problems.

Nitrogen compounds emitted from agricultural sources can affect air quality in two ways: (NH_3) emissions result from fertilizers and livestock, and nitrogen oxides (NO_x) from fuel combustion in farm equipment (Davari *et al.*, 2010). Ammonium diphosphate is the well-known form of NH_3 used as a crop fertiliser. In a study conducted by Divya and Belagali (2012), it was found that 83, 353 tons of chemical fertilizers were applied at Mysore district in India by farmers and that 50% of those fertilisers contained ammonium di-phosphate, approximately 150-200 kg/ha of ammonium di-phosphate.

Ammonia contaminated runoff from fresh manure application sites is toxic to aquatic life, at high levels, NH_3 in surface water will kill fish. Fish are relatively sensitive to NH_3 in water and they could die if exposed to concentrations as low as 0.02 mg/l (Berg *et al.*, 2017).

2.2.2.9 Phosphate

Phosphorus occurs naturally on earth as PO_4 , the earth's crust contains 1 g PO_4 per kilogram. Phosphorus occurs in two different forms; organic and inorganic and they exist in water in both soluble and insoluble phases. Orthophosphates, polyphosphates, metaphosphates, pyrophosphates and organically bound PO_4 are found in natural waters (DWAF, 1996b). According to a study conducted by Davari *et al.* (2010), mined phosphorus is currently used for manufacturing of agriculture and industrial products and as a result a lot of phosphorus is

accumulating in the ecosystems. With respect to nutrients, excessive phosphorus levels can contribute to algal blooms and cyanobacterial growth in surface waters used for recreation and as sources of drinking water (Burkholder *et al.*, 2007). Phosphorus is very reactive and it interacts with cations such as aluminium, iron and calcium to form insoluble compounds precipitates (DWAF, 1996b).

2.3 Water resources management in South Africa

2.3.1 Introduction to water resources management

Water resource management is defined as the process of planning, developing, supplying, and managing the optimum use of water resources, the process also involves the management of the water cycle (Claassen, 2013). The current increase in population also increases the demand of food, expansion of industries and urban development. A lot of pollutants are generated from these activities, and they pose a major impact on water resources hence the need for efficient management and use of water resources. Integrated water resources management (IWRM) concept was introduced during the earth summit that took place in 1992 and it has since then been adopted by the Global Water Partnership (Mitchel, 2005). IWRM is described as a process that encourages co-ordinated development and management of water resources (surface and ground water), land and related resources in order to maximise the economic and social welfare in an equitable manner and also promoting the sustainability of our valuable ecosystems (DWAF, 2004).

The Integrated Water Resources management (IWRM) concept is required to balance water uses to available resources and to land use and ecological services. The concept promotes the need to address causes of pollution at the catchment level and not just to mitigate the effects (Bjorklund, 2001). IWRM principles are enshrined by the National water policy of South Africa (1997) and the National water Act (1998), both documents promote the sustainability and equitable development and use of water resource for the benefit of the current and future generations. Previously in South Africa water resource management was treated as a private good, however, the promulgation of the National Water Act (1998) in South Africa promotes the establishment of institutions such as the catchment management Agencies and water user association, the institutions are aimed at promoting the evolvement and participation of everyone in water resources management including individuals at a local level (DWS, 2016).

2.3.2 Water Quality Management

Integrated management of water quality is important for sustaining food production and achieving overall well-being of a community and also understanding people's perceptions and engagement can play an important role in achieving water and food security (Thoradenia, 2019). Chapter 14 of the National Water Act (1998) gives the Minister of the Department of Water a mandate to establish National water resource monitoring systems. The system must cover amongst others information on the quantity, quality, and health of aquatic ecosystems.

In South Africa water quality monitoring takes place in three different levels, namely national level, catchment (regional) level and local level. The national monitoring programme provides information on the water quality status and trends for the entire country. Catchment (regional) monitoring programmes provides the water quality information required for catchment management purposes. The objective of local monitoring programmes is to fulfil the information needs of local organizations and groups (DWAf, 2004).

Water quality monitoring is essential to determine its suitability for different uses such as domestic, recreational, industrial and agricultural use. Monitoring is also important for determination of trends and also to determine how the environment is affected by the release of contaminants, land-use and other anthropogenic activities such as waste treatment and effluent discharges (Holmer, 2008).

The National Water Act, (36 of 1998) specifically chapter 14 requires the Minister of the Department of Water and Sanitation to establish national monitoring systems for the collection of appropriate data and information that is adequate and responsive to the present and future challenges of efficient management of the country's water resources. To fulfil the requirement of the Act the following National programmes have been developed by the National Department of Water and Sanitation (DWAf, 2004b)):

- (i) Chemical monitoring programme.
- (ii) Microbial monitoring.
- (iii) National Eutrophication monitoring.
- (iv) National toxicity monitoring.
- (v) National Radioactivity.
- (vi) River Ecosystem monitoring.
- (vii) Wetlands monitoring.
- (viii) Estuaries monitoring programme.

South Africa is also participating in the global water quality monitoring programme (GEMS/water) which was initiated by the United Nations environmental programme in collaboration with other United Nations agencies. Data collected from the South African National programmes is fed into the Global water data (GLOWDATA) system. The data is used to develop trends for parameters such as the nutrients, salinity, suspended solids, faecal coliforms and organic pollutants (Griffin *et al.*, 2014). Each and every regional office of the Department of Water and Sanitation is expected to develop surface water quality monitoring for the main rivers and their tributaries. The monitoring programme is developed based on the catchment activities. For point sources such as waste water treatment works, mines, industries and abattoirs monitoring points are set at the discharge point of each and every activity, as well as the upstream and downstream of the activity (Ratau, 2019).

2.4 Water quality impacts caused by agricultural activities

The agricultural sector plays a major role in growth and development and poverty reduction in poor countries (Dethier and Effenberger, 2011). It also plays an important role in providing employment and economic base for households, globally 40% of population is employed under the agricultural sector (Tongwane and Moeletsi, 2018). In the Western Cape province, 180 000 people are employed in the fruit and wine sector, while 126 000 are employed in the Agri- processing sector and this province alone contribute around R530 billion of the south Africa's economy (Le Roux, 2018).

The increasing world population is currently putting a lot of pressure on demand and production of high quality food. The projected population growth is expected to increase from 6 billion to 9 billion by 2050. Global cropland for food production is projected to expand by 13% (956–1076 MHa) in developing countries, primarily in sub-Saharan Africa and South America (Scanlon *et al.*, 2007). New technologies have been developed to try and intensify the agricultural foot print area and food production, however, this development has also increased the impact of agricultural activities on the environment (Lemke *et al.*, 2011). The intensification of food production also increases the application of manure and pesticides (Tilman, 1999).

Different types of agricultural activities are practiced all over the world and this include amongst others cultivation on the rivers, fertilizer application, pesticides application, crop irrigation etc. these activities affect the physical, chemical and biological characteristics of water (Dafter *et al.*, 2019). River bank farming is also responsible for aquatic and ecological damages occurring in most of the rivers, it changes the morphology and natural dynamics of the river (Yamani *et al.*, 2011). Based on Hardlife *et al.* (2017), cultivation on river banks is

growing globally and in the South African cities despite the fact that it is regarded as an illegal activity by environmental authorities and scientists. Likangala River in Malawi is one of the rivers that are highly disturbed due to cultivation (Chimwanza *et al.*, 2006).

Fertilizers and pesticides are used globally to enhance crop production (Mateo Sagasta *et al.*, 2017). The global increase in drinking water contamination by nitrates emanating from agricultural practices has awakened scientist's interest in the investigation of factors influencing nitrate leaching (Chimwaza *et al.*, 2005). Due to the increase in agricultural impact the scientists saw a need for development and implementation of the principles of agricultural sustainability. According to Khwidzhili (2016), sustainable farming is defined as a process of maintaining and increasing biological productivity, while decreasing the level of risk to ensure protection of the quality of the natural resources.

According to Parris (2011), only one third of OECD member countries participate in the monitoring of agricultural pollution of nutrients and pesticides on water bodies and nearly one-half of those countries have recorded that nutrient and pesticide concentrations in surface water and groundwater monitoring sites in agricultural areas exceed national drinking water limits for nutrients and pesticides.

The impact of agricultural pollution on environment and recreational uses are also recorded to be much higher than the recommended national limits or guidelines for environment and recreational uses (Paris, 2011). The impact of agricultural activities are also evident in great lakes of North America and Australia, high nutrient concentration are causing algal blooms (Moteo Sagasta *et al.*, 2017). In Eastern England a study was conducted at Wensum catchment using the Soil and Water Assessment Tool (SWAT) to quantify the long-term impacts of potential changes to agricultural management practices on river water quality (Taylor *et al.*, 2016).

Globally 70% of agricultural irrigation water is used for horticulture (forestry, crop culture and creature cultivation) and it plays a significant role in water pollution (Kumar *et al.*, 2021). As stated by Kumar *et al.* (2021), the commonly practiced agricultural activities contributing to water resources pollution are described below:

Ploughing – as stated by Begum (2019) naturally all soils contain seeds including weeds that are dormant, during ploughing the seeds are moved to the surface of the soil where it starts to germinate, the increase in weeds also increases the amount of pesticides required to clear the area, this activity also generates sediments which contain pesticides and nutrients that are flushed with surface runoff into the rivers, and it also results in siltation of the river. As stated

by Hollis *et al.* (2022) during ploughing CO₂ is generated and released into the atmosphere when carbon rich organic matter is exposed to oxygen resulting in greenhouse gas pollution.

Fertilization -. Fertilisers exist in two forms, chemical and natural or animal manure. The chemical fertilisers are manmade or mined while natural manure is formed through decomposition. Fertilizers contain primary macronutrients (PO₄, NO₃ and K⁺), secondary macronutrients (Ca, Mg and S) and micro nutrients (Cu, Fe, Mn Zn etc) (Chandini *et al.*, 2019). Excess fertilizers stimulate the growth of algal blooms which depletes oxygen in the water, and it results in eutrophication of the resource and suffocation and dearth of other aquatic species such as fish (Berg *et al.*, 2017). Algal blooms can also produce toxins that are harmful to human beings (Sanseverino *et al.*, 2016).

Manure spreading – Fresh manure from warm blooded animals contain micro-organisms such as bacteria, viruses, Parasites and fungi which are pathogenic. Manure also contains nutrients and heavy metals. Ammonia gas is also released from manure into the atmosphere and return back into the water resources through rainfall/precipitation (Berg *et al.*, 2017).

Pesticides – Pesticides are defined as chemicals which are used for controlling pests, weeds and diseases within crops and also for health care of animals and humans (Srivastava *et al.*, 2019). Recently there has been a growing concern in most of the countries regarding pesticides finding their way into surface and ground water resources (Aydinalp and Porca, 2004). In America 75 pounds of pesticides are applied every year to keep bugs off the peapods and petunias, and the chemicals contained in those pesticides reach the water resources through rainfall run off wherein it affects biota resulting in fish and other aquatic species kills (Srivastava *et al.*, 2019).

Feedlots – Feedlot waste contain animal excreta which contain bacteria, virus, nutrients and metals that are capable of posing risk to aquatic life, recreational and drinking water (Rahman *et al.*, 2013). Pesticides such as dichlorodiphenyltrichloroethane (DDT) and other Organophosphates have been discontinued due to their chronic health impacts to humans (Moteo Sagasta *et al.*, 2017). Jonker *et al.* (2009) in his study determined that feedlot effluent has a negative impact on macroinvertebrate diversity.

Irrigation – Rigorous irrigation causes soil erosion (Baldock *et al.*, 2000). Irrigation methods also have an influence on siltation for example methods such as flood irrigation where large amount of water is applied in a short period result in high surface runoff (Leng *et al.*, 2017). The salts that accumulate during irrigation are also washed into the nearby water resources through surface runoff (Ayenew, 2016).

Clear cutting – disruption of riverbanks resulting in erosion and salt load increase in water resources and it affects drinking water supply and the performance of hydro electronic plants (Borelli *et al.*, 2017). The removal of forest during harvesting of field increase soil erosion by reducing the rate of evapotranspiration and increasing water yields (Hicks, 2002). According to Pawson *et al.* (2000) clear fell harvesting has a major impact on aquatic ecosystems due to the fact that it increases microclimatic variability, alters regional water balance and hydrological balance and all these have an impact of soil erosion. All the biotic changes affect species richness found in the water bodies.

Silviculture- silvicultural activities such as road and skid trail construction, tree cutting and removal, site preparation and stand regeneration treatments, herbicide application, fertilizer application, and field burning have the potential to impact water quality by generating nonpoint source pollution. It generates pollutants such as sediment, logging equipment fluids, nutrients from harvested areas and applied fertilizers, forestry pesticides, and increased water temperature or thermal pollution (Fulton and West, undated).

Aquaculture – aquaculture involves farming of aquatic organisms such as fish, mollusks, crustaceans, plants, in natural or controlled marine or freshwater environments (Bhavsar *et al.*, 2016). Different types of chemical are used in grow out farming and hatchery operations (Pathak *et al.*, 2000). Waste discharges from aquaculture contributes to eutrophication of water bodies due to manure, fertilisers and feeds associated with fish stimulation process (Boyd, 2011).

2.4.1 Previous studies conducted globally on the impacts of agricultural activities

Agricultural production releases residuals that may degrade the quality of the environment and water resources and impose costs on water users and due to its nonpoint source nature, it is difficult to quantify the extent of its impact. The costs associated with agricultural activities are in a form of degraded ecosystems, reduced recreational opportunities, reduced commercial fishing and shellfish bed closings, increased water treatment costs, threats to human health, and damage to reservoirs and water conveyance systems (Ribaud and Johansson, 2006).

According to Horrigan *et al.* (2002), the agricultural impact on drinking water is linked to nutrient pollution generated from chemical fertilisers applied in the fields. The same writer also mentions that chemical fertilisers such as ammonium nitrate, ammonium sulphate and inorganic PO_4 contain nutrients which are released through surface runoff into surface and ground water resources. Few studies were conducted about the impacts of agriculture on drinking water. In a study conducted by Nikolaidis *et al.* (2008) in North East of Greece high levels of NO_3 , SO_4 and PO_4 were detected from drinking water boreholes situated near farming

area. A case study to determine the effect of agricultural practices on drinking water quality was conducted by Spitsov *et al.* (2019), the study proved that mineral level in wells situated near farmlands is three times higher as compared to the sites that were far from farmlands. Thoradeniya *et al.* (2017) also confirmed in his study conducted for a district of Sri Lanka that the ground water pollution in the area is influenced by the use of agrochemicals and fertilisers. The Netherlands has also embarked on a project in Over IJssel and Brabant to reduce agricultural impact from drinking water boreholes using voluntary methods (Van den Brink *et al.*, 2021).

Agricultural related impacts are also known to have serious cost implication in the treatment of drinking water especially for removal of nutrients and pesticides. Denmark is one of the countries affected by agricultural nutrient removal or treatment, the treatment cost has also affected the house-hold water price (Parris, 2011). China is also one of the countries affected by agricultural pollution caused by excessive use of agrochemicals, the agrochemicals account for 17% of the total greenhouse gas emissions (Yu and Wu, 2018).

Globally, the most problematic agricultural pollutants have been identified as NO_3 , PO_4 , pesticides, soil sediments, salts and pathogens (Mateo Sagasta *et al.*, 2017). Eutrophication is also one of the challenges faced in aquatic ecosystems and it occurs as a result of nutrient enrichment from agricultural fields. The nutrients result in algal blooms which are problematic in terms of reducing dissolve oxygen in water bodies and this affects the aquatic life (Kumar *et al.*, 2021).

2.4.2 Previous studies conducted in South Africa on the impacts of agricultural activities

A study was conducted recently on ground water quality assessment in South Africa, specifically in areas known to have been impacted by agricultural activities such as the springbok flats, Breede River, Fish River and Hex River valley. It was discovered during the study that several boreholes have been affected as a result of intensive animal husbandry, sewage sludge application, inorganic fertiliser application, irrigation and pesticides usage and the main pollutants associated with those activities are $\text{NO}_3\text{-NO}_2$, K^+ , PO_4 and faecal pollution (Conrad *et al.*, 1999).

Another study was conducted in South Africa in the Middle Olifants catchment by Mudaly and Van der Laan (2020), in this study it was confirmed that agricultural activities are posing a serious threat to surface water resources. The main purpose of their study was to determine the interactions between the irrigated agriculture and surface water quality where it was found

that the concentrations of PO₄, NH₃ and EC increased downstream of the agricultural area especially during high rainfall seasons.

In the Breede Catchment irrigation board a study was done to prove that poor water quality has an impact in terms of increasing the maintenance cost for irrigation systems where it was found that fouling algal blooms and high nutrient levels increased the maintenance cost by R132 million (Cullis *et al.*, 2018). Musingafi (2014) has done a study on fresh water pollution in South Africa where she concluded that the use of non-biodegradable pesticides/ fungicides/ herbicides/ insecticides, use of chemical fertilizers instead of organic manures, are amongst other are causing water pollution in South Africa.

Several water quality studies were conducted in the Mooi River catchment, Koekemoer *et al.* (2021) conducted a study on the influence of land use on water quality of the Mooi River and its tributaries where it was concluded that the tributaries especially the Loop Spruit and Wasgoed Spruit tributaries have a serious influence on the water quality of Mooi River. Bredenhann (2020) also conducted a study on the Loop Spruit where high concentration of Mg²⁺ and pH were noted. Manyatse (2017) also conducted a study on inorganic contaminants in surface water in Potchefstroom and of note was that SO₄, Cl⁻ and K⁺ were high in the surface water.

2.5 Best practice management for the agricultural water sector

Best practice management in agricultural terms refers to land management approaches developed to protect the environment (soil and water resources) from degradation because of agricultural habits and practices. The best practice management from nutrient and sediment reduction include amongst others grassed waterways, buffer strips, reduced tillage and wetlands (Lemke, 2011). Weerasekara (2017) states that globally 70% of fresh water is allocated to the agricultural sector and currently this sector is competing with urban, environmental and industrial sectors for water allocation, and this may lead to reduction of water allocated to agriculture. There is therefore a need for the sector to come up with ways to improve water use efficiency.

2.6 Water management areas

2.6.1 South African water management areas

In October 1999, during the establishment of the National Water Resource Strategy the government of South Africa established 19 water management areas (WMAs) which were defined according to the hydrological boundaries. The boundaries of these areas are along

catchment divides and at that time, the government contemplated the establishment of 19 CMAs (Meissner *et al.*, 2013) one in each WMA. Despite these, only two CMAs have been successfully implemented to date, namely, the Breede-Gouritz and the Inkomati- Usutu CMAs. However, due to the lack of capacity to support the 19 WMAs which was determined during the gazetting process, in 2012, the Department of Water and Sanitation (DWS) decided to reduce the 19 planned CMAs to nine which were further reduced to six. As shown in Figure 1 below, the minister approved the establishment of six CMAs in the newly delineated six WMAs (DWS, 2022).

The six CMAs are Limpopo - Olifants , Inkomati-Pongola , Vaal - Orange, Mzimvubu-Tsitsikamma, Breede-Olifants and Mhlathuze - Mzimkhulu (Claassen, 2013) (Figure 1). Currently and apart from the Breede- Olifants and Inkomati-Pongola CMAs, the remaining four CMAs are considered the so-called proto-CMAs since they are in the process of being established. Those proto-CMAs are managed by the respective regional offices of the DWS (Meissner *et al.*, 2013).

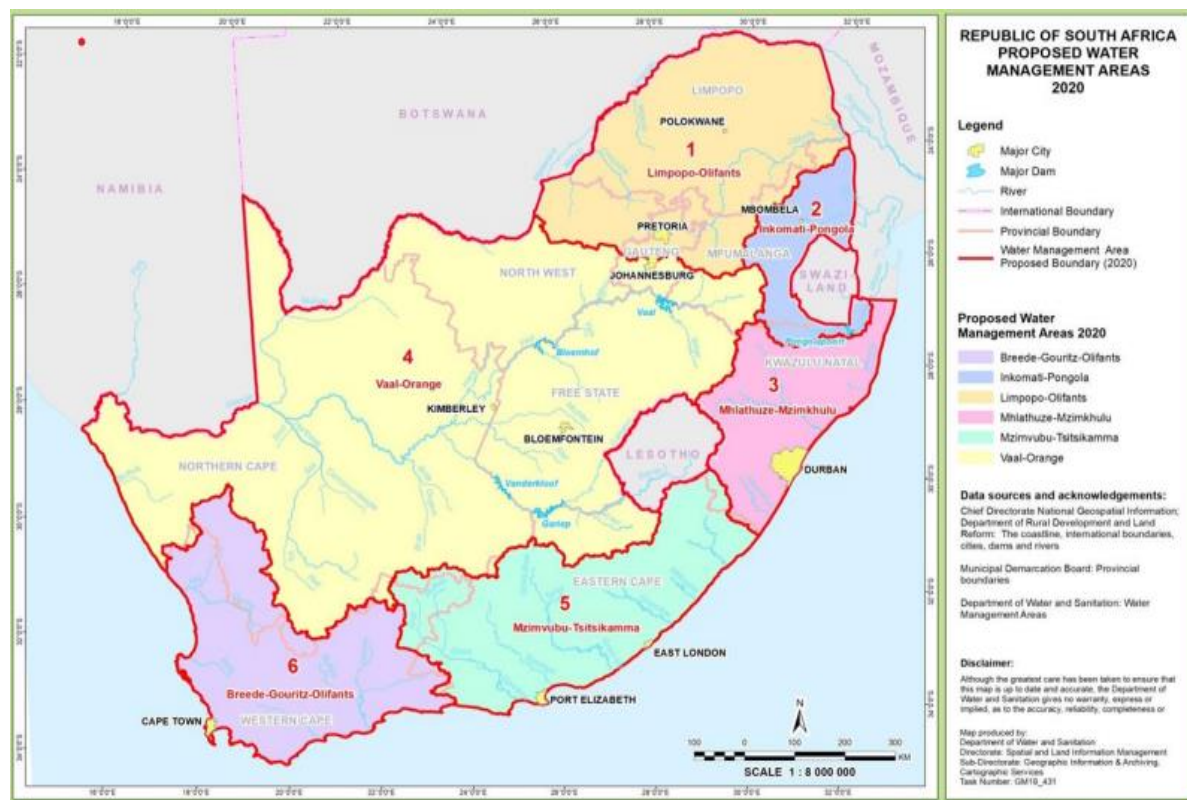


Figure 1:The six South African water management boundary areas as proposed by the Department of Water and Sanitation (source: Chingombe, undated).

2.6.2 Catchment management

According to Fenemor *et al.* (2014), the increase in land-use and competition for water use has triggered the need for holistic approach to land and water management. Bellamy *et al.* (2002) defines Integrated catchment management (ICM) as a “*system-based approach, attempting to blend the objectives of environmental protection, sustainable agriculture and natural resource management which takes into consideration the integrating of land and water use and environmental impacts at a catchment level*”. The ICM approach also promotes participation and involvement of all interested parties in a catchment to work together in planning and implementing catchment management policies.

Some work has been reported at catchment scale for water quality monitoring. To find causes and interactions of physical/chemical variability on rivers and estuaries, work was started by US Geological Survey on creating a wireless catchment in Santa Margarita Ecological Reserve in Southern California. It was intended for high density monitoring of the catchment encompassing mountains, canyons and river channels (Zia *et al.*, 2013). Australia is also one of the countries practicing integrated catchment management, the country has initiated intergovernmental consultations participation through the Murray-Darling Basin Commission and Australian and New Zealand Environment and Conservation Council (ANZECC), and through policies and programs to enhance environmental protection , sustainable agriculture and natural resource management at a catchment and local levels (Bellamy *et al.*, 2002).

Cooke *et al.* (2020) established that a United Kingdom based water company , Seven Trent Water in collaboration with farmers and land-owners came up with a catchment management strategy initiative to reduce pesticide (metaldehyde) at source to improve water quality and environmental benefits. Two incentive methods are attached to this strategy, farmers are incentivized for reducing metaldehyde from their produced final effluents and also for substituting metaldehyde with ferric phosphate.

2.6.3 Integrated Water Resources Management

IWRM is defined by Claassen (2013) as “*the coordinated planning and management of land, water and other environmental resources for their equitable, efficient and sustainable use at the catchment scale*”. The human and natural pressures such as climate change are posing a serious impact on water pollution and freshwater ecosystems, UN Environment Programme Report (2021) estimates that by 2030 2.2 billion people will not have access to drinking water while 4.2 billion will not have access to sanitation worldwide hence a decision was taken to implement IWRM as one of the sustainable development goals. Lenton (2011) describes IWRM as an international coordinated approach to management of water and related

resources and Catchment management on the other hand is a tool used at a local level to achieve IWRM.

2.6.4 Catchment management in South Africa

South Africa is known as a dry and water scarce country with an average annual run-off of 495 mm (Annandale *et al.*, 2011). The country mainly depends on surface water storage and abstraction, and it shares its four main river basin with six neighbouring countries (Botswana, Lesotho, Mozambique, Namibia, Swaziland and Zimbabwe). Sixty percent surface area of the four river basins is situated in South Africa and 40% of the total mean annual runoff falls in this area (DWAF, 2004).

Just like other countries, South Africa is also affected by the climate change which is currently changing the runoff and hydrology patterns. The decrease in water availability is affecting the ecological systems and social system and it calls for innovative and efficient ways for management of water resources. With the current climate change challenges and the vulnerability of surface water to evaporation it will be difficult to meet the nations water demand through construction of new dams or water storage facilities. In response to the challenges South Africa has since the mid 1990 adopted the integrated water resources management principles in order to improve the water use efficiency (Herrfahrdt-Pahle, 2010).

The National Water Act (1998) specifically Chapter 7 calls for establishment of catchment management agencies (CMAs). The CMA's main function is to ensure that water resources are managed at a regional or local level to ensure participation of all stakeholders and local communities. Each and every catchment management agency is expected to develop a catchment management strategy. This strategy outlines a plan on how to protect, use, development, conserve, manage and control water resources at a catchment level (DWAF, 2004). Figure 2 below provides information on catchment quaternary drainages in South Africa.

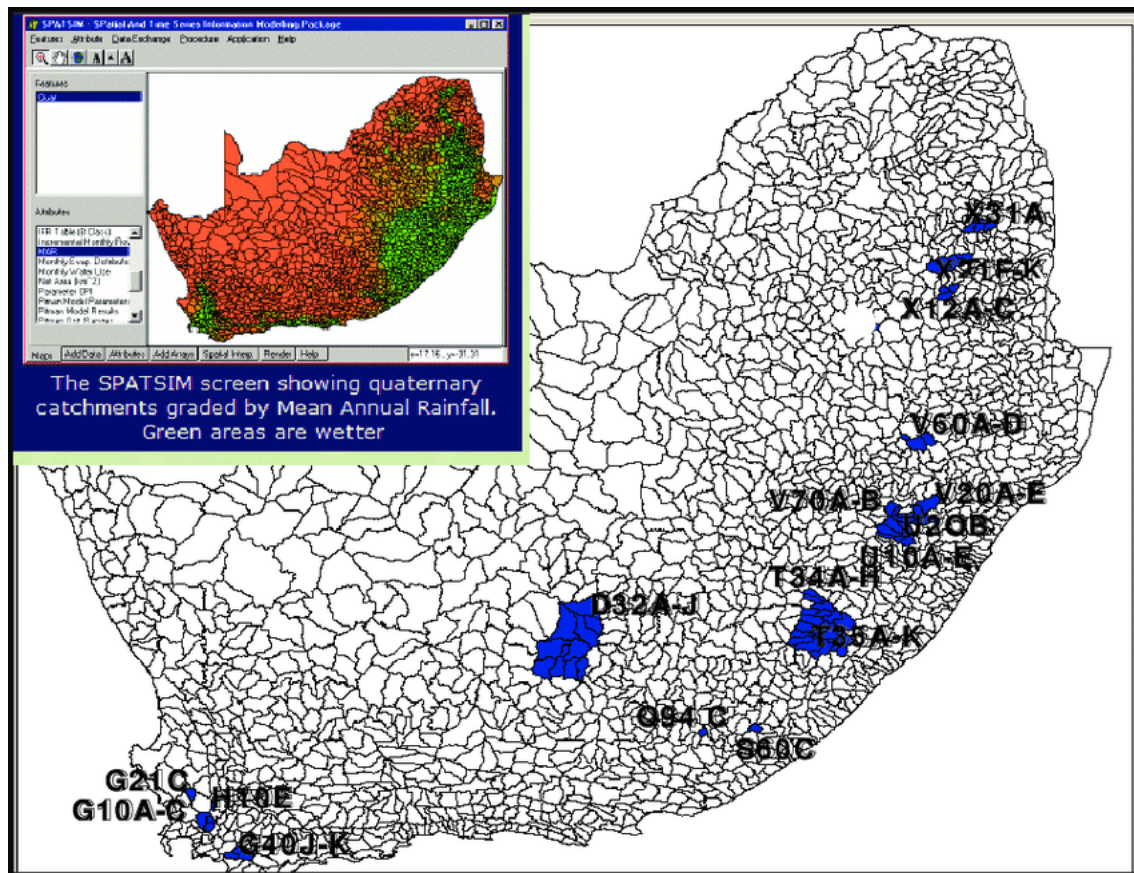


Figure 2: Quaternary catchments map in South Africa with the most wetter areas highlighted in blue (source: Aunyama, 2008).

2.6.5. Overview of Mooi River Catchment

The Mooi River is situated in the Upper Vaal Water Management area, its upper section falls within the Gauteng Province, while the lower section falls within the North-West Province (DWS, 2012). As presented on Figure 3 below, the study area covers the Mooi River catchment which is drained by Mooi River (the main watercourse) and its main tributaries (Wonderfontein Spruit and Loop Spruit). The Mooi River and its tributaries also pass through the Magisterial Districts of Potchefstroom, Westonaria, Oberholzer, Fochville and Carletonville (DWS, 2015).

The Mooi River begins at the southern slopes of the Magaliesburg, near to Boons and Derby. From this area it flows in a southerly direction where it confluences with the Vaal River downstream of Potchefstroom town. Wonderfontein Spruit and Loop Spruit are the main tributaries to the Mooi River (Institute of Water Quality Services, 1999).

Various dams are found in the catchment area, and these include amongst others the Klerkskraal, Donaldson, Klipdrift, Boskop and Potchefstroom (Lakeside) dams (DWS, 2015).

Boskop Dam was constructed in 1959 and the initial purpose of the dam was. to supply water for irrigation purposes The Klerkskraal Dam which is in the headwaters of the Mooi River was constructed in 1965 with the purpose of meeting the irrigation needs of the downstream users (DWS, 2012).

An irrigation water scheme (The Mooi River Government Water Scheme) which manages and supply water to the local farmers is located in the study area, and it bisects the Ventersdorp and Tlokwe Local municipalities. (DWS, 2015). Figure 3 below shows the Mooi River and its tributaries.

2.6.6 Description of sampling points

Records of data obtained from the Department of Water and Sanitation Gauteng Region water management system, surface water quality monitoring programme for Mooi River catchment was established around 1980s. Due to limited time the existing DWS monitoring programme was used to select sites for this study. The water quality data was sourced from the Department of Water and Sanitation water management system (WMS). As shown on Figure 3 below a total number of seven water quality monitoring stations located in areas where agricultural activities are practiced were identified and selected. Table 1 below provides the list and description of the monitoring points, while Figure 3 shows the location of the selected water quality monitoring sites. Five sites are located within the Mooi River, while two points are located on the tributaries to Mooi River.

Table 1: List of sampling sites, description and geographical location.

SITE NAME	DESCRIPTION	COORDINATES
1. Klerskskraal Dam	Located below the Klerkskraal Dam	-26.25222 27.16056
2. Mooi River at Blaaubank	Between Boskop Dam and Potchefstroom town	-26.37556 27.23083
3. Loop Spruit	Situated on the tributary of Mooi River downstream of Klipdrift Dam	-26.433056 27.554167
4. Mooi River at the downstream of Boskop Dam	Situated downstream of Boskop Dam	-26.6855 27.101556
5. Mooi River at Potchefstroom	Located along the Mooi River in town	-26.70072222 27.10430556
6. Wasgoed Spruit	Located along the tributary to Mooi River downstream of industrial site	-26.728889 27.126111
7. Mooi River Hoegekraal	Situated downstream of Potchefstroom town before the confluence with Vaal River.	-26.880278 26.965

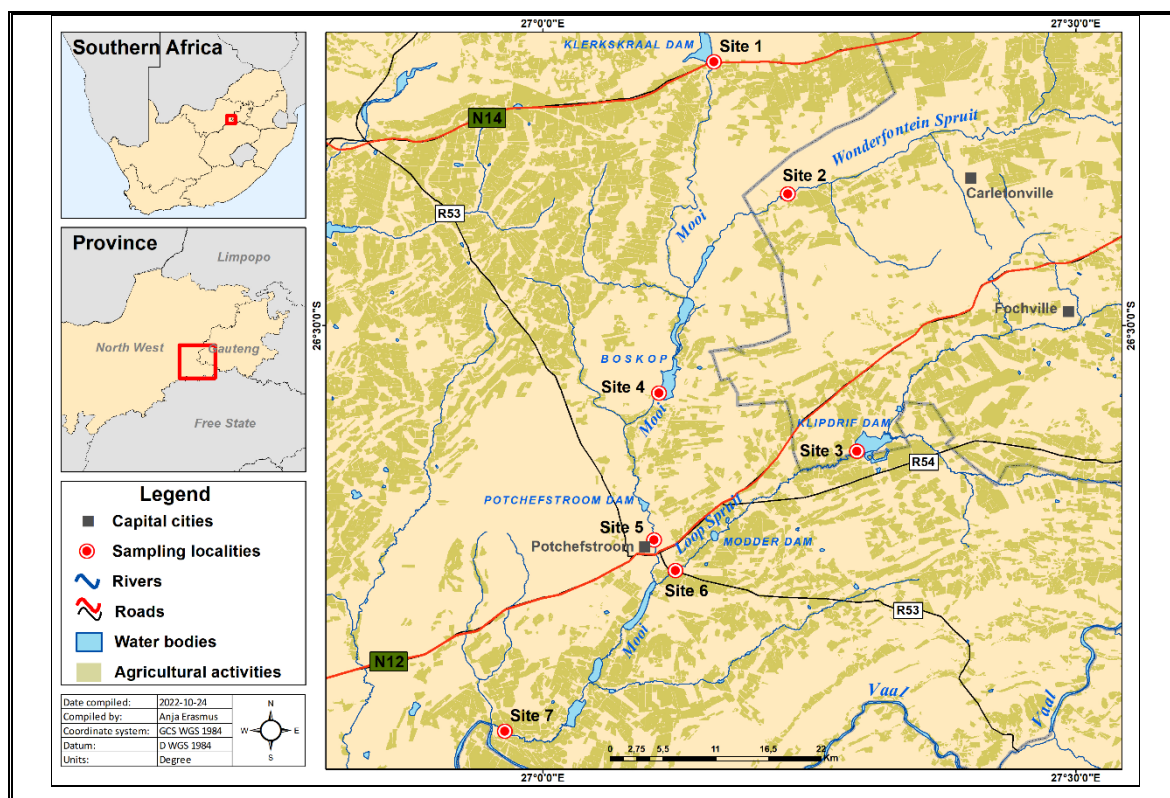


Figure 3: Map showing locations of the seven sampling sites along the Mooi River from the source to the confluence with Vaal River.

2.6.7 Precipitation

The rainfall for Mooi River Catchment is divided into two climatic zones the upper and the lower zone. The mean annual run off for the upper zone ranges between 500 and 599 mm, while precipitation for the lower zone is between 600 and 699mm (DWS, 2012).

2.6.8 Geology

The upper and the middle catchments are covered by dolomitic layers of Malmani subgroup and Chuniespoort subgroup, while some of the parts of the catchment are characterised by moderate to deep sandy loam soils which is known to be very good for agricultural activities. (DWA, 2012).

2.7 Water quality parameters

Water quality can be classified into four types, namely potable water, palatable water, contaminated (polluted) water, and infected water (Omer, 2019). Water quality parameters are classified into three categories namely physical, chemical and biological parameters. Example of physical parameters are temperature, turbidity, colour, taste, EC and odour. Chemical parameters include pH, alkalinity, acidity, Cl^- , SO_4 , NH_3 , dissolved oxygen, chemical oxygen

demand etc. Bacteria, algae, protozoa, indicator organisms and viruses are examples of biological parameters (Omer, 2019). Water quality parameters are good indicators of potential problems hence they should be tested frequently (DWAF, 1998). Agricultural related water quality parameters are discussed under section 2.2.1 above.

2.8 Water quality guidelines

The DWS is the custodian of South Africa's water resources. Part of its mission is to ensure that the quality of water resources remains fit for recognised water uses and that the viability of aquatic ecosystems are maintained and protected (NWA, 1998) . The South African Water Quality Guidelines serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of the health of aquatic ecosystems. The Department recognises that water quality guidelines are not static and will therefore update and modify the guidelines on a regular basis, as determined by ongoing research and review of local and international information on the effects of water quality on water uses and aquatic ecosystems (DWA, 1996e) . The South African Water Quality Guidelines are used as a basis for developing materials to inform water users about the physical, chemical, biological and aesthetic properties of water. It consists of the water quality criteria, the Target Water Quality Range (TWQR), and support information, such as the occurrence of the constituent in the aquatic environment, its effects on water uses, how these effects can be mitigated and possible treatment options (DWAF, 1996a).

The TWQR for a particular water use is defined as the range of concentrations or levels at which the presence of the constituent would have no known adverse or anticipated effects on the fitness on the water assuming long-term continuous use, and for safeguarding the health of aquatic ecosystems. All the different TWQR for all the different water use sectors are dealt with in South African Water Quality Guidelines volumes one to seven (DWAF, 1996e). For the purpose of this study only three guidelines as summarised below were selected.

2.8.1 Domestic water quality guidelines

Domestic water refers to water that is used in domestic environment and also refers to all uses water can be put to in this environment. These include water for drinking, food and beverage preparation, hot water systems, bathing and personal hygiene, laundry and gardening. Domestic water users can experience a range of impacts like health, aesthetic and economic impacts as a result of changes in water quality. Water quality problems are associated with the presence of constituents and the interactions between them. Table 2 below provides the TWQR for domestic use.

Table 2: Target water quality ranges for domestic water use (DWAF, 1996a).

Parameters	Guideline/standard
pH	6-9
Electrical conductivity	70 mg/l
Potassium	50 mg/l
Magnesium	30 mg/l
Ammonia	1 mg/l
Nitrate-nitrite	6 mg/l
Sodium	100 mg/l
Phosphate	No limit
COD	No limit
Sulphate	200 mg/l
Chloride	100 mg/l

2.8.2 Agricultural water use

The DWAF(1996c) categorise agricultural water uses in to three categories namely:

- Crop Irrigation,
- Livestock watering,
- And aquaculture.

Each category has different water quality needs or requirements. The TWQR for agricultural use are provided in table 3.

Table 3: Target water quality ranges for agricultural water use (DWAF, 1996c and DWAF, 1996d).

Parameters	Guideline/standard for irrigation use	Standard for livestock watering
Potassium	-	-
Magnesium	-	50 mg/l
Ammonia	-	
Nitrate-nitrite	-	100 mg/l
Phosphate	-	-
pH	6.6-8.5	-
Electrical conductivity	40 mS/m	-
Chloride	100 mg/l	-
Sulphate	-	1000 mg/l

2.8.3 Agricultural water use: irrigation

Irrigation water is described by DWAF (1996c) as water that is set aside to supply water requirements for crops and plants which are not dependent from rain, and refers to all uses water may be put to in this environment. These include water for:

- the production of commercial crops
- irrigation water application and distribution systems
- home gardening
- the production of commercial floricultural crops
- potted plants.

The expected impacts from irrigation water users as described by Baldock (2000) may include amongst others:

- Reduced crop yield as a result of increased salinity or the presence of constituents that are toxic to plants.
- Impaired crop quality, this may results in inferior products or pose health to consumers
- Impairment of soil suitability as a result of the degradation of soil properties and accumulation of undesirable constituents or toxic constituents

2.8.4 Agricultural water use: Livestock watering

The use of water for livestock production depends on several factors, such as the type of production system in use (intensive or extensive), the type of livestock and the type of livestock products. The potable quality of water for livestock may be defined according to the palatability of the water which would affect intake and hence production, as well as its degree of contamination with pathogenic micro-organisms, hydrocarbons, pesticides and salts such as nitrates, sulphates, fluoride and the salts of heavy metals (DWAF, 1996d).

There are different impacts that may be experienced as a result of changes in water quality. These include:

- livestock consumption (toxicological and palatability effects)
- livestock distribution systems (economic impacts on the effects of scaling, corrosion or deposition of sediments in the distributing system)
- livestock product quality (consumer health hazards and product quality problems).

2.8.5 Agricultural water use: Aquaculture

Aquaculture is aquatic agriculture and includes the husbandry, management, nutrition, genetics and controlled propagation of all aquatic organisms for use by humans (DWAF, 1996f).

Aquaculture can be divided into several sectors:

- Cage culture in dams or natural lakes
- Extensive farming in small earthen farm dams
- Extensive and semi-extensive fish farming in purpose designed fish ponds
- Intensive farming in raceways and tanks.

The greatest threat to freshwater aquaculture is industrial pollution of rivers, the effects of afforestation and deforestation on the water quality and quantity, the poor use of agricultural and riparian land, and of herbicides and pesticides (Malik *et al*, 2020).

2.8.6 Aquatic ecosystem

Aquatic ecosystems in these guidelines refer to the abiotic and biotic components, habitats and ecological processes contained within rivers and their riparian zones, reservoirs lakes and wetlands and their vegetation. Since the aquatic ecosystems serve as the resource base, they must be effectively protected and managed to ensure that water resources remain fit for agricultural, domestic, recreational and industrial uses on a sustainable basis. For the aquatic ecosystems guidelines, the TWQR is not a water quality criterion as it is for other water uses, but rather a management objective that has been derived from quantitative and qualitative criteria (DWAF, 1996e). The TWQR for aquatic ecosystems are listed in table 4 below.

Table 4: Target water quality ranges for aquatic ecosystem (DWAF, 1996e).

Parameters	Guideline/standard
Potassium	-
Magnesium	-
Ammonia	7 mg/l
Nitrate-nitrite	-
Phosphate	5 mg/l
pH	6.6 – 9.5
Electrical conductivity	-
Chloride	-
Sulphate	-

2.9 Resource quality objectives

For the sustainable and continuous use of the Nations water resources chapter 2 of the Act (1998) gives mandate for the establishment of resource directed measures (RDM) which are aimed at the protection of water resources. RDM measures consists of three sections Resource classification, reserve determination and resource quality objectives. Water resource classification is defined as procedures that are used to determine or set desired characteristics of a resource (DWAF, 2006). The Reserve is defined as water that is set aside for the basic human needs and the ecological reserve. The basic human need reserve provides for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene.

Ecological reserve relates to the water required to protect aquatic ecosystems and the water resource. The Reserve refers both to the quantity and quality of the water in the resource, and will vary depending on the class of the resource (DWAF, 2004). The resource quality objectives are described as the numerical or descriptive statements of conditions or goals that should be met for particular resource. water resource quality consists of not only the water component (quality and quantity), but also other aspects of the aquatic ecosystem, such as riparian vegetation, geomorphology, etc. (DWA, 2011).

2.10 Resource quality objectives for the Mooi River

The Mooi River is a tributary of the Vaal River and it is situated in the Upper Vaal water management area (Labuschagne, 2017). The classes and resource quality objectives for this area were set and gazetted on 22 April 2016 by the Minister of the Department of Water and Sanitation. The quality component of the Mooi River only covers few parameters such as pH (5.9-8.8 mg/l), PO_4 (0.025 mg/l), NO_3 (1 mg/l), EC (111 mS/m) and toxics (aluminium, arsenic, cadmium, chromium, copper, mercury, manganese and lead). Salts such as Mg^{2+} , K^+ and Cl^- were not covered by the gazetted RQOs.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 Research design and approach

Research design provides the framework for the proposed study (Jilcha, 2019). This requires that the design processes are selected together with the approach to be followed. Specifying the research design and approach assist in collecting the relevant data for the study.

The research approach is quantitative in design. According to Apuke (2019), quantitative research study entail quantifying and analysing variables of interest type. Apuke (2019) further identifies three types of quantitative research designs and these are: survey, correlational, experimental and casual-comparative research designs. Correlational designs are further divided into explanatory and prediction design. Creswell and Garrett (2008) defines correlational as a study in which a researchers intend to explore “the extents to which two or more variables co-vary, and that is, where changes in one variable are reflected in changes in the other variable”. Prediction design is studies in which the purpose is to predict the outcome of variables using a predictor variable (Apuke, 2019). This study is a correlational explanatory study since it seeks to determine the trends of water quality variables and establish their correlation.

The proposed study is a cross sectional due to time limitations and descriptive in approach. Water samples were collected along the Mooi River catchment from 7 monitoring points. These monitoring points were established by the National Department of Water and Sanitation, and they are the part of the integrated catchment management plan for the Water Management Area. Land based activities within the Mooi River Catchment were be identified using Arial photographs and Geographic Information System (GIS). Water sample analysis results were sourced from the National Department Database called Water Management System.

3.2 Data collection

Due to limited time for the study, it was considered to collect secondary data from available sources. The source for data for this study was obtained from Water Management System (WMS). According to Johnston (2014), secondary data is data which was collected for other purposes. The use of secondary data may have its own shortcomings, and that is the person who collected this data may not have covered all information required for the current research. Data for two periods was extracted from the WMS system for the purpose of this study, 2014-2015 data will be compared with 2018-2019.

3.2.1 Water Management System (WMS)

WMS is a database which is used by the DWS to store water quality monitoring data including sampling points and their location within the catchment. This system has been in use since 2004 and all water quality data for all catchments within the country WMA's are stored in this database. The WMS database is managed and operated by the Institute of Water Quality Studies (IWQS) of the DWS. The institute is fully operated and owned by the DWS. Thus, the water quality was sourced as part of obtaining access for this research. The selected was downloaded into and saved into a memory stick for later sorting and analysis.

The system was designed as computerised functionality to co-ordinate and manage national and catchment based resource quality monitoring programmes. All registered water quality monitoring programme requirements are consolidated, and this aid in eliminating duplication of monitoring and analysis. The system is scheduled to ensure that effective monitoring and analysis is carried for every programme. Samples and results are automatically registered, and all analyses are subjected to standard quality control procedures.

3.2.2 Selection of water quality variables

Water quality parameters can be classified into chemical, physical and biological (Omer, 2019). Physical parameters include parameters such as turbidity, temperature, EC, dissolved solids and pH, while chemical parameters include amongst others SO_4 , Cl^- , PO_4 , etc. and biological parameters which are the indicator microscopic organisms or other organism which live in water (Tomar, 1999). In this study physical and chemical parameters were considered, and these comprises of PO_4 , NH_3 , $\text{NO}_3\text{-NO}_2$, K^+ , Mg^{2+} , SO_4 and Cl^- as chemical parameters, pH and EC were selected for physical analysis, and no parameters were selected for biological analysis since this was not in the data extracted from the WMS database. The above mentioned parameters were selected based on the type of pollution expected from agricultural activities and the availability of data. According to Mateo Sagasta *et al.* (2017), farming activities are capable of producing agrochemicals, organic matter, drug residues, sediments and salts.

3.2.3 Sample collection

The Probability sampling technique was used to select the samples for the research. According to Pace (2021), probability sampling employs random sampling from a larger population. One characteristic of random sampling technique is that the results can be generalised for the entire population (Sharma, 2017). Probability sampling techniques can be

divided into four main types of sampling techniques and these are: Herewith four types of sampling procedures for random sampling:

- Simple Random Sampling in which a number is generated to choose a sample.
- Stratified Random Sampling, in in which the samples are clustered according to a predetermined criteria.
- Cluster Random Sampling, in which samples are divided into strata or subgroups which share characteristics; and
- Systematic Random Sampling in which members from the same population are selected based on a regular interval.

This research used clustered random sampling technique. There are two types of data collection, namely primary and secondary data. Primary data comprises data which has been generated by the researcher and is unaltered whereas secondary data is data which has been collected by another person or institution for other purposes other than for the current study (Taherdoost, 2021). The advantage of primary data is that it has more validity, reliability, objectivity, and authenticity since it has not been altered. Taherdoost (2021) encourages that secondary data must be examined carefully by the researcher before it used in order to increase its validity. This research has used secondary data which was obtained from the WMS of the DWS and the researcher conducted a check for completeness, correctness and specification for the methods used for the analysis in order to increase validity and reliability.

3.2.3.1 Chemical field samples collection equipment and procedure

For chemical analysis 1000 mL plastic bottles were used for sample collection. Water resistant paper labels and water proof pens were used to mark the sampling bottles. The samples were then placed in a cooler box with cubed ice, this was done to prevent the change in chemical characteristics of water. The samples were then delivered to the laboratory within six hours of collection and analysed within 24 hours. No preservatives were added since the analysis was conducted within 24 hours. The samples were analysed in accordance with the methods as prescribed under Table 3 below.

3.2.3.2 Physical samples field collection procedures

For EC and pH portable automated Radiometer TIM 870 meter were used to collect reading on site.

3.4 Data analysis

Data was cleaned by averaging the outliers. All data was completed and thus there was no need for computing missing data. All data was presented in tabular format to depict data ranges for periods January – February, March – May, June – July, August – September and October – December.

3.4.1 Sample analysis procedures/methods

The summary of analysis methods is summarised on the below section and the list of parameters and instrument is provided in Table 5.

3.4.1.1 *Physical parameters*

The pH and EC were measured on site using a portable automated Radiometer TIM 870. Before any pH measurement the electrode was calibrated using certified buffer solution at pH 7, pH 4 and pH 10. The electrode was then cleaned properly and dipped 30 cm from the surface of the water. Sufficient time was allowed for the instrument to stabilize before the reading was recorded. The results were recorded on a field data sheet. For EC, a commercial conductivity standard 101.5 mS/m plus/minus 0.05% @ 25° C (0.05%NaCL) was used for electrode calibration.

3.4.1.2 *Chemical parameters*

The nitrate was determined by means of Aquakem photometric method, the process involved the reduction of nitrate to nitrite using hydrazine under alkaline conditions, the total nitrite ions then reacted with sulphanilamide and N-1 Naphthylenediamine dihydrochloride under acidic to form pink dye. the absorbance which is related to Total Oxidised Nitrogen (TON) or $\text{NO}_3 + \text{NO}_2\text{-N}$ was therefore measured at 540 nm by means of a calibration curve.

Ammonia was also measured with photometric determination method wherein the NH_3 is allowed to react with hypochlorite ions generated by means of alkaline hydrolysis of sodium dichloroisocyanurate to form monochloramine, this further reacts with salicylate ions in the presence of sodium nitroprusside at the pH of 12.6 to form blue compound, the absorbance of the compound is measured spectrophotometrically at a wavelength of 660 nm and this is related to NH_3 concentration.

Aquakem photometric determination method was used to obtain Ca^{2+} and Mg^{2+} readings. Samples were filtered through a prewashed 0.45 μm membrane, a calibration curve was then

used to determine the concentration of Ca^{2+} and Mg^{2+} in the samples by comparing the sample concentration to the set calibration standards with known concentration.

Chloride results were obtained by allowing the chloride to react with mercury (II) thiocyanate to form a soluble non-ionic compound. Thiocyanate ions were released to react with acidic solution with iron (III) nitrate to form a red/brown iron thiocyanate complex and the resulting intensity of the stable colour produced was measured spectrophotometrically at a wavelength of 480 nm which is related to chloride concentration by means of calibration curve.

Sulphate ion was precipitated in a strong acid medium with barium chloride, the resulting turbidity was measured photometrically at 420 nm and compared with appropriate calibration standard solution.

The orthophosphate concentration was obtained by allowing the orthophosphate ion to react with ammonium molybdate and antimony potassium tartrate as a catalyst under acidic conditions to form a 12 molybdatephosphoric acid complex. The complex was then reduced with ascorbic acid to form a blue heteropoly compound. The compound absorbance was measured spectrophotometrically at a wavelength of 880 nm and this is related to the PO_4 concentration through a calibration curve.

Potassium was measured using GBC SavantAA atomic absorption spectrophotometer instrument. The samples were aspirated into a flame and atomised where a light beam is directed through the flame into a monochromator and onto a detector that measures the amount of light absorbed by the atomised element in the flame. The amount of energy at the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample over a limited concentration range.

Table 5: Laboratory analysis methods and procedures used for selected parameters.

Parameter	Analysis Method and instrument used
EC	potable automated Radiometer TIM 870
pH	potable automated Radiometer TIM 870
Ca ²⁺	Will be measured using an automated 0.45 µm filter membrane atomic absorption AA S240
K ⁺	Automated filter 0.45 µm GBC atomic absorption AA500
Mg ²⁺	Automated AA Spectrophotometer
NH ₃ ⁺	Automated colorimetric indophenol blue Technicon auto analyser 660 nm
NO ₃ + NO ₂	Automated colorimetric cadmium reduction diazo dye Technicon auto analyser
PO ₄	Automated colorimetric orthophosphate Technicon auto analyser 880nm
SO ₄	Automated colorimetric turbidity measurement Technicon auto analyser 420 nm
Cl ⁻	Automated flame emission air propane photometer

3.5 Statistical data analysis

Statistical analysis of data includes parametric and non-parametric analysis. These analyses assist in the trend identification based on descriptive data analysis. Parametric test is an assumption type of test which assumes that data comes from probability distribution and that it makes inference with the parameters while non-parametric is described as a non-distribution and non-assumptive test (Akwi *et al.*, 2016). According to Sentas *et al.* (2016), parametric statistical tests include regression line of best fit, the Z test, t test, Chi-square test for population variance, Skewness and Kurtosis test, Shapiro Wilkson and ANOVA, while the non-parametric include the Spearman's Rank Correlation test, Mann Whitney U test, Chi-square for r and c tables and multivariate tests such as Principal Component Analysis (PCA). Other parametric tests are Mann-Kendal test, Dickey-fuller augmented test. In this study ANOVA, Pearson co-efficient correlation and Shapiro-Wilk tests was conducted.

3.5.1 Descriptive statistical analysis

Qualitative data was also subjected to descriptive statistical analysis. Real Statistics Resource Pack software 2016 was used to calculate descriptive statistics for the data. Three types of descriptive statistics are: measure of frequency (frequency, percentage), measures of central tendency (mean, median and mode), and measures of dispersion or variation (variance, SD, standard error, quartile, interquartile range, percentile, range, and coefficient of variation

(Mishra *et al.*, 2019). Frequency measures the number of times a value or number appears in data and it is described as ratio, rates, proportions and percentages. Central tendency is described as a single value that summarizes the whole set of data. Mean, median and mode are the three measures of central tendency. Dispersion outlines the extent of similarity and diversity of values in a variable. Descriptive data is interpreted graphically using box plots. Box plots are constructed using 25th percentile, 50th percentile (median) and 75th percentile, the minimum and maximum data value (Kaur *et al.*, 2018)

3.5.2 Pearson correlation coefficient

Pearson correlation is a parametric statistical analysis methods used to estimate the degree of linear correlation between two or more variables involved in a study. For this type of analysis a correlation matrix has to be calculated, the matrix shows the degree of a linear association between any two of the parameters, and it is measured by the degree of correlation as a coefficient (R). R-value is used to identify the highly correlated and interrelated water quality parameter that may influence the water quality of the area. The value of R ranges from -1 to +1 . Where R = 1 or near to 1 it indicates that there is a strong positive linear correlation between the parameters and where R = to -1 or near -1 it gives an indication that the linear relation between the parameters are strongly negative (Rousseau *et al.*, 2018).

3.5.3 Test for normality

Normality test is applied to test data if the data comes from a population with a normal distribution (Mishra *et al.*, 2019). Tests for normality includes: Kolmogorov-Smirnov (K-S) test, Shapiro-Wilk test, Anderson-Darling test, D'Agostino skewness test, Anscombe-Glynn kurtosis test, D'Agostino-Pearson omnibus test, and the Jarque-Bera test (Ghasemi and Zahediasl, 2012). Only the Shapiro-Wilk test was applied for the test of normality in the data for this study. For this reason, other tests will not be discussed in this study.

Shapiro-Wilk test entails regression and correlation test using ordered sample. The test compares the ordered sample values with the corresponding order statistics from the specified distribution. The test is most commonly used to test if data fits into a normal distribution. Shapiro-Wilk test is calculated by the formula:

$$W = \frac{(\sum_{i=1}^n a_i y_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2}$$

Where,

y^i is the i^{th} order statistics

$\bar{y}$ is the sample mean

$$\alpha^i = (\alpha_1, \dots, \alpha_n) = m^T V^{-1} / m^T V^{-1} m)^{1/2}$$

$$m = (m_1, \dots, m_n)^T$$

V is the covariance matrix of order statistics

Values for W lies between 0 and 1

In calculating the values for W, a value less than 1 indicate data which is not normal whereas normal data is indicated by a value of 1. Other normality test involves calculation of moments, which is normality tests derived from departure from normality simply called skewedness or kurtosis. D'Agostino Pearson test (1973) offer the best approximation for skewedness and Kurtosis.

Skewness and Kurtosis are values which can be derived from descriptive statistics. Skewness measures the degree of symmetry of distribution in a normal distribution, in which a value of 0 indicate a normal distribution, value between -0.5 and 0.5 indicate a fairly symmetrical data whereas -0.5 and 1 indicate moderately skewed data.

Kurtosis indicates the extent of the peak in a distribution. Kurtosis decreases in a case where the tale of the distribution become lighter and increase where the tails becomes heavier. Kurtosis can also be referred to as standardised central moment in a distribution modelling. Data with a positive kurtosis has more data located in the tail of a normal distribution whereas negative kurtosis indicates less data in the tail (DeCarlo, 1997).

A normal distribution curve has a p value ≥ 0.05 however p values less than 0.05 indicate a distribution curve which is not normal. In hypothesis testing, modelling of data using normal distribution lead to acceptance of a null hypothesis while the opposite is true considering the sensitivity of the test relative to number of data points (Paiva, 2010).

Test for normality test determine whether data distribution follows a normal distribution or not. Distribution plot, difference value between mean and median, skewness and kurtosis and Q-Q biplots are the four methods used to determine the rough estimation normality (Kwak and Park, 2019). According to the same author the aforementioned test cannot be used to draw conclusion on whether the data satisfy normal distribution therefore statistical normality test must be conducted to obtain definite answer.

3.5.4 One way ANOVA and two way ANOVA comparison tests

Analysis of variance (ANOVA) is used to determine differences between the means of three or more groups using pairwise post-hoc testing to determine whether there is a difference between the mean of all possible pairs using a studentized range distribution (Lee and Lee, 2018). There are two different types of ANOVA statistical tests, one-way ANOVA and two way ANOVA. One-way ANOVA statistical test is used to compare the variance in the group means within a sample and it only takes into consideration only one independent variable or factor (Mackenzie, 2018). One way ANOVA is used for testing of null- hypothesis (H_0) and alternative hypothesis (H_1). According to Patel *et al.* (2015), one way ANOVA assumes that the sample is collected from a normally distributed population, each sample is independent, the variance of data in different groups is similar and that the dependant variable should be continuous. Similar to one way ANOVA, two way ANOVA is also a hypothesis based test however in this type of test each sample is described in two ways and categorised into two groups (Mackenzie, 2018). The two-way ANOVA determines the impact of two factors on a dependent variable and also determines whether the two factors affect each other to influence the continuous variable (McHugh, 2011). Assumptions of two way ANOVA are that the dependant variable is continuous, the two independent variables should be in categorical independent groups, that each sample has been drawn independently of the other samples, the variance of data in the different groups should be the same, and that each sample is taken from a normally distributed population (Mackenzie, 2018). Examples of multiple comparison tests include amongst others test such as the Tukey method, Newman-Keuls method, Bonferroni method, Dunnett method, Scheffé's test (Lee and Lee, 2018). For this study one way ANOVA test will be used for hypothesis testing and the two way ANOVA Tukey's test will be used to compare significant difference between the selected water quality parameters for the different sites. Significance was regarded as $p < 0.05$.

3.5.5 PCA Biplots

Principal Components analysis is a technique that is used in most cases for interpretation of large data sets, it does so by reducing the extent of data and making it easier to interpret without losing information. Biplots are described as two-way dimensional chart representing the relationship between the rows and columns of a table and it is created by means of map dialog box. The plots are generated on an excel or power point sheets (Jolliffe and Cadima, 2016).

Biplots depict existing or occurring distances, as well as variances and correlations of variables of large datasets. They are also used to show or discuss clustering, and occurrence of high intercorrelations between two or more independent variables in a multiple regression

model, and a combination of unusual scores on at least two variables or more variables. Biplots consists of lines and dots. Lines are used to show the variables of the dataset while dots are used to describe the observations. The length of the lines gives a rough estimation of variances between variables, the longer the line, the higher the variance. The size of the angle between the lines estimates the correlation between the variables they represent. The closer the angle is to 90, or 270 degrees, the smaller the correlation. An angle of 0 or 180 degrees shows a strong correlation of 1 or -1 , respectively (Kohler and Luniak, 2005).

3.5.6 Ethical considerations

All ethical requirements of the North-West University have been complied with (NWU-01502-20-A9).

CHAPTER 4: RESULTS

4.1 Water quality trends

Trend analysis is defined as a strategy that uses historical data to determine anticipated future changes. It allows comparison of data points over a given period of time and identify uptrends, downtrends, and stagnation (Ball and Tunger, 2006). Trend analysis provides information for the two research periods (2014-2015 & 2018-2019).

The pH measured at the seven sites in the Mooi River between 2014 and 2019 are presented in Figure 4a. At Klerkskraal Dam (Site 1) the pH ranged from 8.2 and 8.3, the results demonstrated a slight increase in pH during the two assessment periods. pH for Mooi River at Blaaubank (Site 2) was higher in 2014/15 (8.2-8.3) and reduced to 7.9 in 2019. The pH value for Mooi River downstream of Boskop Dam (Site 3) showed variable results during the entire period and fluctuated between 7.9 and 8.1. Loop Spruit (Site 4) recorded the lowest pH as compared to all the other sites, in 2014/15 pH changed from 7.2 to 7.7 and in 2018/19 it reduced to 7.6 and 7.3. For Site 5 (Mooi River at Potchefstroom) pH fluctuated from 8.0 to 8.3. Wasgoed Spruit (Site 6), fluctuations were noted with the lowest value of 7.8 in 2015 and the highest value of 8.2 in 2019. For the Mooi River at Hoegekraal (Site 7), small pH changes were observed, in 2014 it was at 8.5 and it increased to 8.6 in 2019.

The EC measured at the seven sites in the Mooi River between 2014 and 2019 are shown in Figure 4b below. The EC for Site 1 was at 41 mS/m in 2014 and increased to 50 mS/m in 2015, while in the second monitoring cycle (2018/2019) it decreased to 37 mS/m. Site 2, no serious changes occurred during both cycles (2014/15 & 2018/19) the concentration ranged between 104-110 mS/m. Site 3, 86 mS/m was recorded initially and decreased to 74 mS/m in 2015 and increased during the second cycle to 97 mS/m. For Site 4, in 2014 the highest reading of 102 mS/m was recorded and it gradually decrease to a value of 52 mS/m in 2019. For Site 5, the highest concentrations were recorded in the beginning of both cycles 2014 and 2018 respectively and the lowest concentrations were recorded in the second years of each cycle 74 mS/m and 78 mS/m respectively. Site 6, 149 mS/m was recorded in 2014 and went down to 119 mS/m in 2015, in the second cycle a sharp increase to 181 mS/m was noted in 2019. Site 7, the lowest value of 82 mS/m was recorded in 2014 which increase to 90 mS/m in 2015, in the beginning of the second cycle conductivity increased to 107 mS/m and decreased to 87 mS/m in 2019. All sites located along the Mooi River presented similar results with slight changes during both sampling periods and the EC recorded at this sites are higher with a maximum of 110 mS/m as compared to the EC recorded at Site 1 with a maximum EC

of 50mS/m. Site 6 (Wasgoed Spruit) recorded the highest EC (181 mS/m) and this site which is located on the tributary has a major impact on the Mooi River.

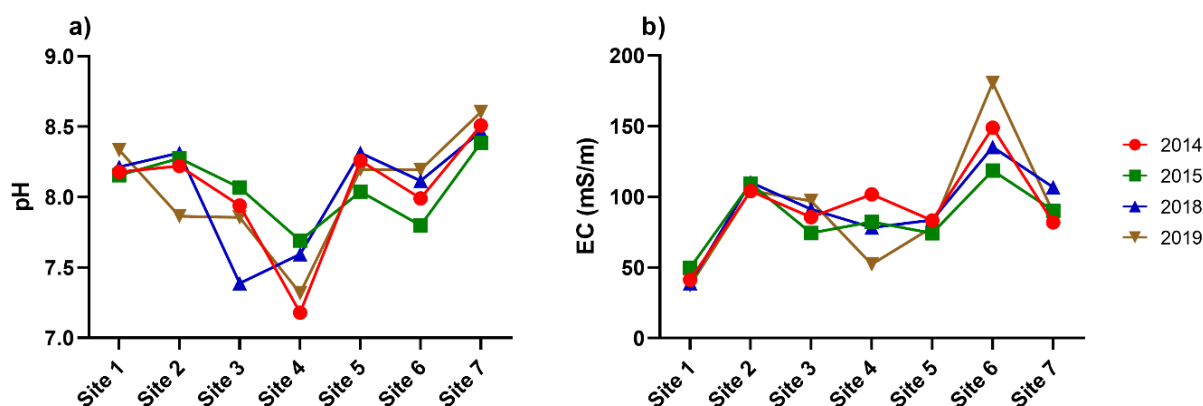


FIGURE 4: pH (a) and EC (b) for the period 2014-2019 at seven sites in the Mooi River from the source to the confluence with the Vaal River.

Potassium trends are shown in Figure 5a below. For Site 1, K^+ water quality concentration was at 15 mg/l (in 2014) and it increased slowly during the assessment period to 25,1 mg/l (in 2019). Site 2, a decrease from 8.2 mg/l to 6.6 mg/l was observed. Site 3, lower value of 3.4 mg/l was recorded in 2014, the value increased in 2015 and 2018 to 9.2 mg/l and 11 mg/l subsequently and reduced to 3.8 mg/l in 2019. Site 4, a reading of 7.5 mg/l was recorded at the beginning of the period and slightly increased to 9.2 mg/l and 11 mg/l in 2018 & 2019. Site 5, the reading was constant (7 mg/l) during the first three years and increased to 8.9 mg/l in 2019. Site 6, in 2014 -2015 K^+ increased from 4.2 mg/l to 5.8 mg/l and in the beginning of the second period a major increase of 14.7 mg/l was noted with a small change of 12.9 mg/l in 2019. Site 7, in 2014/15 an increase from 6.8 to 9.1 (mg/l) was noted, the value then decreases to 7.1 mg/l (in 2018) and 7.6 mg/l in 2019 .Site 1 showed different water quality characteristics with K^+ value higher than those recorded at the sites located downstream during both assessment periods. Site 6 (Wasgoed Spruit) also recorded higher values during both cycles and different from the other Mooi River sites.

As presented in Figure 5b, Mg^{2+} at Site 1 increased slowly during both cycles from 14.2 mg/l to 25.1 mg/l. Site 2, in the beginning of the sampling circle (2014) the Mg^{2+} content in the water quality was at 41.8 mg/l and moved to 45 mg/l in 2015 and 2018 and back to 40 mg/l in 2019. Site 3, a slight increase from 48.2 to 56.2 was noted during the sampling cycle. Site 4, Mg^{2+}

was low in 2014 (21.6 mg/l) and increased in 2015 to 27 mg/l and it remained constant throughout . Site 5, lowest value (36.1 mg/l) was noted in 2014, it increased to 46 mg/l in 2015 and decreased to 42.3 mg/l in 2019. For site 6, fluctuations were observed with the lowest values recorded in 2014 and 2018 and highest values of 94 mg/l and 89 mg/l noted in 2015 & 2019 subsequently. Site 7, Mg^{2+} content in the water was at 46 mg/l in the beginning and slowly increased to 52 mg/l in 2015 & 2018 and declined to 47 mg/l in 2019.

The chloride trend in Figure 5c showed that in 2014 and 2015 site 1 recorded the lowest chloride values of 5.6 mg/l and 9.6 mg/l subsequently and a sharp increase of 36 mg/l and 38 mg/l in 2018 and 2019. Site 2, elevated chloride levels of 67 mg/l and 68 mg/l were picked up in 2014/2015 and a decline of 40 mg/l in 2019. Site 3, variable results were noted for the site with the lowest values recorded in 2014 and 2019 and the highest reading of 85 mg/l in 2015. Site 4, values fluctuated from 45- 67 mg/l with the highest value recorded in 2015. Site 5, chloride gradually increased from 60.2 mg/l to 71,2 mg/l. site 6, a sharp increase from 70 mg/l to 160 mg/l was observed. For site 7, chloride increased slightly from 56.1- 65,7 mg/l.

As depicted in Figure 5d the SO_4 trend demonstrated that in 2014/15 SO_4 content at Site 1 was low (22 mg/l) and it increased to 87 mg/l during the second assessment period. Site 2, in 2014 SO_4 was at 271 mg/l and increased to 286 mg/l in 2015 and lessened to 250 mg/l in 2019. Site 3, SO_4 varied from 113 to 169 mg/l with the lowest reading recorded in 2015 and the highest recorded in 2018. Site 4, the trend demonstrated decrease from 266 to 124 mg/l. Site 5, trends showed slight SO_4 increase. Site 6, SO_4 varied from 145 to 596 mg/l, the lowest value was noted in 2014 and the highest in 2018 . Site 7 SO_4 readings varied from 115 to 152 mg/l with the lowest reading recorded in 2014 and the highest recorded in 2018.

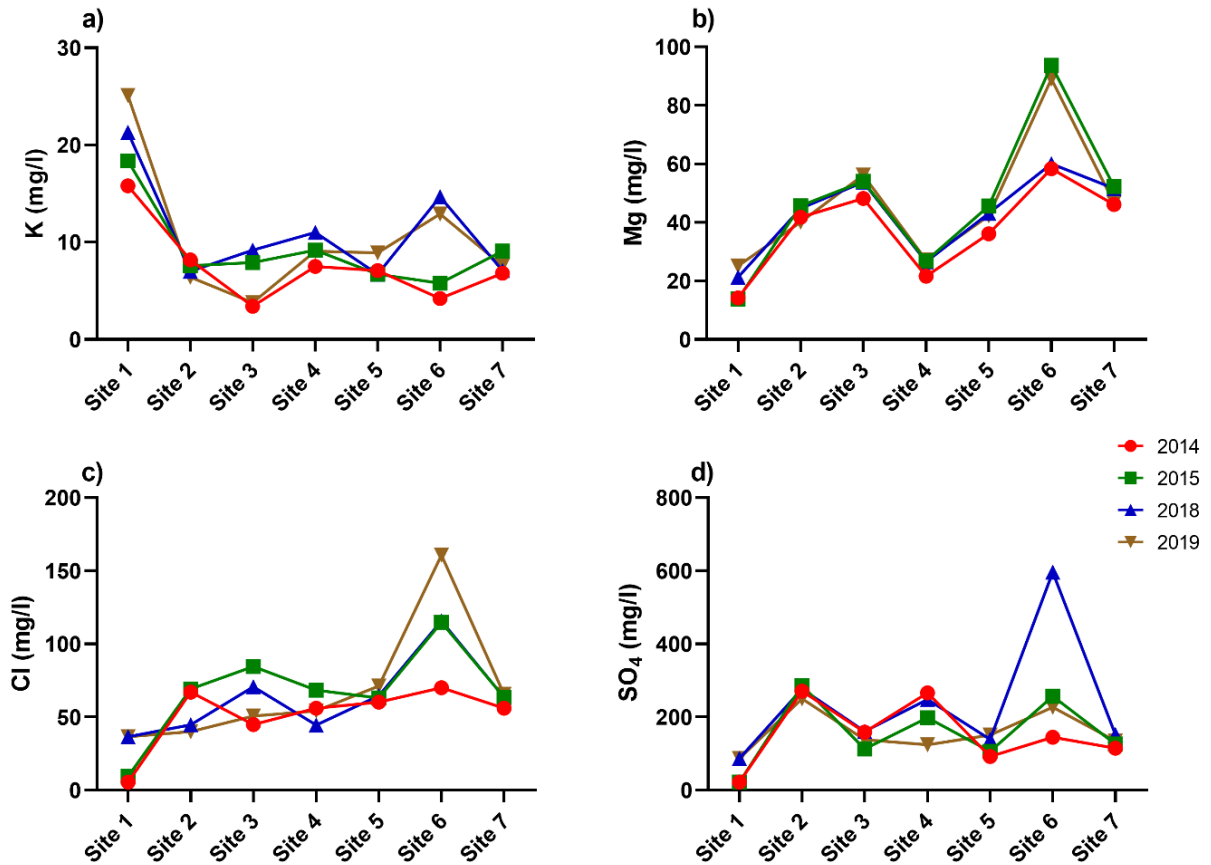


FIGURE 5: K⁺ (a), Mg²⁺ (b), Cl⁻ (c) and SO₄ (d) concentration in mg/l for the period 2014-2019 at seven site in the Mooi River from the source to the confluence with the Vaal River.

The NH₃ concentration for Site 1 as shown in Figure 6a demonstrated some slight increase with fluctuations throughout the period in 2014/15 an increase from 0.18 to 0.2 mg/l was noted, however, it dropped to 0.05 mg/l in 2018 and increased again to 0.2 mg/l in 2019. For Site 2, NH₃ varied from 0.166 to 0.69 mg/l, the smallest reading was captured in 2018 and the highest in 2015. For Site 3 the trends demonstrated an increase in NH₃ concentration throughout the study period. Site 4 also demonstrated some slight increase from 2014 to 2019. Site 5 showed an increase from 0.009-0.27 mg/l from the start to the end of the study period. For Site 6 the trend showed that NH₃ is increasing in the stream. And also at Site 5 an increase in ammonia concentration was also noted.

Figure 6b showed that at Site 1, from 2014-2018 the NO₃-NO₂ value was constant (0.5 mg/l) and increased to 1.8 mg/l in 2019. For Site 2 NO₃-NO₂ value was at 0.4 mg/l and moved slowly to 1.0 mg/l in 2019. Site 3 varied values were recorded with the lowest values of 0.4 and 0.7 in 2015 and 2019 respectively and the highest values of 2.5 and 2.9 were noted in 2014 and 2018. For site 4 concentration varied from 5.5 mg/l to 11.5 mg/l, the smallest concentrations were recorded in 2014 and 2018. For site 5, a decline from 1.6 to 0.1 was recorded. At Site 6,

in 2014/15 $\text{NO}_3\text{-NO}_2$ ranged from 1.2-2.1 and in 2018/2019 it was very low. Site 7, $\text{NO}_3\text{-NO}_2$ fluctuated between 0.5-1.0 mg/l.

The PO_4 trends as provided in Figure 6c showed stable results for Klerkskraal Dam in 2014, 2018 and 2019 except for 2015 where it was slightly higher. Mooi River at Blaaubank a reduction in concentration was noted in 2015 and 2018 and a slight increase again in 2019. For the site located downstream of Boskop Dam the recorded values showed an increase from 0.3 mg/l to 0.8 mg/l between 2014 and 2015 and an extreme increase of 3.8 mg/l in 2018. Loop Spruit, the values recorded were stable in 2014/2015 however an increase from 0.8 mg/l to 1.1 mg/l was recorded in 2018 and a slight decrease in 2019. Mooi River at Potchefstroom fluctuations were noted, the concentration was low (0.1 mg/l) in 2014 and increased to 0.8 mg/l in 2015, it dropped down in 2018 and increased to 0.7 mg/l again in 2019. Wasgoed Spruit the highest reading of 3.3 mg/l was recorded in 2014 and gradually decreased to 1.3 mg/l in 2019. Mooi River at Hoegekraal the lowest value of 0.4 mg/l was recorded in the beginning of the sampling period and slowly increased in 2015 and 2018 and dropped down to 0.5 mg/l in 2019.

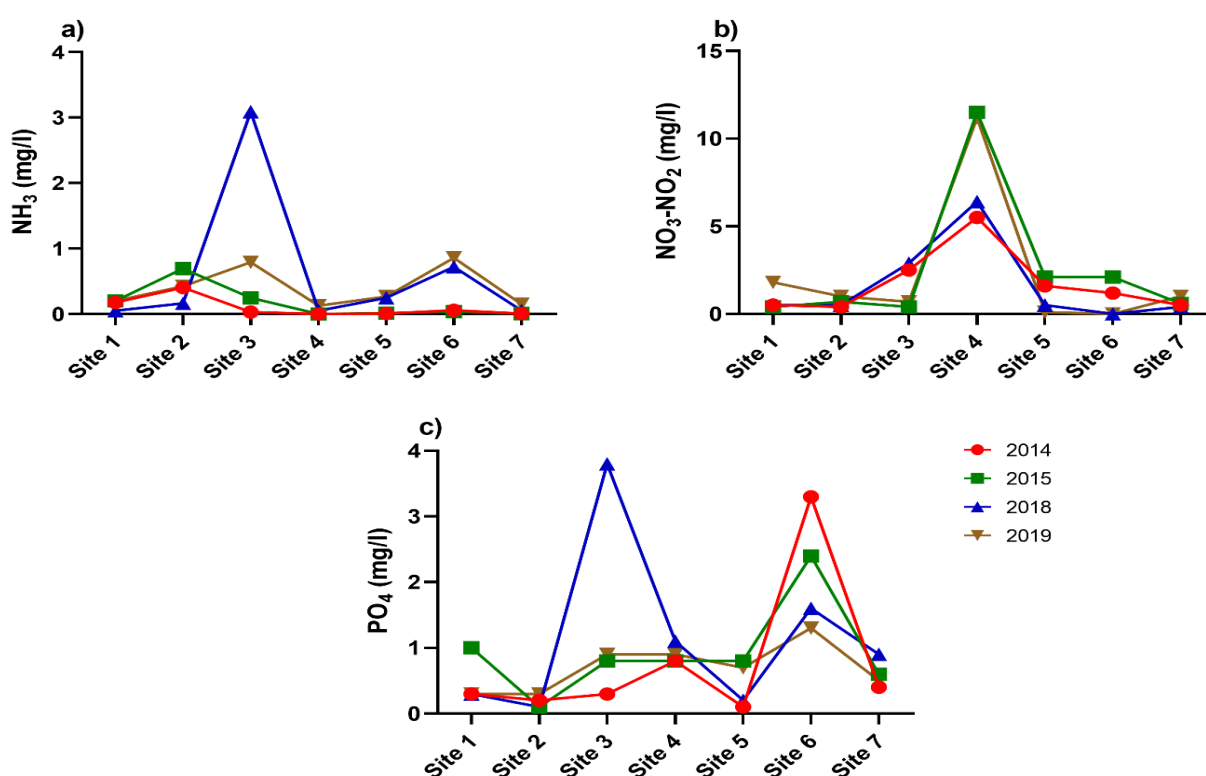


FIGURE 6: NH_3 (a), $\text{NO}_3\text{-NO}_2$ (b), and PO_4 (c) concentration (mg/l) for the period 2014-2019 at seven site in the Mooi River from the source to the confluence with the Vaal River.

4.2 Temporal and spatial variation in water quality variables (2014-2019)

The spatial variation was determined between the seven sampling sites located within the Mooi River and its tributaries. Temporal variations were determined at each of the seven sampling sites for the two time periods 2014/2015 and 2018/2019. Significant differences between sites are indicated with an asterisk, while significant differences at a site between time periods are indicated by linked lines.

4.2.1 pH

The pH at Site 4 was significantly lower ($p < 0.0001$) than all of the other sites (Figure 7a). Only Site 3 showed a significant difference ($p = 0.012$) in pH between the two sampling periods. There was a significant influence of sites ($F = 28.02$; $p < 0.0001$) and the interaction between the sites and surveys ($F = 3.08$; $p = 0.0075$) for pH.

4.2.2 Electrical conductivity

As demonstrated in Figure 7b the EC at Site 1 was very low and it was significantly different ($p < 0.0001$) to the other sites. The EC and at Site 4 ($p = 0.016$) and Site 6 ($p = 0.037$) were influenced by the change in sampling periods. Only the sites had a significant influence ($F = 54.13$; $p < 0.0001$) on the EC, with a significant interaction between sites and surveys ($F = 3.74$; $p = 0.002$).

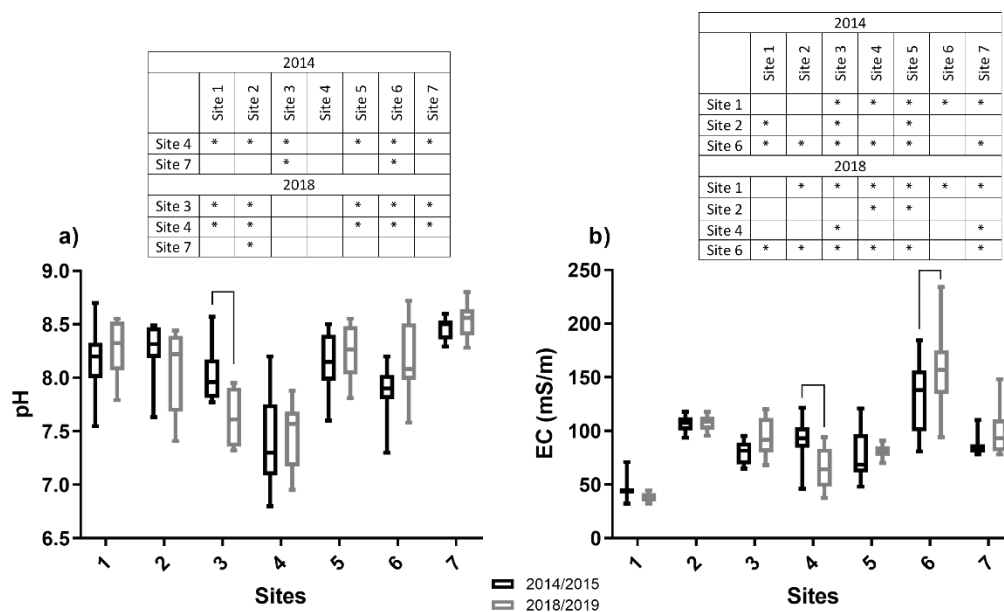


FIGURE 7: Box and whisker plots for pH (a) and EC (b) represent the median and 5-95th percentiles. Outliers are represented by whiskers. Significant differences between sites are

indicated with an asterisks, while significant differences at a site between time periods are indicated by linked lines. Significance was set at $p < 0.05$.

4.2.3 Potassium

The K^+ concentration at Site 1 was higher and significantly different ($p < 0.001$) from the other sites (Figure 8a). The same figure also showed that the change in concentration at Site 1 ($p = 0.003$) and Site 6 ($p < 0.0001$) are influenced by the change in sampling periods. There was a significant influence of sites ($F = 31.89$; $p < 0.0001$) and surveys ($F = 13.33$; $p = 0.0004$), as well as the interaction between the two factors ($F = 4.72$; $p = 0.0002$) for K^+ .

4.2.4 Magnesium

Site 1 and Site 4 recorded the lowest Mg^{2+} values hence they are significantly different ($p < 0.0001$) from the other sites (Figure 8b). The change in sampling periods did not have an impact on Mg^{2+} content in all sites. Only the sites had a significant influence ($F = 46.21$; $p < 0.0001$) on Mg^{2+} .

4.2.5 Chloride

The results as presented in Figure 8c demonstrated that Site 1 and Site 6 were significantly different ($p < 0.0001$) with the other sites due to the lowest concentration recorded at Site 1 and the highest concentrations recorded at Sites 6. Site 1 ($p = 0.014$), 2 ($p = 0.042$) and 6 ($p < 0.0001$) were highly affected by the change in sampling periods. Only the sites had a significant influence ($F = 35.64$; $p < 0.0001$) on the Cl, with a significant interaction between sites and surveys ($F = 7.04$; $p < 0.0001$).

4.2.6 Sulphate

Site 1 and Site 5 recorded the lowest SO_4 concentrations and they both showed significant difference ($p < 0.0001$) with the other sites (Figure 8d). The same figure showed that Site 6 ($p < 0.0001$) was affected by the changing periods with the highest concentration of 596 mg/l recorded for the site. There was a significant influence of sites ($F = 30.57$; $p < 0.0001$) and surveys ($F = 12.13$; $p = 0.0007$), as well as the interaction between the two factors ($F = 6.56$; $p < 0.0001$) for SO_4 .

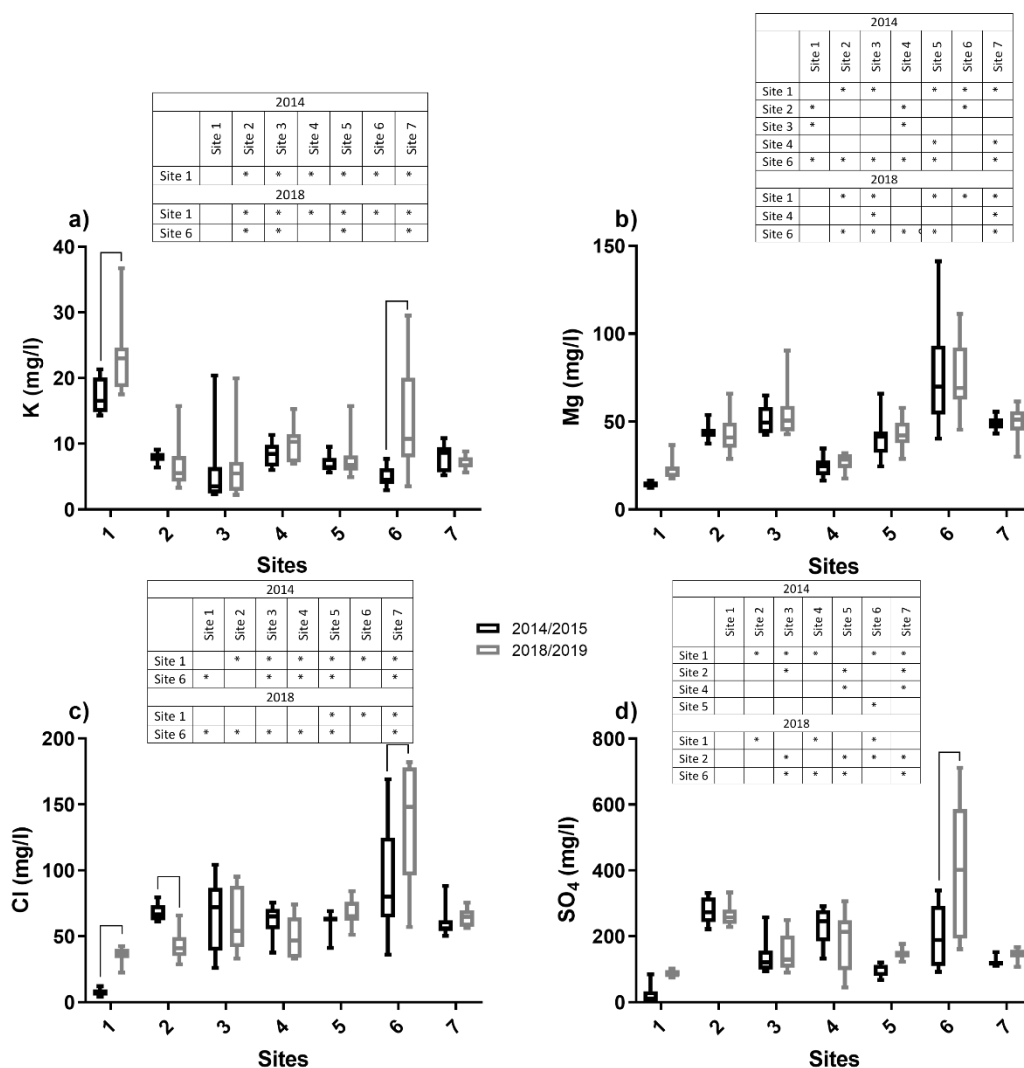


FIGURE 8: Box and whisker plots for K^+ (a), Mg^{2+} (b), Cl^- (c) and SO_4 (d) represent the median and 5-95th percentiles. Outliers are represented by whiskers. Significant differences between sites are indicated with an asterisk, while significant differences at a site between time periods are indicated by linked lines. Significance was set at $p < 0.05$.

4.2.7 Ammonia

The NH_3 trend as shown in Figure 9a demonstrated that Site 3 was significantly different ($p < 0.001$) and recorded higher values as compared to all the other sites, which recorded lower values. The change in concentration at Site 3 ($p < 0.0001$) is attributed to the change in sampling periods. There was a significant influence of sites ($F = 3.54$; $p = 0.003$) and surveys ($F = 7.16$; $p = 0.009$), as well as the interaction between the two factors ($F = 3.49$; $p = 0.003$) for NH_3 .

4.2.8 Nitrate - nitrite

Site 4 recorded the highest concentration of $\text{NO}_3\text{-NO}_2$ and it is therefore significantly different ($p < 0.0001$) to all the other six sites (Figure 9b). The change in water quality at all 7 sites were not influenced by the change in sampling periods. Only the sites had a significant influence ($F = 44.18$; $p < 0.0001$) on the $\text{NO}_3\text{-NO}_2$.

4.2.9 Phosphate

As shown in Figure 9c PO_4 at Site 3 and Site 6 were significantly higher ($p < 0.05$) than the other sites and the change that occurred at both sites are attributed to the change in sampling period ($p < 0.0001$ and $p = 0.0023$, respectively). Only the sites had a significant influence ($F = 13.67$; $p < 0.0001$) on the PO_4 , with a significant interaction between sites and surveys ($F = 6.26$; $p < 0.0001$).

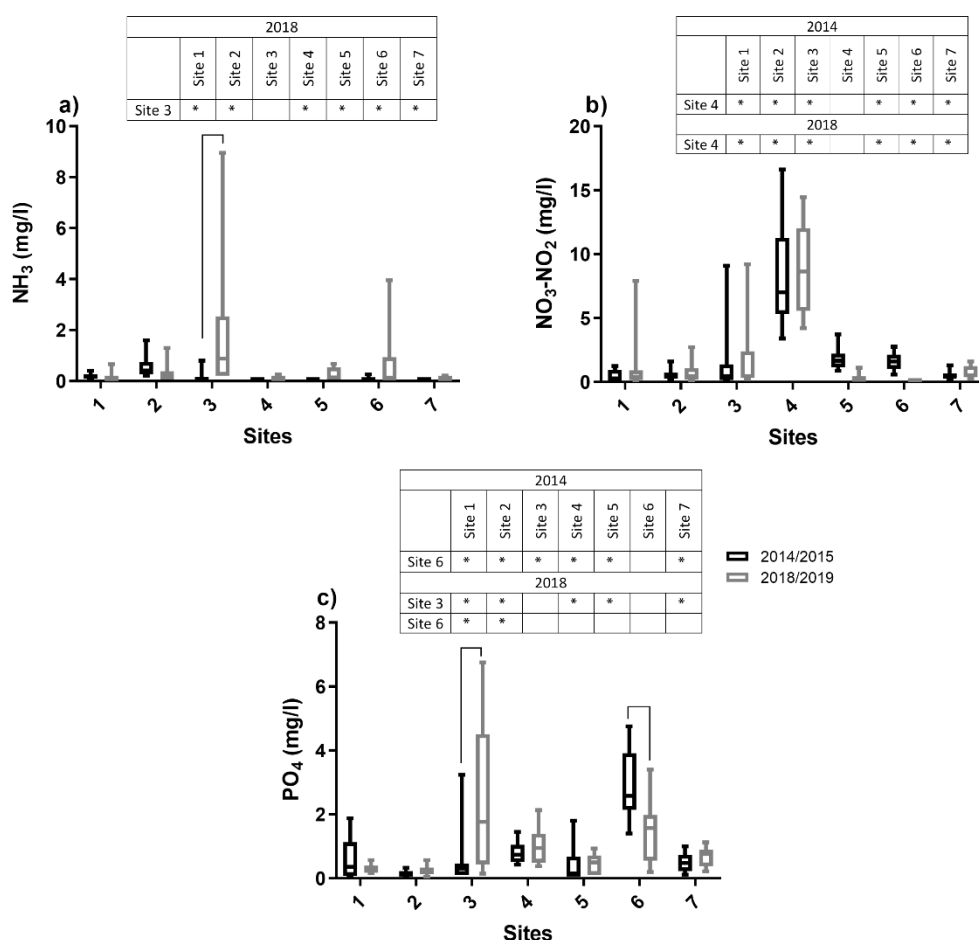


FIGURE 9: Box and whisker plots for NH_3 (a), $\text{NO}_3\text{-NO}_2$ (b), PO_4 (c) represent the median and 5-95th percentiles. Outliers are represented by whiskers. Significant differences between sites are indicated with an asterisk, while significant differences at a site between time periods are indicated by linked lines. Significance was set at $p < 0.05$.

4.3 Spatial and temporal relationships in water quality data

The biplot (Figure 10) describes 67.4% of the total variation, with 44.6% on the first axis and 22.8% on the second axis. Majority of the change lies on the first axis, site 1 is different with the other sites especially Site 6. Water quality at Site 6 is influenced by salts (Mg^{2+} , Cl^- , SO_4 & EC) and nutrients (NH_3 and PO_4). Site 7 is influenced by pH, while Site 4 is influenced by nitrate-nitrite. The remaining sites are not influenced by any of the parameters. Based on the ordination it was clear that there is distinction between the sites but not sampling periods.

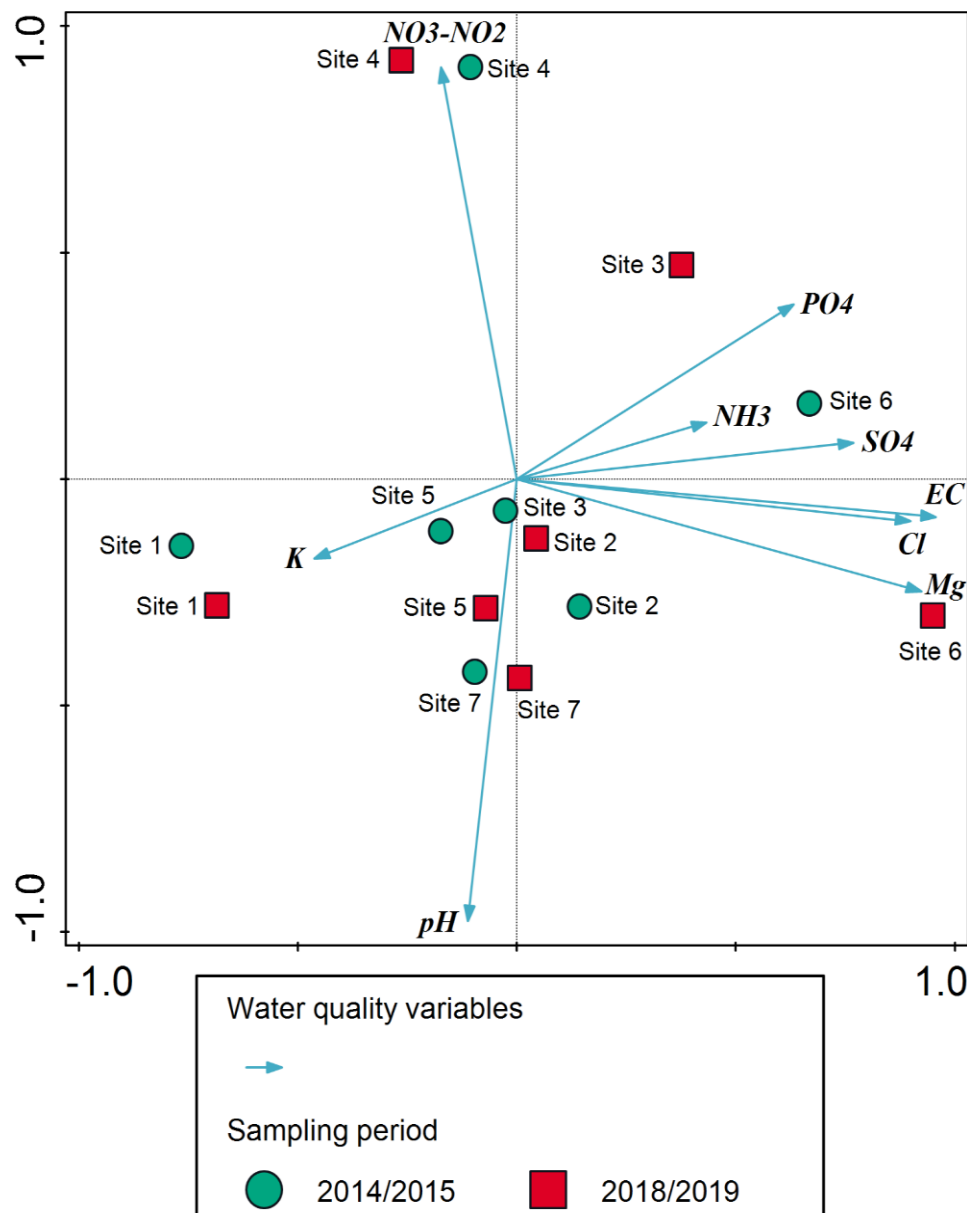


Figure: 10: Principal component analysis of the water quality at the Mooi River sites from the headquarters to the confluence with Vaal River. The first two axes describe 44.6% of the total variation while the second two axis depicts 22.8% of the variation.

4.4 Compliance of the Mooi River sites to target water quality ranges for different water users and RQO's

Table 6: Comparison of the averaged water quality data for all sites along the Mooi River with the target water quality ranges for different water uses and the resource quality objectives. Non-compliance to TWQR for domestic use, Agriculture, aquatic ecosystem and RQOs is highlighted in orange, green, purple and red respectively (DWAF, 1996a; DWAF, 1996b; DWAF, 1996e & DWAF, 2011).

Parameters	Average concentration							TWQR Domestic use	TWQR Agricultural use	TWQR Aquatic Ecosystems	RQO's
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7				
pH	8.2	8.2	7.8	7.5	8.2	8.0	8.5	6-9	6.6-8.5	6.6-9.5	5.9-8.8
EC	41.2	106.8	87	78.5	79.8	146	92	70 mS/m	40 mS/m	-	111 mS/m
Mg ²⁺	18.6	43.1	53.1	25.5	41.8	72.3	40.2	30 mg/l	50 mg/l	-	-
K ⁺	20.5	7.3	6.1	9.2	7.35	9.23	7.65	50 mg/l	-	-	-
Cl ⁻	22.2	58.8	62.8	55.9	64.8	115.4	62.2	100 mg/l	100 mg/l	-	-
SO ₄	55	271	143	209	122	306	132	200 mg/l	1000 mg/l	-	-
NO ₃ -NO ₂	0.8	0.7	1.6	8.65	1.1	0.8	0.63	6 mg/l	100 mg/l	-	1 mg/l
NH ₃	0.16	0.42	1.2	0.05	0.13	0.42	0.06	1 mg/l	-	7 mg/l	-
PO ₄	0.5	0.2	1.5	0.9	0.5	2.2	0.6	-	-	5 mg/l	0.025 mg/l

CHAPTER 5: DISCUSSION

5.1 Spatial and temporal changes in water quality of the Mooi River

5.1.1 pH

The pH at all the sites and during both survey periods were within the guideline values for domestic (DWAF, 1996a), agriculture (DWAF, 1996c) and aquatic ecosystem use (DWAF, 1996b), as well as the RQOs (DWS, 2016). A historical trend analysis by Potgieter (2019) indicated that since 1970's-1980's the pH has stayed fairly constant. When compared to other studies on the Mooi River the pH at the site below Klerkskraal Dam were relatively high with a maximum of 8.2 and the pH at the downstream sites were low (Koekemoer, 2019). The decrease in pH observed at Sites 3 and 4 (downstream of the confluence of the Wonderfontein Spruit) when compared to the other sites can be attributed to the mining activities located upstream of this points (Barnard *et al.*, 2013).

5.1.2 Electrical conductivity

The EC at all six sites except for the site below Klerkskraal Dam exceeded the target water quality ranges as prescribed in the domestic (DWAF, 1996a) and agricultural (DWAF, 1996e) water use guidelines. All sites that demonstrated high EC were situated downstream of the Wonderfontein Spruit which is heavily impacted by mines located in the Krugersdorp and Carletonville areas. The results of this study gives a clear indication that human activities such as mining, agriculture and rural and urban settlement are largely contributing to the elevated concentration of EC downstream of the confluence with the Wonderfontein Spruit, at the reference site (Klerkskraal) the highest EC value recorded was 52 mS/m while the downstream site recorded the highest value of 110 mS/m. The EC for the point situated along the Wasgoed Spruit also exceed the resource water quality objectives (DWS, 2016) for the Mooi River. A study conducted for the period (1995-2010) by Barnard *et al.* (2013) also picked up high levels of EC along the Mooi River and its impoundments and based on this study the high EC levels were associated with the mining activities taking place in the Wonderfontein Spruit sub-catchment area. Another study conducted by Koekemoer (2019) picked up high EC in the tributaries of the Mooi River and this study emphasised that the high EC levels were associated with irrigation, industrial effluent and sewage effluent.

5.1.3 Potassium

The statistical analysis demonstrated that K^+ at Site 1 is higher and significantly different from the other sites with an average of 20.5 mg/l. The average K^+ for all sites were found to be compliant to the TWQR for domestic water use and the resource quality objectives. Based on the literature review potassium was not included in most of the studies conducted for the Mooi River Catchment, however, trend analysis done by Potgieter (2019) showed that K^+ was extremely high along the Wonderfontein Spruit during the 1990's. Based on Gandebe *et al.* (2017) 95% of K^+ compounds are used as fertilisers, while DWAF (1996a) indicates that potassium iodide is used as an animal feed. Although agriculture is the main source of K^+ pollution the findings on this study could be different since Klerkskraal Dam is fed by natural springs located on the Northern side of the dam and the high K^+ content in the water could be derived from natural weathering of minerals/rocks.

5.1.4 Magnesium

Magnesium at Sites 2, 5, and 7 during the entire assessment period was found to be higher than the target water quality range for domestic water use (DWAF, 1996a). Site 3 and Site 6 were both above the domestic and agricultural target water quality ranges. Labuschagne's (2017) study also discovered that Mg^{2+} slowly increased downstream of the Mooi River towards the confluence with Vaal River. Figure 2-3 shows that Sites 2, 6 and 7 are located within the Mooi River downstream of the Wonderfontein Spruit. According to Barnard *et al.* (2013) water quality at the Wonderfontein Spruit is mostly influenced by the mining activities occurring at the Western basin, however, based on Ugya *et al.* (2020) the types of pollutants expected from mining activities include amongst others high total dissolved solids, SO_4 and heavy metals. Figure 2-3 shows that Sites 2, 6 and 7 are surrounded by agricultural activities. Magnesium minerals such as magnesium carbonate and silicate are known to be used by farmers as animal feed and fertiliser (Chandini *et al.*, 2019). Site 6 as depicted in Figure 2-3 is located along the Loop Spruit just below Klipdrift Dam, this area is surrounded by agricultural activities and as a result the elevated Mg^{2+} concentration at this site could also be attributed to those agricultural activities.

5.1.5 Chloride

The Cl^- at Site 1 complied with the target water quality ranges for domestic (DWAF, 1996a) , agricultural (DWAF, 1996c) and aquatic ecosystem (DWAF, 1996b) water uses, however, the increasing trends picked up during the assessment period is concerning. During 2014/15 cycle Cl^- concentration ranged between 5.6 mg/l – 9.6 mg/l and it elevated to 36 mg/l and 38 mg/l

in 2018 and 2019, respectively. Chloride levels at the Wasgoed Spruit were found during both assessment periods to be above the target water quality range of 100 mg/l which is applicable for both domestic and agricultural water uses. Based on other studies conducted Site 1 was found to be low in Cl^- concentration (5 mg/l) and the Mooi River below the confluence with Wonderfontein Spruit was found to be higher with a maximum of 42.42 mg/l which is similar to the findings of this study (Koekemoer, 2019). The difference in Cl^- content between Site 1 and the downstream sites indicates that human activities play a significant role in the elevated Cl^- levels. As documented by Pelser (2015), the land use activities such as agriculture and mining have an influence on the concentration of cations and anions found in the Mooi River.

5.1.6 Sulphate

The averaged SO_4 concentration at all the Mooi River sites specifically downstream of the confluence with Wonderfontein Spruit showed decreasing trends and also complied with the target water quality ranges for domestic and agricultural water uses. Jordaan and Bezuidenhout (2016) and Labuschagne (2017) studies do not concur with the findings of this study, in their assessment they both concluded that SO_4 in the Mooi River after the confluence with Wonderfontein Spruit were consistently higher than the resource quality objectives. Site 1 also complied with the target water quality ranges, however, the trend analysis for this site demonstrated an increase in SO_4 from 22 mg/l in 2014 to 87 mg/l. A study conducted by van der Walt et al. (2002) highlighted that agricultural activities are slowly causing changes in water quality in the upper reaches of Mooi River. Sulphate at the two tributaries Wasgoed Spruit and Loop Spruit exceeded the target water quality range for domestic water use. Based on Koekemoer (2019), the Wasgoed Spruit sub-catchment area is characterised by industrial activities and informal and formal settlements and both activities are highly contributing to water quality deterioration in the area.

5.1.7 Ammonia

The site located downstream of the Boskop Dam is the only site that did not comply with the 1 mg/l domestic water use target water quality range (DWAF, 1996a), however, the trend analysis conducted by Potgieter (2019) demonstrated that NH_3 at this site was low and constant for the period 1965 to 2010. The trend analysis for this study also demonstrated that NH_3 is increasing at the last site (Site 7) along the Mooi River just below the confluence with Vaal River, other studies such as Potgieter (2019) also picked up elevated concentration of NH_3 at Site 7 from 1979-1994 and a decrease thereafter. Increasing NH_3 trends were also noted for Wasgoed Spruit site. According to Prevention (2007), NH_3 exists in natural water as a result of decomposition of organic matter however other writers such as Davari *et al.* (2010)

and Du *et al.* (2017) emphasize that high concentration of NH_3 in surface water and shallow ground water is known to be associated with anthropogenic sources such as domestic and industrial effluents, industrial emissions and leakage of manure from fertilizers and other agricultural activities. According to Guthrie *et al.* (2018), the main source of NH_3 pollution is the manure and slurry released from agricultural practices and the application of manmade fertiliser which constitutes 82 % of NH_3 emissions in the UK.

5.1.8 Nitrate - Nitrite

Nitrate - nitrite at Site 4 demonstrated significant differences with the other sites with an average concentration of 8.65 mg/l. During the entire sampling period Site 4 did not comply with the target water quality range for domestic use (DWAF, 1999a) and the resource quality objectives (DWS, 2016), while Sites 3 and 5 did not comply with the RQOs. Labuschagne (2017) study established that the average nitrate- nitrite for the entire Mooi River was at 0.877 mg/l that indicates a mesotrophic algal state condition. The same author also found that the high nitrate - nitrite concentration is as a result of agricultural activities taking place around the Mooi River especially agricultural runoff. The results for this study demonstrated that nitrate for Site 1 in 2015 was at 0.4 mg/l, Site 4 was the highest with 11.5 mg/l and Site 7 was at 0.5 mg/l. Jordaan and Bezuidenhout (2015) results also concurs with the findings of this study for Site 1 (0.5 mg/l) and Site 7 (0.5 mg/l), except for Site 4.

5.1.9 Phosphate

The average PO_4 for at all seven sites exceeded the 0.025 mg/l RQO value with Sites 3 and 6 significantly higher than the other sites. Based on this study, PO_4 at all sites ranged between 0.2 and 2.2 mg/l with the highest readings recorded at Sites 3 and 6, the trend analysis by Potgieter (2019) demonstrated that PO_4 remained constant from 1966 until 1970 where it exceeded the RQO limits, Labuschagne (2017) found that the average PO_4 for Mooi River was at 0.163 mg/l, while Jordaan and Bezuidenhout (2015) also found PO_4 to be within the Department of Water Affairs's recommended resource water quality objectives

5.2 The suitability of water quality in the Mooi River for different water uses

Water quality in the Mooi River especially for the sites after the confluence with the Wonderfontein Spruit is not suitable for domestic and agricultural water uses. EC, Mg^{2+} , SO_4 , NH_3 , PO_4 and NO_3 - NO_2 are the most problematic parameters. As stipulated by Barnard *et al.* (2013) high levels of EC and SO_4 along the Mooi River are associated with the mining activities taking place in the catchment area. As concluded by Labuschagne (2017) nutrients (NH_3 , NO_3 - NO_2 and PO_4) in the Mooi River are generated from livestock, sewage runoff from informal settlements, agricultural runoff and abattoirs. The high Mg^{2+} concentration in the Mooi River is associated with the agricultural activities. For the upper Mooi River site (Klerkskraal Dam) K^+ is the only problematic parameter, the primary source of water for this site is ground water and the high concentration of K^+ could be ascribed to the geological conditions of the site. Ammonia, NO_3 - NO_2 and PO_4 exceed the resource quality objectives for Mooi River. The Wasgoed Spruit water quality EC, Cl^- and SO_4 does not comply with the domestic and agricultural water uses. As concluded by Koekemoer (2019), high salt concentration in the Wasgoed Spruit is mostly associated with the industrial activities and informal and formal settlements dominating the area. For the Loop Spruit water quality is not suitable for domestic water use due to high SO_4 concentrations and site does not also comply to the resource quality objectives for PO_4 . The Loop Spruit site is located in an agricultural area and the high SO_4 and PO_4 could be as a result of the agricultural activities.

The PCA biplots have also demonstrated some strong relationship between pH, Mg^{2+} , Cl^- , PO_4 and NO_3 , while the two way ANOVA test demonstrated significant differences in EC, Mg^{2+} and Cl^- at sites located in the Mooi River below the confluence with Wonderfontein Spruit. This study concluded that the agricultural salts such as Cl^- and Mg^{2+} and nutrients are of main concern in terms of agricultural pollution in the catchment and the study concurs with other studies conducted locally and globally which concluded that PO_4 , NO_3 - NO_2 , pesticides, soil sediments, EC and pathogens are the most problematic pollutants emanating from agricultural activities (Conrad *et al.*, 1999; Mateo Sagasta *et al.*, 2017, Mudaly and Van der Laan, 2020).

CHAPTER 6: CONCLUSIONS AND RECOMMENDATION

6.1 Conclusions

The main aim of this research was to assess the extent of the impact of agricultural activities on different water uses in the Mooi River by analysing the historical data for two time periods (2014-15; 2018-2019) and comparing it with water quality guidelines for different water uses and the resource quality objectives. The objectives of the study were achieved by analysing the data trends and also by determining the degree of change in water quality between different selected parameters and sites using two way ANOVA test and PCA biplots.

Furthermore, a null hypothesis which states that *“Poor agricultural practices will negatively impact the water quality in the Mooi River and have a negative effect on different water use sectors”* was set and tested using two way ANOVA test and the outcome of the results indicated that the p values for 2014-15 and 2018-19 were 0.99 and 0.72 respectively and both are greater than 0.05 which implies that the null hypothesis is supported.

Based on the results and discussion as outlined in chapter 4 and 5 the aim and objectives of the study were met and the null hypothesis supports the findings of the study. The most problematic parameters noted during the study were Mg^{2+} , Cl^- , K^+ , NO_3-NO_2 , PO_4 , EC and SO_4 . The electrical conductivity for all sites located along the Mooi River except for the point below Klerkskraal Dam exceeds the agricultural (40 mg/l) and domestic (70 mg/l) standards. Four sites along the Mooi River, as well as the tributary Wasgoed Spruit did not comply with 30 mg/l Mg^{2+} domestic guideline in both assessment periods with average concentration ranging from 46.14 – 52.26 mg/l, this finding is almost similar to Labuschagne's (2017) study findings where he discovered that the average Mg^{2+} concentration in the Mooi River was about 35.5 mg/L, Bredenhann (2020) study also recorded Mg^{2+} concentration of 41.30 mg/L along the Loop Spruit just before the confluence with Mooi River. Chloride demonstrated some increase in trends within two sites situated at the upstream and downstream (Klerkskraal and Hoegekraal) of the Mooi River, as well as Wasgoed Spruit. Potassium trend increase is evident at the point located downstream of the Klekskraal Dam. All sites along the Mooi River were observed to be complying with all the nitrates standards, however, the increasing trends at monitoring points below the two dams (Klerkskraal and Boskop) is concerning. Loop Spruit was found to be not complying with the nitrate RQOs (1 mg/l), and domestic (6 mg/l) standards. Phosphate was found to be problematic in all sites with average PO_4 concentration ranges, Klerkskraal (0.3 mg/l -1.0 mg/l), Mooi River at Blaaubank (0.1 mg/l-0.3 mg/l), downstream of Boskop (0.3 mg/l -3.8 mg/l), Loop Spruit (0.8 mg/l-1.1 mg/l), Mooi River at Potchefstroom (0.1mg/l-0.8 mg/l), Wasgoed Spruit (1.3-3.3 mg/l), Hoegekraal (0.4-0.9 mg/l) all mentioned

values are above the RQO value of 0.025 mg/l. Bredehann (2020) concluded in his study that the Loop Spruit is highly contributing to high PO_4 concentrations in the Mooi River with the highest recorded value of 4 mg/l. The Mooi River and its tributaries have also been found to have high SO_4 which are influenced mostly by mining activities. Manyatse (2017) also concluded in his study that SO_4 , Cl^- and K^+ in the Mooi River are high with maximum concentrations of 1300 mg/l, 183 mg/l and 34.32 mg/l, respectively.

In summary, based on the high Cl^- , EC and Mg^{2+} it is clear that the Mooi River downstream of the confluence with Wonderfontein Spruit is affected by both mining and agricultural activities. The high Cl^- and Mg^{2+} levels in the Loop Spruit showed that site 6 is affected by agricultural activities and the Wasgoed Spruit with high Cl^- and NH_3 is caused by industrial pollution.

6.2 Limitations

Due to time constraints samples were not collected but historical data for period 2014-2015 and 2018-2019 was extracted from the Department of Water and Sanitation Water Management Systems and used for this study. According to the research proposal sodium, calcium and coliforms were supposed to form part of the study, however, due to gaps identified on the system the mentioned parameters were not included. The purpose of this study was to assess the impact of agricultural activities on different water uses including the recreational water use activity. However the South African water quality guideline for recreational water use is the only guideline available to assess recreational water use associated health impacts and the guide was not designed to have the physical and chemical parameters standard or limits instead algae is used to determine the suitability of water for use. The resource quality objectives for Mooi River catchment do not have numerical limits for salts it only caters for nutrients and heavy metals.

6.3 Recommendations

Based on Pimentel (2005), the most common sources of pollution emanating from agriculture are sediments, nutrients, animal feeding operations, irrigation, pesticides, and livestock grazing, these sources of pollution are also common for the Mooi River. Based on the information gathered from literature review the most practiced agricultural activities in the Mooi River Catchment, include amongst others, crop farming, cattle and poultry which include chicken hatchery and processing, and cattle farming (Taruzza, 2016; Koekermoe *et al.*, 2021). The findings of this study concluded that salts (EC, Mg^{2+} and Cl^-) and nutrients (NO_3 and PO_4) are the main parameters of concern to be dealt with to reduce agricultural related impacts in

the Mooi River catchment. Based on the findings it is therefore recommended that best management practices be identified and implemented to deal with pollution in the catchment. Jain and Singh (2019) describes Best management practice (BMP) as *“management, agronomic/ vegetative and structural practices that permit economical and viable production while achieving the least adverse impact on the environment including water quality”*.

According to Gandebe *et al.* (2017), as well as Divia and Bagali (2012) natural (animal manure) and artificial (chemical) fertilisers are the sources of nutrient pollution in agriculture. Cunningham (2009) recommends manure storage before application as one of the best management practices, this technique helps in the reduction of high nitrogen content which is contained in fresh manure and during the storage process nitrogen is converted into ammonium which is released into the atmosphere and deposited on land through precipitation. Through the regulatory authorities awareness meeting the farmers in the Mooi River must be encouraged to practice this method to minimise nutrient from the source before it is washed off into the environment.

The government departments responsible for environmental management and water resources management should strengthen the regulatory responsibilities to ensure compliance with the applicable legislations and regulatory tools such as water use licences and waste management licences. Proper storm water management system must be installed in farms to prevent the interaction of dirty water with clean run off. Regular compliance monitoring must be conducted to ensure effluent discharged from agricultural facilities comply with the applicable standards.

Communication and awareness platforms such as catchment management forums and environmental forums must be established to promote collaboration of a wide range of people, stakeholders, organizations, and government departments at a catchment level and also to promote better management of catchment activities.

The study only focused on measuring and comparing trends for two time periods (2014/2015; 2018/2019). To obtain a good indication of the changes that took place as a result of agricultural impact it is recommended that future studies be conducted for a full ten year period and the study must include parameters such as sodium, alkalinity, pathogens and pesticides. The agricultural impact on ground water resources must also be done in future.

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