UNIVERSITY OF ZULULAND

FULL DISSERTATION

Submitted in fulfilment of the requirements for the degree of MASTER OF SCIENCE in the field of HYDROLOGY in the Faculty of Science and Agriculture at the University of Zululand

With the title:

THE VARIANCE IN THE WATER QUALITY OF THE LOWER ORANGE RIVER

FACULTY OF SCIENCE AND AGRICULTURE

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DECLARATION

I declare that this is my own unaided work and that it has never been submitted before in this or any other university for examination.

ABSTRACT

The monitoring and assessment of rivers is important for measuring the status of river ecosystems, water quality and water demand, and can provide early warning for management intervention with regard to water quality and quantity. This can be quite a daunting undertaking for rivers that cross national boundaries such as the Orange River.

Concepts such as Integrated Water Resource Management were introduced to enhance the sustainable use and management of such water resources. In addition, transboundary bodies such as the Orange-Senqu River Commission were established between member states in the Southern African region to provide a platform for coordinated water resource management of the river.

The DWS has various water quality monitoring programmes throughout the country. The National Chemical Monitoring Programme is the longest running of the national monitoring programmes. While the National Microbiological Monitoring Programme provides data for determining the potential health risks to people related with the potential utilization of pathogenically polluted water resources.

This study identified and evaluated the effectiveness of sampling locations by analysing water quality trends from monitoring points in the Lower Orange River located in the Northern Cape. Historical data from the Department of Water and Sanitation’s Water Management System and National Integrated Water Information System were utilised to illustrate changes in the water quality temporally and spatially. The legislative requirement of water quality in South Africa, according to the South African Water Quality Guidelines, was applied to the data sets.

The current water quality network of the Lower Orange is under-utilised. The various sites are not monitored on a consistent basis. A large number of sites have been left inactive and not monitored. Creating a situation where the latest data may not be available for management decisions. The general trend of the river water quality indicates a general increase in the Total Alkalinity in the river. This potentially is the results of years of runoff from irrigation practices into the river. The river also displays high levels of phosphate, nitrate and magnesium at some monitoring points.

There are large gaps in data, and thus limited information, in terms of water quality of the Lower Orange River. Studies conducted by organisations such as the ORASECOM also indicate a lack of information with regard to Persistent Organic Pollutants, heavy metals and radio nuclides. These potential major pollutants are currently not being given priority compared to other parameters..

Water management authorities and institutions require research that supplies a constant flow of information in order to adequately respond to water quality changes in the river. This study identified gaps between the monitoring and management of the Lower Orange River. In addition, it provides potential mitigation measures that could help ensure the gaps are closed and water quality data is converted into information that can enhance understanding of the water quality in the Lower Orange River. Policy formulation for water quality management in the arid Northern Cape can be made much easier with this information.

DEDICATION

To my late sister: Your memory has been an inspiration. You are missed.

To my parents: Your prayers and words of wisdom have kept me strong throughout this journey. Thank you.

To my wife: Your prayers, support, help and understanding throughout my studies have been incredible and you kept me focused. Thanks Mio.

This is for you Zawi and Kia.

To my siblings: Being your big brother is a stimulus on its own and I hope this motivates you as well.

To ‘Sir’ (Simonis): You always believed in me and pushed me to go beyond my boundaries. Thank you.

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LIST OF ABBREVIATIONS

CGS	COUNCIL FOR GEOSCIENCE
CMA	CATCHMENT MANAGEMENT AGENCY
DST	DEPARTMENT OF SCIENCE AND TECHNOLOGY
DWAF	DEPARTMENT OF WATER AFFAIRS AND FORESTRY
DWS	DEPARTMENT OF WATER AND SANITATION
EC	ELECTRICAL CONDUCTIVITY
GDP	GROSS DOMESTIC PRODUCT
GEF	GLOBAL ENVIRONMENT FACILITY
GIS	GEOGRAPHICAL INFORMATION SYSTEMS
GWP	GLOBAL WATER PARTNERSHIP
ICM	INTEGRATED CATCHMENT MANAGEMENT
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
IWRM	INTEGRATED WATER RESOURCE MANAGEMENT
MAR	MEAN ANNUAL RUNOFF
NAEBP	NATIONAL AQUATIC ECOSYSTEM BIO-MONITORING PROGRAMME
NAEHMP	NATIONAL AQUATIC ECOSYSTEM HEALTH MONITORING PROGRAMME
NDP	NATIONAL DEVELOPMENT PLAN
NEMA	NATIONAL ENVIRONMENTAL MANAGEMENT ACT
NIWIS	NATIONAL INTEGRATED WATER INFORMATION SYSTEM
NMMP	NATIONAL MICROBIAL MONITORING PROGRAMME
NWA	NATIONAL WATER ACT
NWRS	NATIONAL WATER RESOURCE STRATEGY
ORASECOM	ORANGE-SENQU RIVER COMMISSION
POPS	PERSISTENT ORGANIC POLLUTANTS

RDM	RESOURCE DIRECTED MEASURES
REMP	RIVER ECO-STATUS MONITORING PROGRAMME
RHP	RIVER HEALTH PROGRAMME
RQO	RESOURCE QUALITY OBJECTIVES
SADC	SOUTHERN AFRICAN DEVELOPMENT COMMUNITY
SANBI	SOUTH AFRICAN NATIONAL BIODIVERSITY INSTITUTE
TDA	TRANSBOUNDARY DIAGNOSTIC ANALYSIS
TDS	TOTAL DISSOLVED SOLIDS
UNDP	UNITED NATIONS DEVELOPMENT PROGRAMME
WAR	WATER ALLOCATION REFORM
WCWDM	WATER CONSERVATION AND WATER DEMAND MANAGEMENT
WHO	WORLD HEALTH ORGANISATION
WMA	WATER MANAGEMENT AREA
WMS	WATER MANAGEMENT SYSTEM
WQMT	WATER QUALITY MANAGEMENT TOOL
WRC	WATER RESEARCH COMMISSION
WSA	WATER SERVICES ACT
WSDP	WATER SERVICES DEVELOPMENT PLAN
WUA	WATER USER ASSOCIATIONS

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CHAPTER 1: BACKGROUND AND INTRODUCTION

Natural river water flows have been greatly altered by the construction of reservoirs and inter-basin transfers. The usage of water domestically, industrially and agriculturally throughout history has also altered water quality (DST, 2010; Gregory, 2006; Ludwig *et al*., 2013; DWS, 2013a; DWS, 2016). Temporal land use change from natural land cover to largely anthropogenic use has had a big impact on the quantity and quality of water resources in South Africa (Gregory, 2006). This has led to the over exploitation of South Africa's already stressed water resources. Pressure on water resources is expected to increase as the population increases and the economy of the country grows (Ngcobo *et al.*, 2013; DST, 2010; McKenzie & Craig, 2001; Viljoen & Armour, 2002).

The monitoring and assessment of rivers is crucial for the measurement of the status of river ecosystems and can provide an early warning system for management intervention with regard to water quality and quantity. However, water quality management can be more complicated in rivers that have transnational boundaries such as the Orange River (Chapman, 1996; DWS, 1996; ORASECOM, 2008; Langhans *et al.*, 2013; Rivers-Moore *et al.*, 2013; DWS 2016).

The Lower Orange River is the most important source of surface water to the largely arid Northern Cape Province of South Africa. The area constitutes the largest portion of the Lower Orange Catchment. For most of the Catchment, the river is the only source of water and there is the need to preserve it for all water use sectors in the future. Therefore, management of the river is important for economic, social and ecological development (DWS, 2004b; ORASECOM, 2008; DWS 2016).

International water protection laws are created to assess the ecological standing of freshwater ecosystems, to classify sources of poor river conditions, and control the attainment of good river quality and are employed in response to the deteriorating conditions of river ecosystems across the world (Seyam *et al.*, 2003; Langhans *et al.*, 2013; Rivers-Moore *et al.*, 2013; ORASECOM, 2008). Meanwhile, the protection, development, management, use, conservation and control of South African water resources in accordance with the National Water Act (NWA) No. 36 of 1998 are outlined in the National Water Resource Strategy (NWRS) and now in the NWRS 2 (DWS, 2004a; Nastar & Ramasar, 2012; DWS, 2013b; Bourblanc & Blanchon, 2013). The Water

Services Act (WSA) No. 108 of 1997 also tasks local authorities to ensure that the water resources of the country are of good quality for the sustenance of human and ecological health. These injunctions are in put in place to reduce and minimise cross-boundary risks to, and impacts on, countries sharing water resources. This is outlined in the Water Services Development Plans (WSDP) which highlights the sustainable supply and management of the water value chain (DWS, 2013a).

In addition to basic human needs, the water status in South Africa is of concern with regard to economic growth and the needs of terrestrial and aquatic ecosystems (Viljoen & Armour, 2002; Lange *et al.*, 2007; DST, 2010; Rivers-Moore *et al.*, 2013; DWS, 2016). Aridity and water scarcity in the country has made monitoring of water resources highly critical given the importance of this resource in sectors such as energy, mining, agriculture and tourism (Swanevelder, 1981; McKenzie & Craig, 2001; Viljoen *et al.*, 2004; DWS, 2013b).

According to the Department of Water and Sanitation (2016), South Africa's water quality management strategies and practices are based on the following:

- Management of water quality must be carried out in an integrated and holistic manner, acknowledging that all elements of the environment are interrelated.
- Decision-making must ensure that the best practicable environmental option is adopted by taking account of all aspects of the environment including all the people in the environment.
- Precautionary approach to water quality management applies, in which active measures are taken to avert or minimise potential risk of undesirable impacts on the environment.
- In general, the principle of Polluter Pays, applies. In accordance with this principle, the cost of remedying pollution, degradation of resource quality and consequent adverse health effects, and of preventing, minimising or controlling pollution is the responsibility of the polluter.
- Participative management in the management of water quality must be advocated, ensuring that all interested and affected parties, and previously disadvantaged persons have an equal opportunity to participate.
- Transparency and openness must underlie all decision-making processes, and all information must be made accessible in accordance with the law (WQM in SA).

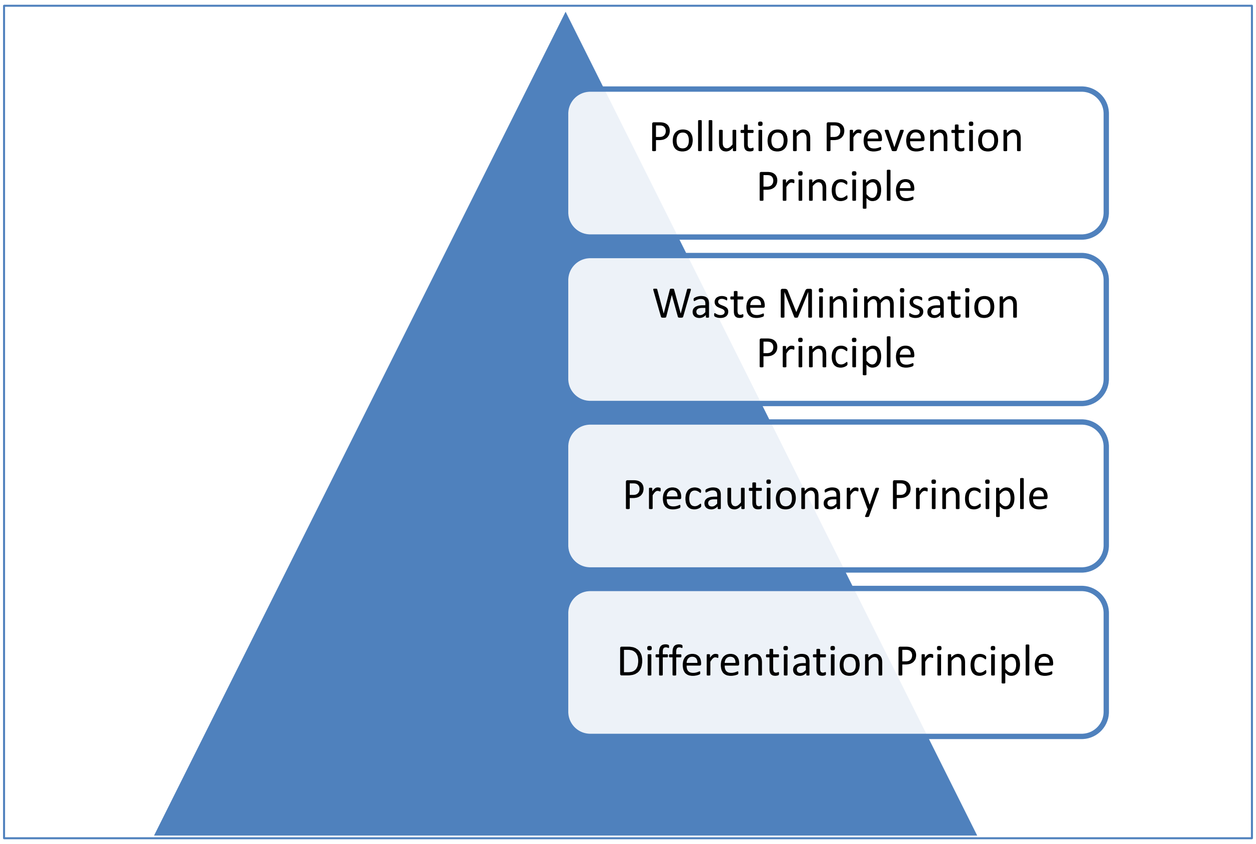

Figure 1.1: Hierarchy of water quality decision making (DWS, 2016)

Figure 1.1 shows the water quality decision making process which involves the following principles:

- Prevention principle: The prevention of pollution to water resources and the production of waste;
- Waste minimisation principle: The reduction of inevitable waste production. This may include recycling and re-use;
- Precautionary principle: Applicable where there is no alternative to the disposal or discharge of waste. Waste discharge standards and requirements are then applied.
- Differentiation principle: This is the relaxation of the precautionary principle where the receiving environment is able to withstand the additional waste discharged. Technology and socio-economic impacts are considered and can be used for justification of the additional discharge.

1.1 Water quality monitoring

According to Chapman (1996), pollutants can enter a water body in multiple ways. These sources include the following:

- Atmospheric sources: Deposition of contaminants either as solutes in precipitation or in particulate form. Occurs over a wide area where they are spread over the soils, forest or water surface.
- Point sources: Occurs through a single outlet that discharges effluents directly into a water resource.
- Non-atmospheric diffuse sources: Cannot be associated with a single point or activity. They may include domestic, urban or agricultural runoffs.

Water quality monitoring is the identification and measurement of the impacts of these pollutants on a river as well as its fitness for purpose. Monitoring is important for the purpose of measuring the status of river ecosystems and can provide early warnings for management intervention. This applies to both water quality and quantity.

An effective water quality monitoring network should be spread throughout the length of a river catchment and its potential sources of pollution. The monitoring network needs to be able to detect variations in water quality both temporally and spatially. Water management requires an understanding of the catchment and its properties such as geology, flow, biota, vegetation, and the location of point and non-point sources (Chapman, 1996; Lange *et al.*, 2007; Rivers-Moore *et al.*, 2013). This enhances the need for adequate research into the representative positioning of each monitoring point (DWS, 2004a).

The selection of the water quality parameters measured comes from this understanding and the potential natural or anthropogenic impacts anticipated. However, the parameters to be measured can at times dependent on economical means (Chapman, 1996). This then determines the methods and the frequency of the analysis of the water quality. The monitoring site and its location – for those areas that may need specialised vehicles or tools to access – may potentially be affected by budget constraints.

1.2 Integrated Water Resource Management

Concepts such as Integrated Water Resource Management (IWRM) were introduced to enhance the sustainable use and management of watercourses such as the Orange River (Agyenim & Gupta 2012; Ludwig *et al*., 2013; DWS, 2016). The Global Water Partnership (GWP) [2014] defines IWRM as

> A process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (The Need for an Integrated Approach).

Although IWRM focused initially on predicting future fluctuations in the bio-physical river system, water quality is now one of its central concerns in terms of what is deemed good management. The historical concept of single sector focus in water management organisations has proven to be unsuccessful in dealing with the multi-dimensional nature of water (Agyenim & Gupta, 2012).

Due to limited availability and the deteriorating quality of water resources, more comprehensive management plans are required. The management of water quality in any river catchment requires an integrated approach. Such an approach includes consideration of impacts from all users be it through abstraction, storage, processing or discharge into the aquatic or terrestrial environment. This approach encompasses not only economical returns, but also social and ecological issues while promoting equitable and sustainable access to water resources. The collection and sharing of water quality data among the different water use sectors is also vital for sustainable use of water resources (Seyam *et al.*, 2003; ORASECOM, 2008; Savenije & Van der Zaag, 2008; Braid & Görgens, 2010; DWS, 2013b; Ludwig *et al*., 2013; Rivers-Moore *et al.*, 2013;).

There are four main dimensions (Figure 1-2) required for water resource management according to Savenije & Van der Zaag (2008) and Braid & Görgens (2010):

1. Water resources: Refers to the resource itself. It takes into consideration the flow of water through the hydrological cycle and factors that affect it along this cycle.
2. Water users: Human users, their needs and the sectors they use/need the water in.

3. Spatial scale: Distribution of water resources and their uses throughout the country. This also considers the water management scale of the resource – individuals versus water boards.
4. Temporal scale: Time-based variance in water use, availability and demand. It also takes into consideration the physical structures built over time in order to match demand with supply (dams, etc.). Water quality changes with time are also monitored for effective resource management.

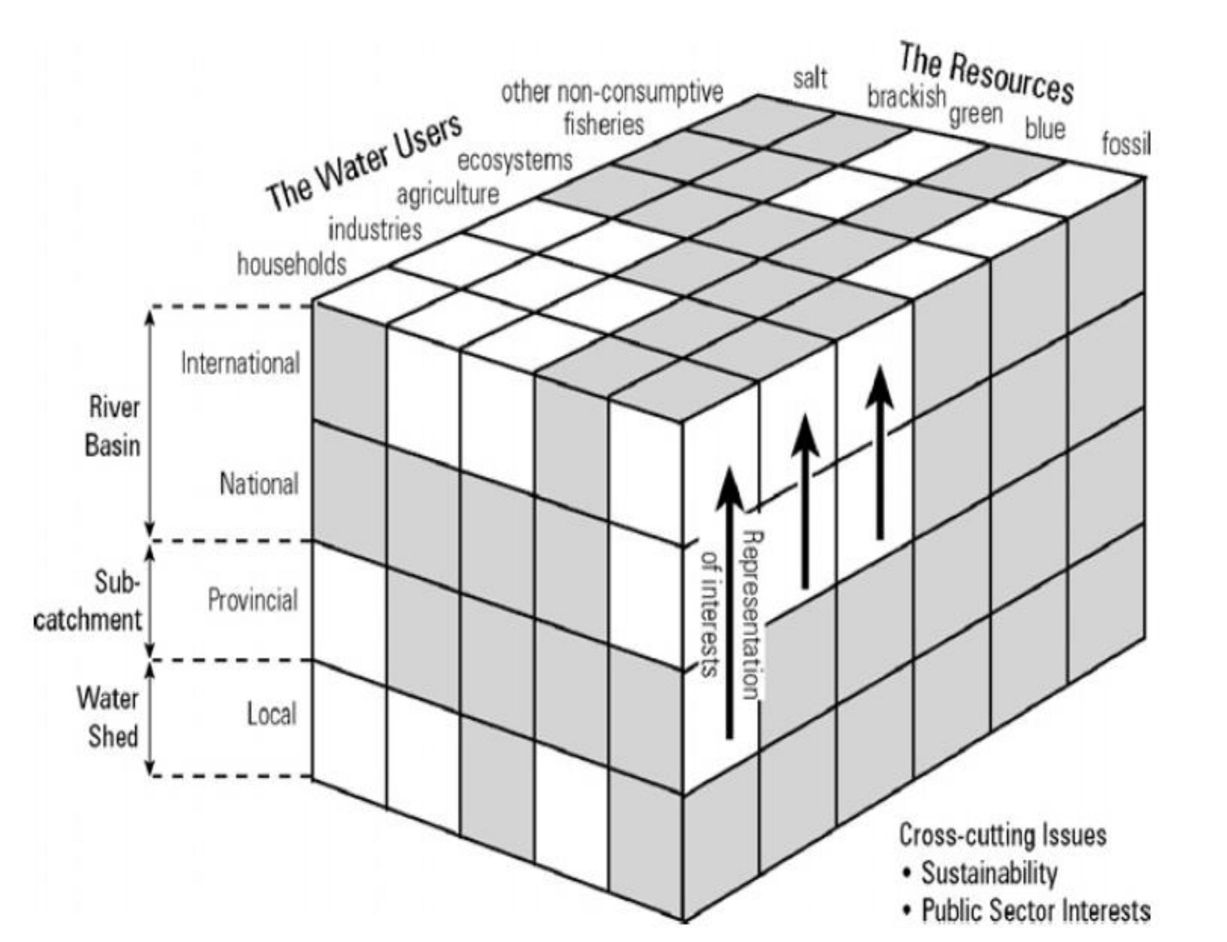

Figure 1-2: Dimensions of IWRM according to Savenije & Van der Zaag (2008)

Increasing demand for good quality water associated with socio-economic development puts additional stress on already stressed water resources. Table 3 outlines additional aspects to be taken into consideration for adequate implementation of IWRM. According to Agyenim & Gupta (2012), IWRM is important for the following reasons:

a) Complete approach to water management in that all sectors, all water types and all ecological resources are considered simultaneously. Furthermore, it reaffirms an environmental approach to the use of land and development.
b) Links the biophysical environment to livelihoods of all users in the catchment and the reliance on water in particular.
c) In line with new management tactics of greater stakeholder participation in the policy making process;
d) Promotes good water governance in the form of coordination and stakeholder involvement in the decision making process.

Table 1: Understanding of IWRM (Agyenim & Gupta, 2012; DWS, 2013b)

Integration	**Definition**
Sectoral integration	The IWRM entails the use of various water types (agricultural, industrial, domestic etc.) and the various water use sectors to coordinate plans, technologies, tools and programmes for sustainable water resource management.
Integration of water resources management in the broader development context	The use of IWRM to link social, economic and environmental development to adequate prior planning that meet a nation's complete developmental necessities.
Water as an integral part of the ecosystem	Involves the consideration of both socio-economical needs and the aquatic ecosystem (animal and vegetation) requirements together with a country's use of land and developmental projects.
Spatial integration	The incorporation of both downstream and upstream use into a single-focus unit recognising the common reliance on the water resource.
Blending of actions and objectives	The blending of programmes and objectives that are considered important by all stakeholders in order to ensure effective and sustainable use of water resources.

Integration	Definition
Political, Technical Cooperation, and Legal pillars	The development of IWRM policies and legislation that identify gaps in data and supports the distribution of this data amongst local, provincial and national institutes with other catchment management agencies and/or boards.
Supply and Demand	The sustainable management of demand of water to ensure that supply is met. The implementation of good Water Conservation and Water Demand Management (WCWDM) is vital in this regard.

The identification of both ecological and socio-economical needs of the system should result in the implementation of good resource management policies and tactics. The control of both abstraction rates and discharge quality into the resource should also be considered and monitored accordingly (Savenije & Van der Zaag, 2008; Braid & Görgens, 2010).

1.3 Water management authorities and institutions

The Orange-Senqu River Catchment system, located in the territories of South Africa, Botswana, Lesotho and Namibia, is an important international river system for the Southern African region. Transboundary bodies such as the Orange-Senqu River Commission (ORASECOM) were established between member states in the region to provide a platform for coordinated water resource management for the river (Viljoen *et al.*, 2004; ORASECOM, 2007a; Lange *et al.*, 2007; ORASECOM, 2008).

Many communities in the Southern African Development Community (SADC) rely on water produced outside their country's boundaries for approximately more than half their water supply. South Africa, Namibia, Lesotho and Botswana have varying degrees of dependency on the Orange River System for the provision water for mining, manufacturing, energy production, ecological conservation, agriculture and domestic use (ORASECOM, 2008; DWS, 2013b; Lange *et al.*, 2007; Braid & Görgens, 2010; DWS, 2013b; Deksissa *et al.,* 2003).

Table 2 shows the area and rainfall contributions of the countries within the Orange River Catchment indicating that most of the catchment area is located within South Africa, while Lesotho contributes more in terms of rainfall (ORASECOM, 2008).

Table 2: Area and rainfall of the Orange River Catchment by country (Lange *et al*., 2007)

Country	Total area of the country (km^2)	Area of the country within the basin (km^2)	Total area of basin (%)	Total area of country (%)	Average annual rainfall in the basin area (mm)		
					Min.	Max.	Mean
Botswana	581,730	71,000	8	12	165	520	295
Namibia	824,900	219,249	25	27	35	415	185
Lesotho	30,350	30,350	3	100	575	1040	755
South Africa	1,221,040	575,769	64	47	35	1035	365
Orange River Catchment		**896,368**	**100**		**35**	**1040**	**325**

Throughout history, water quality management has very rarely involved the control of pollution in the treaties signed by countries which share water resources. Quite often, economic development becomes the primary focus of such bilateral agreements. According to Shmueli (1999),

> The combination of scientific findings that have exposed water pollution hazards, and aroused public concern, has now given political prominence to water pollution issues. Both a cause and a result of this prominence is that pollution measurement has become more accurate, and the identification of pollution causes has become more sophisticated (p. 438).

Unfortunately, due to deteriorating water quality, the control of pollution and its sources are now taking centre stage in these agreements (Chapman, 1996; Preul, 2014; Sharma, 2014).

1.4 The Orange River Catchment

A water catchment is commonly known as an area of land where rainfall collects and drains off into a common channel. With an approximate westerly direction and a length of 2 300 km, the Orange River constitutes the biggest water catchment in South Africa, with more than 20% of the country's total river flow. This is demonstrated in Table 3 which also shows that the system drains more than 48% of the country's surface land area. The mean annual precipitation of the Catchment ranges from 2000 mm in highlands of Lesotho, to approximately 40 mm towards the river mouth at Alexander Bay. Therefore, very little rainfall is contributed by the lower reaches of the river (Swanevelder, 1981, Viljoen *et al.*, 2004; Lange *et al.*, 2007; ORASECOM, 2007a; ORASECOM, 2008; Rouby *et al.,* 2009).

Table 3: Rainfall per South African Catchments (Swanevelder, 1981; DWS, 2004a)

Region	**Total Drainage Area (km^2)**	**Total Area (%)**	**Average Annual Runoff (m^3 x 10^6)**	**Total Runoff (%)**
Limpopo-Sabic	211 700	16.9	8 490	16.6
Orange River (Vaal included)	606 100	48.5	11 370	22.2
West Coast	77 500	6.2	1 090	2.1
South West Coast	40 800	3.3	4 100	8.0
South Coast	87 000	6.9	1 910	3.7
East Coast	227 100	18.2	24 340	47.4
Total	**1 250 000**	**100**	**51 300**	**100**

Approximately 15 km west of the Northern Cape town of Douglas, the Orange River is linked with its most significant tributary, the Vaal River. Despite being the longer of the two before the confluence, the Vaal River is, in fact, the smaller of the two rivers. The Vaal River drains the major population, mining and industrial regions of the country. The combination of these factors have resulted in the deteriorating quality of water supplied to the Orange River below the confluence (Swanevelder, 1981; Viljoen & Armour, 2002; ORASECOM, 2007a; ORASECOM, 2008).

Seyam *et al. (*2003) defines the value of a water particle as the route it would follow within the hydrological cycle and its associated value along this path. Given its contribution to the socio-economic development of its adjacent water users – commercial and domestic – the value of the Lower Orange River to the region cannot then be overstated (Swanevelder, 1981; Viljoen *et al.*, 2004).

1.5 Catchment management

Macleod *et al.* (2007) supports the idea of Integrated Catchment Management (ICM) in which policies, legislation, science and management are integrated in order to achieve the goal of sustainable catchment management. ICM requires the combination of current and future legislation and policies for proper usage of water resources, including water quantity and quality (Seyam *et al.*, 2003; Viljoen *et al.*, 2004; Macleod *et al.,* 2007; Savenije & Van der Zaag, 2008; GWP, 2014).

The provision of good quality water is an important function of sustainable catchments. In 2004, the NWRS created 19 Catchment Management Agencies (CMA) to operate within 19 Water Management Areas (WMA). The CMAs were originally envisioned to manage South African water resources in hydrological defined areas as shown in Figure 1-3 (DWS, 2004a; Macleod *et al.,* 2007; ORASECOM, 2007a; Savenije & Van der Zaag, 2008; ORASECOM, 2008; Braid & Görgens, 2010).

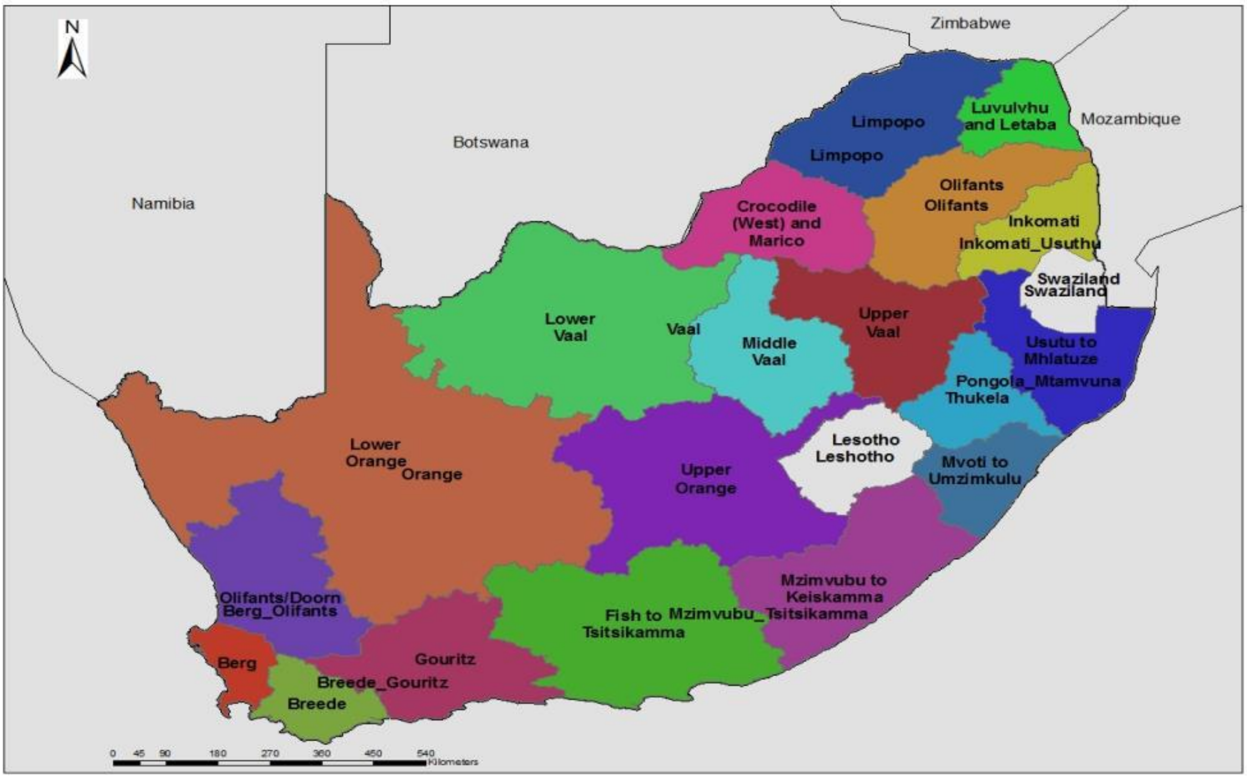

Figure 1-3: Original 19 South African WMAs

Not all CMAs however, have been fully delegated with the power and financial means to handle the responsibility. In order to address this and other issues, such as capacity and skills, the new NWRS 2 outlined the consolidation and establishment of only 9 CMAs (Figure 1-4) (DWS, 2004b; DWS, 2013b). The implementation of the strategy would be the first step towards good water quality management not only in the Lower Orange River system but also in the country as a whole (DWS, 2004a).

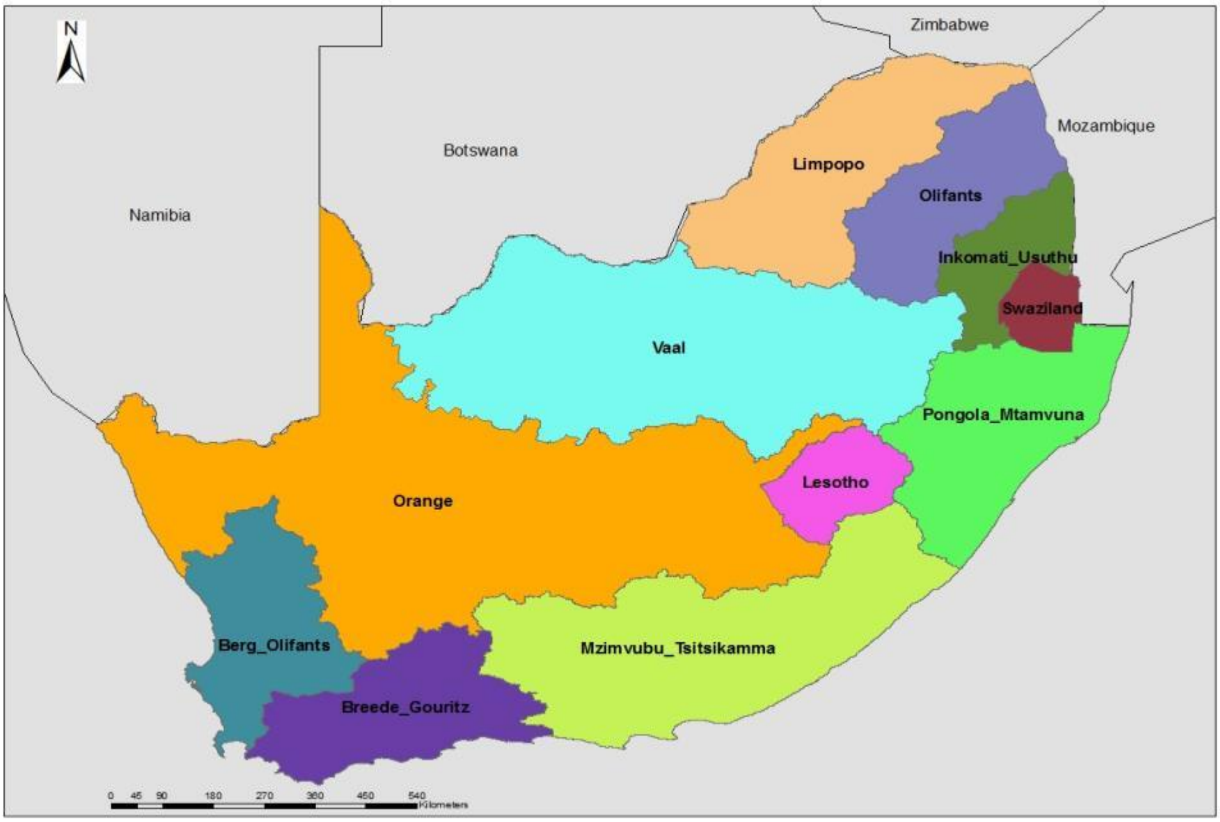

Figure 1-4: Proposed new 9 WMAs

South Africa has a history of inequitable access to water resources. In order to address past imbalances in water allocation, a Water Allocation Reform (WAR) was proposed. The ultimate aim of streamlining WAR and environmental flow monitoring programmes – including biological, chemical and physical water quality – however remains an important challenge. South Africa's National Development Plan (NDP) recognises the need to balance social and ecological needs with the economic needs of the country and the sustainable supply of good quality water should also be part of this vision (DWS, 2013b).

Although various countries, including South Africa, have adopted the principles of IWRM and ICM, its implementation remains a challenge. Water is still, unfortunately, still either seen as an economic commodity or a “heritage of humankind” but typically not both (Agyenim & Gupta, 2012). The linking of these schools of thought is required so that water quality monitoring is seen as a vital component for overall development.

1.6 Problem statement

Sections of the Lower Orange River in the Northern Cape have over the years experienced significant changes in water quality. Some of the well-known water quality parameters (such as pH; phosphorous and nitrogen; electrical conductivity; dissolved solids and coliforms) have recorded temporal increases in magnitude while new major components of water quality have also emerged.

Water quality deterioration in the Orange River System is cumulative from the upper to lower parts of the Catchment and several studies have attributed these changes to new land use mechanisms in the Catchment as well as the expansion of existing practices that impact on the Orange River.

The main tributary, the Vaal River, flows from highly industrialised and mined areas in the upper-to-middle Catchment to highly irrigated areas in the middle-to-lower reaches. Gold and coal mining take place in the upper Catchment while the middle to lower Catchment is characterised by alluvial diamond mining. The quality of water that comes downstream from the Vaal River into the Orange River greatly impacts on the general water quality in the Orange River.

The current water quality monitoring networks, which are managed by the Department of Water and Sanitation, have not been able to monitor these continual changes temporally and spatially. The target of generating reliable and representative data, which is the main aim of water quality monitoring, has not often been met by these current networks. The actual parameters that influence water quality have not always been accurately reflected. As a result, the integrity of the Lower Orange River water quality has been compromised as a consequence of the gap between data collection and water resource management.

This study evaluated the current water quality of the Lower Orange River investigating the following: The identification and understanding of the current water quality networks and their measured parameters; an analysis of the current and historic water quality trends through mobile monitoring and a comparison of these trends against regulatory requirements. The ultimate purpose was the improvement of monitoring and mitigation measures to support catchment management decisions.

Broad participation in water resource protection and management can be stimulated by clear communication, inclusive stakeholder participation, improved monitoring and analyses of river water quality status. Trend analysis can be used as an early indicator for management changes required to maintain the integrity of the Lower Orange River leading to improved water quality and satisfied stakeholders. For some stakeholders, complex statistical analysis can be useful in setting long-term management and pollution prevention goals. For others, the use of graphs and maps created through software such as Geographical Information Systems (GIS) may provide useful information, while still others need a simple variable statistic for managing purposes. For all users, the accuracy of the data as well as the accurate representation of data is vital for improved participation.

1.7 Aim and objectives of the study

1.7.1 Aim

The study compared the historic water quality parameters of the Lower Orange River in the Northern Cape to the present parameters of water quality through a trend analysis (audit) of the present monitoring data versus historic data. These water quality trends of the Lower Orange River were also analysed with regulatory requirements in mind for the purpose of ultimately providing a decision making tool for the resource quality objectives of the Orange River.

1.7.2 Objectives

1. To identify and understand the current water quality monitoring network and chemical parameters measured in the Lower Orange;

2. To compare the current water quality status to historic records and regulatory requirements;

3. To provide improved monitoring and mitigation procedures required for the effective water quality monitoring of the Lower Orange and support management decision making.

1.8 Research hypothesis

The water quality of the Orange River has been constantly deteriorating through the years as a result of mining, agricultural activities, ageing urban infrastructure and increased industrial discharges. Water infrastructure, such as dams and weirs, also reduce the natural flow patterns of the river and can decrease the efficiency of processes such as dilution together with its potential to improve water quality through 'flushing'. The relationship between temporal and spatial water quality changes can be used to support the management of water resources. Current monitoring networks have not adequately kept pace with these changes and thus improved monitoring methods are required to provide accurate 'real time' data for improved management decision making. Can the water quality management of the Lower Orange River be improved to adequately manage the water resource?

1.9 Organization of the dissertation

The dissertation is arranged into six chapters:

Chapter 1 provides the background to the study, the statement of the problem, the study aims and objectives and hypothesis.

Chapter 2 covers the description of the study area in terms of the location, topography, geology, land use, climate, socio-economic outlook and vegetation.

Chapter 3 provides the literature review on the general hydrology of the Lower Orange River, major water quality constituents, the position of the National Water Act No. 36 of 1998 on water quality in the Lower Orange, the potential impact of the climate on the water quality and the implementation of the National Water Resource Strategy.

Chapter 4 focuses on the research methodology including instrumentation, data collection, data sources and sampling procedures.

Chapter 5 provides an analysis of the results and outcomes of the data analysis as well as an outline of the main findings of the study.

Chapter 6 is the conclusion of the study and provides recommendations for future related research.

CHAPTER 2: STUDY AREA

2.1 Location

The Lower Orange forms part of the lower sub-catchments of the larger Orange-Senqu River Catchment which drains most of Lesotho, South Africa, Botswana and Namibia (ORASECOM, 2007a; Lange *et al.*, 2007; ORASECOM, 2008). This system drains the interior of South Africa towards the west into the Atlantic Ocean forming a flowery ribbon through an otherwise arid region that mostly falls within the Northern Cape Province of South Africa (DWS, 2004b). The research area starts from the confluence with the Vaal River at Douglas, all the way to the mouth where the Orange River flows into the Atlantic Ocean at Alexander Bay. It flows in from the Free State Province through towns such as Douglas and Upington (Figure 2-1).

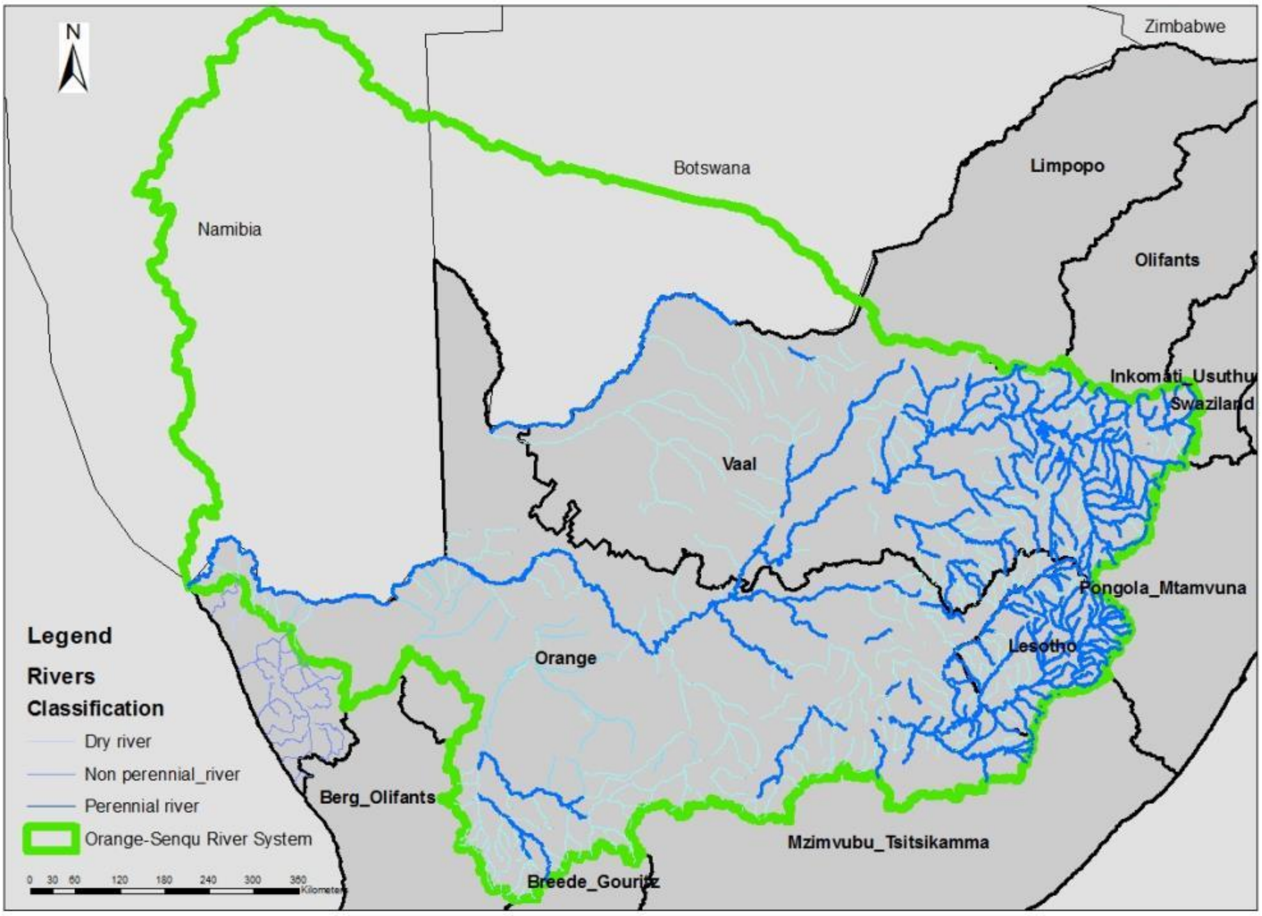

Figure 2.1: Orange-Senqu River Catchment

Most of the study area lies within the largest and most scarcely populated South African province of the Northern Cape (Figure 2-2). The Orange River finally forms the national border with Namibia to the northwest (Lange *et al.*, 2007).

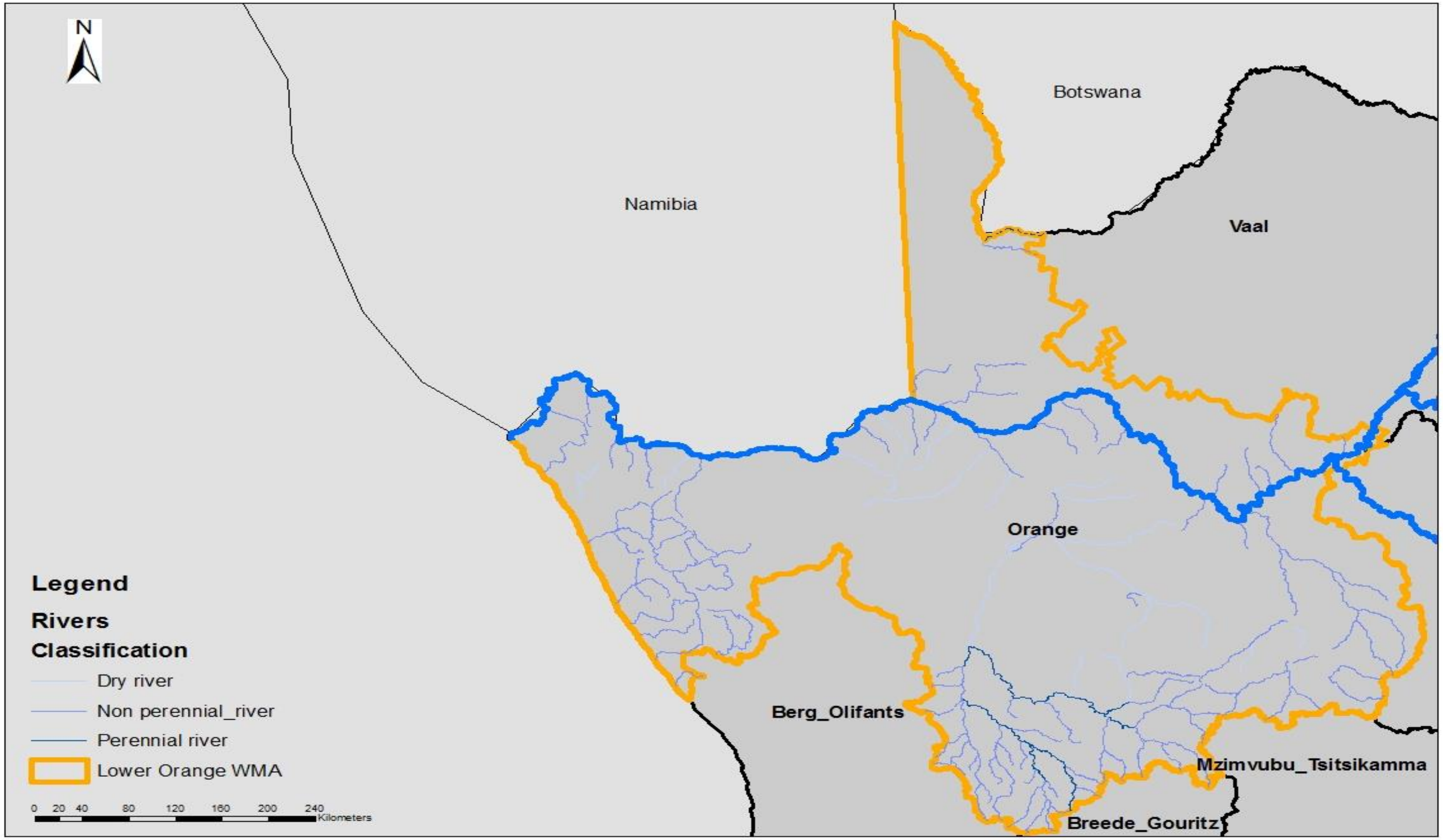

Figure 2-2: Lower Orange located within the Northern Cape

2.2 DWS monitoring network

The DWS has a total of approximately 6559 water quality sampling points nationally. These points are used to provide a comprehensive assessment of the overall water quality status of the country's water resources. Water quality monitoring generally starts at different time periods depending on the needs of a river system.

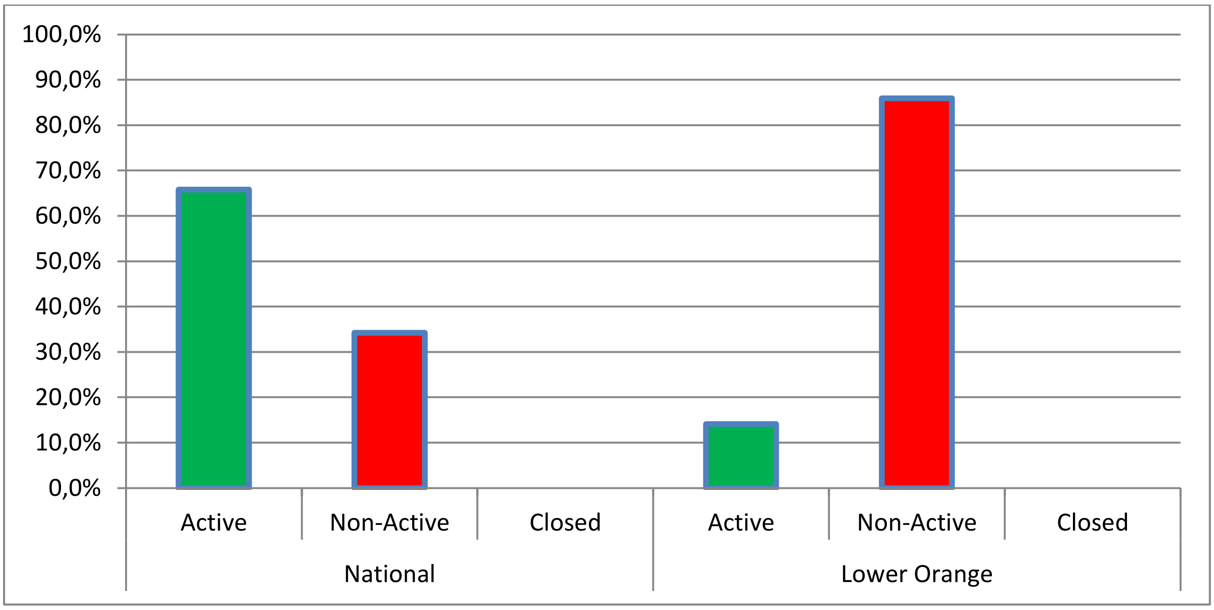

Figure 2-3: Status of the total water quality monitoring stations in the Lower Orange

In contrast to the national status (Figure 2-3), the Lower Orange has the majority of its water quality monitoring points classified as inactive. Reasons such as lack of funding and a lapsed contract with an accredited laboratory are given for the lack of monitoring for most of the sites. The fact that 86 % of the sites are inactive is cause for concern. No sites have been closed.

The water quality monitoring points in the Lower Orange river are predominately positioned in the upper part of the river. They are centred on the confluence (Douglas) and the larger town of Upington further downstream. This is due to the potential impact from the Vaal River as well as the large agricultural and mining activity concentration from the confluence area.

These national monitoring points are positioned to give a representative understanding of the country's water resources. They are also designed to cover various water resources, watercourses and water use sectors. This includes both surface water and groundwater resources. As shown in Figure 2-4, the majority (85.4%) are groundwater monitoring points due to the arid conditions found in the majority of the Catchment (Karoo Region).

Most of the water use activities in the Catchment rely solely on groundwater for survival. The correlation between the number of monitoring points in the river and transfer schemes into the Catchment indicates the aridity of the region and its reliance on water sourced from external Catchments (upstream Lower Vaal and Upper Orange).

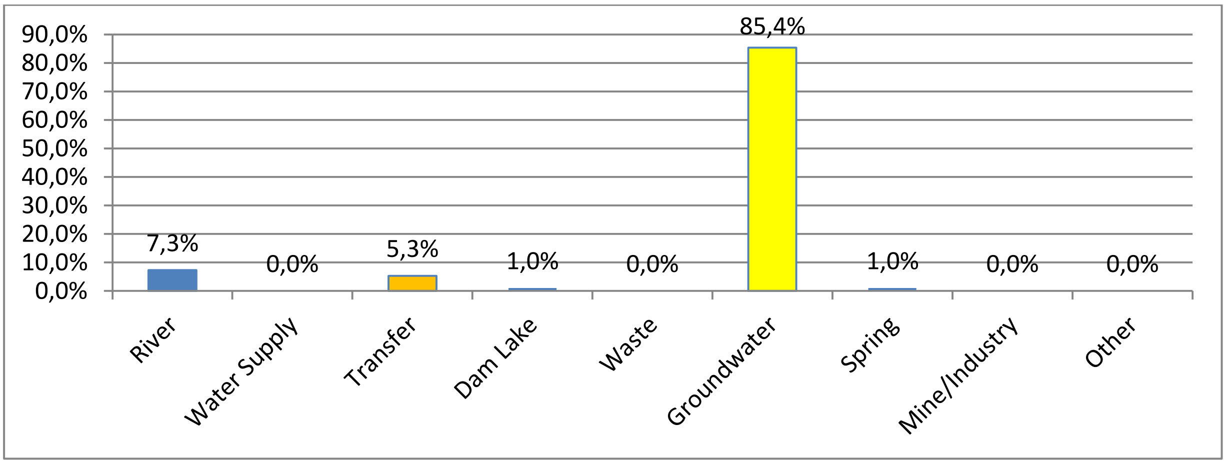

Figure 2-4: Types of water quality monitoring stations in the Lower Orange River

The Lower Orange region does not have major towns or industries along the Orange River other than Upington which is the largest urban settlement. However, given the numerous agricultural activities and the length of the river, attention should be given to the low number of monitoring points serving this part of the Orange River System. Diamond mining activities are found close to the mouth and also upstream of the estuary. However, there are no active monitoring points found upstream and downstream of these mining activities. This should also be a cause for concern.

According to Table 4 the Lower Orange has 18 water quality monitoring and sampling points (ordered upstream to downstream) along the Orange River. These are points registered on the DWS WMS / NIWIS databases. These sites are located along the river itself or in dams / barrages and canals found along the river. All these dams, barrages and canals receive water diverted or impeded (according to Section 21 (c) water use) directly from the Orange River.

Table 4: Water quality monitoring points in the Lower Orange (Fig.2-5)

No.	WMS Site Code	DWS Site Code	Site Name	First Sample Date	Last Sample Date	Site Type	° Latitude	° Longitude
1	WMS101824	D3H008Q01	Marksdrift	29/03/1966	12/09/2018	Orange River	-29.161667	23.696389
2	WMS90905	C9H017Q01	St. Clair Douglas Bucklands Canal	10/12/1992	19/06/2018	Canal	-29.045306	23.835917
3	WMS90907	C9H019Q01	Atherton 82 Canal	09/12/1992	28/10/2015	Canal	-29.043306	23.832222
4	WMS101771	C9H025Q01	St. Clair 148 Douglas Oranje-Vaal Canal	13/12/1995	23/09/2015	Canal	-29.047262	23.839129
5	WMS101787	C9R003Q01	St. Clair 148 Douglas Vaal River	03/10/1977	01/04/2016	Dam/ Barrage	-29.043306	23.836917
6	WMS101830	D3H019Q01	Nottingham 153 Oranje-Vaal Canal	15/02/1995	02/02/2016	Canal	-29.152889	23.702
7	WMS101881	D7H012Q01	Irene	27/02/1989	19/06/2018	Orange River	-29.1825	23.575556

No.	WMS Site Code	DWS Site Code	Site Name	First Sample Date	Last Sample Date	Site Type	° Latitude	° Longitude
8	WMS101874	D7H002Q01	Prieska	24/10/1952	17/04/2018	Orange River	-29.655895	22.745965
9	WMS101886	D7R001Q01	Boegoeberg Dam wall	01/04/1996	13/01/2014	Dam/ Barrage	-29.042194	22.201917
10	WMS101877	D7H005Q01	Upington	01/11/1965	26/02/2016	Orange River	-28.460806	21.248889
11	WMS101878	D7H008Q01	Boegoeberg Reserve/ Zeekoebaart	01/04/1966	18/04/2017	Orange River	-29.029694	22.187778
12	WMS101883	D7H014Q01	Kakamas South/ Neusberg Left Side	02/01/1995	05/08/2015	Orange River	-28.768056	20.720556
13	WMS101884	D7H015Q01	kakamas South Canal/ Neusberg	01/08/1994	19/08/2015	Canal	-28.769429	20.719501
14	WMS101885	D7H016Q01	Kakamas North Canal/ Neusberg	25/08/1995	29/05/2015	Canal	-28.766097	20.720182
15	WMS182750	N/A	Volgraafsig Canal	16/10/2000	02/12/2014	Canal	-28.732861	21.84109
16	WMS182756	N/A	Bloemsmond Kanoneiland	04/08/2000	13/12/2016	Canal	-28.640583	21.064389
17	WMS101893	D8H008Q01	Pella Mission	28/04/1980	20/05/2015	Orange River	-28.963611	19.154833
18	WMS101888	D8H003Q01	Vioolsdrift	11/11/1965	14/05/2018	Orange River	-28.760806	17.730278

The quality of water in the canal systems may also not necessarily be a true reflection of the water quality in the river system. The water in such systems is not exposed to all the other environmental elements that the water-body in a river would experience. This includes the movement and dissolution of rocks and gravel in and out of current; sediments in suspension; and vegetation in and out of current (Chapman, 1996). Where there are multiple sampling points in close proximity, the point situated in the Orange River will be prioritized. This is also dependent on the availability of data at that point. Using this criterion, Table 5 demonstrates the monitoring points that are in close proximity. A representative point was selected from these monitoring points for further analysis.

Table 5: Lower Orange monitoring points and representative point selected

Monitoring Points	Representative Point
Boegoeberg Dam wall	
Boegoeberg Reserve/ Zeekoebaart	Boegoeberg Reserve/ Zeekoebaart
Volgraafsig Canal	
St. Clair Douglas Bucklands Canal	
Atherton 82 Canal	St. Clair Douglas Bucklands Canal
St. Clair 148 Douglas Oranje-Vaal Canal	
St. Clair 148 Douglas Vaal River	
Marksdrift	Marksdrift
Nottingham 153 Oranje-Vaal Canal	
Kakamas South/ Neusberg Left Side	
Kakamas South Canal/ Neusberg	Kakamas North Canal/ Neusberg (due to data availability)
Kakamas North Canal/ Neusberg	

Therefore, from the 18 monitoring points along the Lower Orange River, ultimately only 10 were utilized for analysis. These 10 points are spread along the length of the river and will provide more representative data of the water quality found in the river. Figure 2-5 illustrates the position of the monitoring sites used as part of this study.

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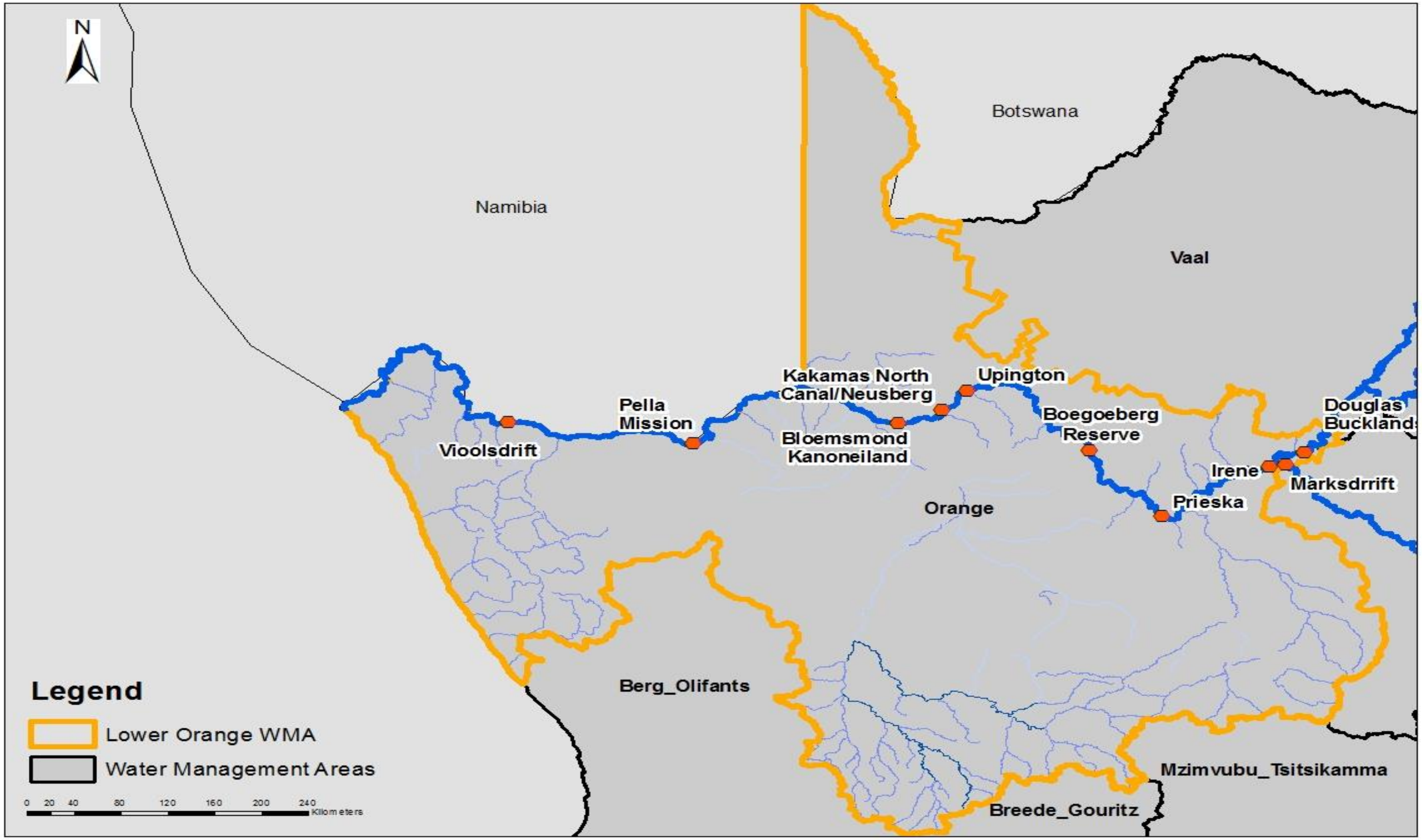

Figure 2-5: Lower Orange water quality network

There is also inconsistency between parameters measured from point to point. Table 6 shows the major water quality parameters measured in the Lower Orange's monitoring stations. These are constituents that are mostly found throughout the monitoring programme.

Table 6: Major water quality parameters measured in the Lower Orange

Major Water Quality Parameters	**Units**
TDS (Total Dissolved Solids)	Mg/L
EC (Electrical Conductivity)	mS/m
pH	*pH
Na^{+} (Sodium)	Mg/L
K^{+} (Potassium)	Mg/L
Ca^{+2} (Calcium)	Mg/L
Mg^{+2} (Magnesium)	Mg/L
Cl^{-} (Chloride)	Mg/L
SO_4^{-2} (Sulphates)	Mg/L
TAL (Total Alkalinity)	Mg/L
F^{-} (Fluoride)	Mg/L
PO_4^{-3} (Phosphates)	Mg/L
(NO_2^{-} + NO_3^{-}) (Nitrogen)	Mg/L
NH_4^{+} (Ammonium)	Mg/L

The data indicates that there are periods where little to no sampling took place. For example, there was very little sampling done for the Marksdrift site from 1966 to the 1970s, while there was no sampling at all from 1997 to 1992. The data also indicates instances (such as the Upington site) where a sample was taken, however not all parameters where measured.

2.3 Hydrology

It is estimated that most (90%) of the runoff generated in the Orange River System is generated in the Upper Orange which includes the high rainfall area in the mountainous Lesotho (DWS, 2004b). This is significant as groundwater provide very little base flow to rivers in the western part of South Africa (Hughes *et al*., 2007; ORASECOM, 2007a). The Lower Orange River Catchment system, due to a lack of rainfall, generates very little runoff itself. Most of the runoff in the Catchment is generated in the Fish River (Namibia), but this only enters the Orange River very close to the mouth.

Groundwater, however, is a very important source of water in the Lower Orange, particularly in the very dry parts such as the Karoo where it is at times the only source of freshwater. The aridity of the region also has a huge impact on the recharge potential of aquifers in the region with sustainability proving a huge challenge (DWS, 2004b). This further emphasises the importance of the Lower Orange River to the region.

2.4 Topography

The Orange River meanders from the east to the west of the country draining large parts of the country with an upstream topography that is typical of the Southern African topography at altitudes above 900m (Figure 2.2). It passes through flat plains and mountain ridges with a sharp decline in height occurring at the Augrabies Falls in the Kakamas area. The Falls also create a major tourist attraction for the region (DWS, 2004b; Rouby *et al.,* 2009).

Due to the aridity and size of the Northern Cape Province, distances between towns are large. The western coastal part is dominated by the famous flower season in the mountainous Namaqualand region. The south and south-east of the province is high lying in the Roggeveld and Nuweveld regions (Watkeys 1999).

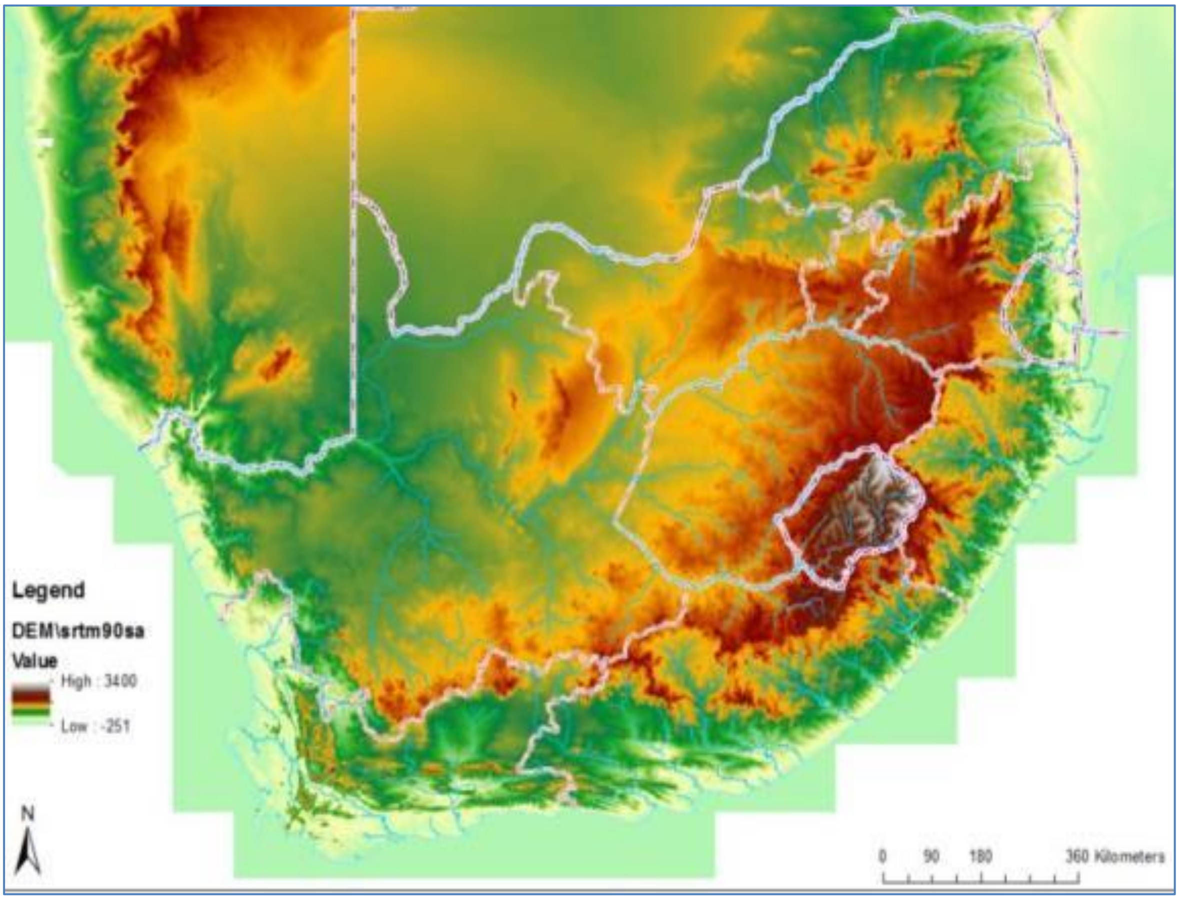

Figure 2.6: Topographical profile of South Africa

As Figures 2-6 and 2-7 show, the Orange River ranges from the high altitudes of the Lesotho highlands to the low lying areas of the Richtersveld in the west of South Africa (2700m – 200m). The highlands are responsible for most of the flow in the river system.

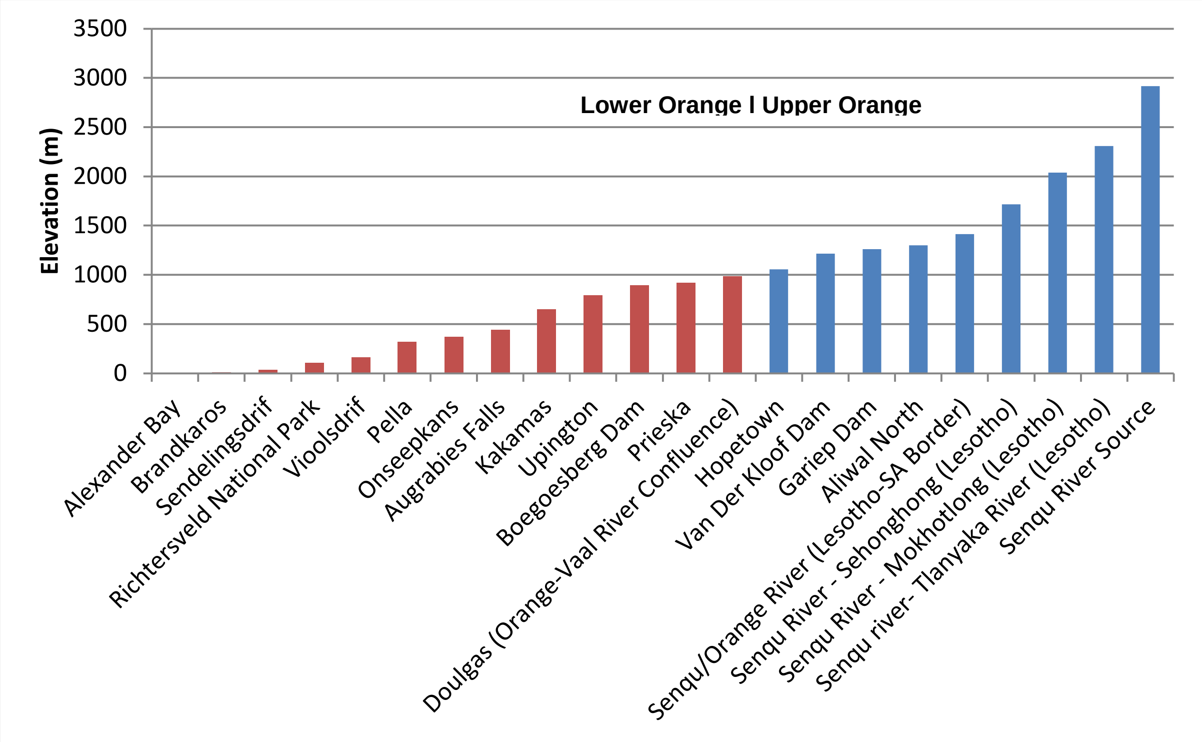

Figure 2-7: Orange River elevation profile (DWS, 2004b)

The central region of the research area is generally flat with scattered salt pans that do not contribute much in terms of runoff into the Orange River (DWS, 2004b). The Karoo region is dotted with kimberlite intrusions which are associated with diamonds that forms part of the province's most important natural resources. Alluvial diamond mining is the main mining activity along the river. The main concern when it comes to this form of mining is the increased sediment load in the Orange River. The north of the Lower Orange is characterised by red sand dunes and the acacia tree dry savannah of the Kalahari Desert (Watkeys 1999; Almond & Pether, 2009).

2.5 Geology

The underlying geology of a region can have an impact on the water quality of rivers that run over it. The geological make-up is capable of increasing and decreasing the acidity of water through processes such as weathering and hydrolysis while increasing the suspended load in river (Giller & Malmqvist, 1998).

The geology of the Northern Cape region is characterised by the Transvaal Supergroup, the Gariep Supergroup, the Dwyka and Ecca Groups and the Kalahari

Group units as Figure 2.8 shows that the Lower Orange River itself is mostly underlain by the Namaqualand-Natal metamorphic and granitic rocks which are mostly found to the west of the region. The formation is made up of schistose and gneiss meta-sedimentary, meta-volcanic and intrusive rocks. This formation is found in the area along the Orange River near Prieska in the east and all the way to the Atlantic Ocean in the west (Watkeys 1999; Lloyd 1999; CGS, 2015; GCS, 2015).

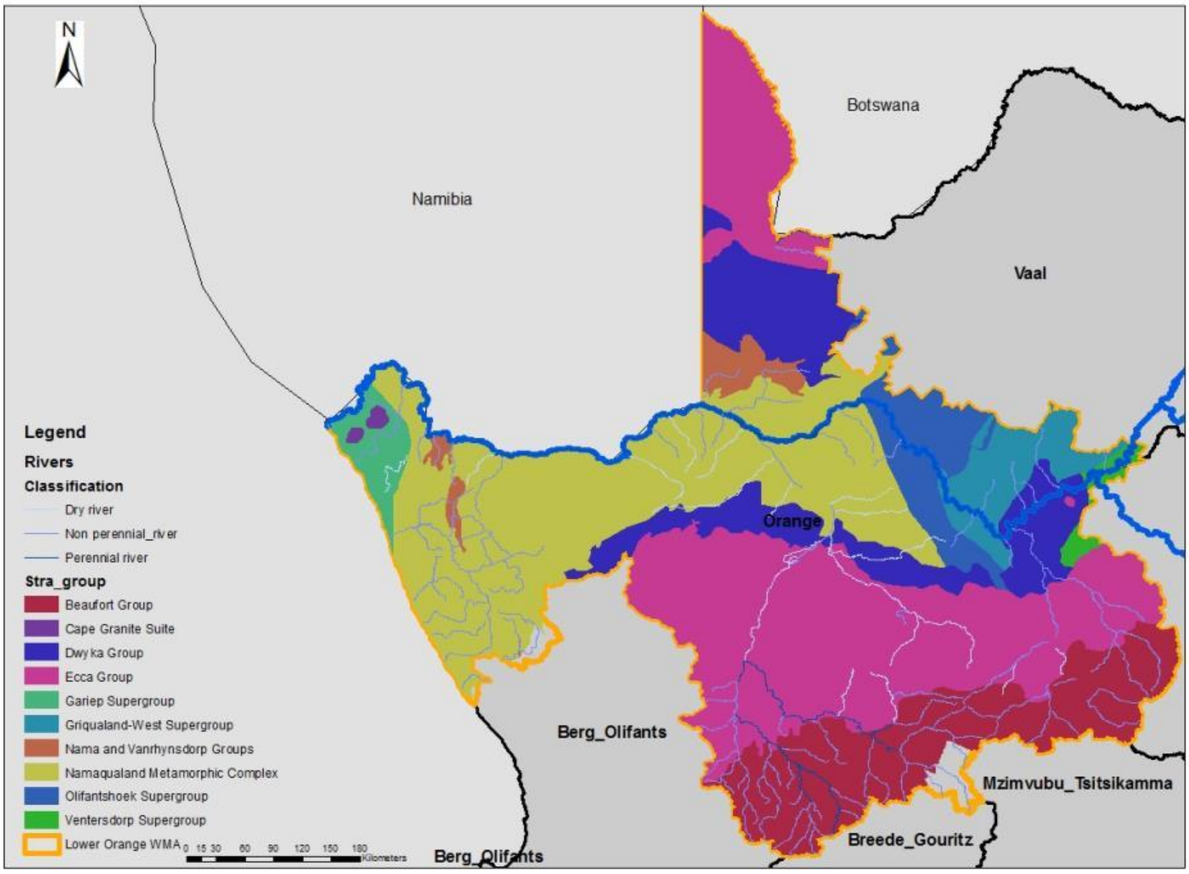

Figure 2.8: Simplified geology of the Northern Cape

2.5.1 Groundwater

The interface between the water and the rock matrix in which an aquifer is found largely determines the physical behaviour of the entire aquifer system (Woodford & Chevallier, 2002). Groundwater has been found to provide very little base flow to rivers in the western part of South Africa (Orange River System) (Hughes *et al.*, 2007; ORASECOM, 2007a; ORASECOM, 2007b). This indicates that there is very little connection between the Orange River and its adjacent aquifers. This is intriguing given the importance of both these sources of water to their respective supply areas. This may indicate a loss to the aquifer.

The rest of the Lower Orange River Catchment, except in certain areas, does not generally provide boreholes with high borehole yields (ORASECOM, 2007b; Woodford & Chevallier, 2002). This is due to the low areal extent and openings of the water-yielding fractures in the regional aquifers and limited recharge (Botha *et al.,* 1998). The aridity of the region also has a huge impact on the recharge potential of aquifers in the region, with sustainability proving a huge challenge (DWS, 2004b). This in turn, requires large expenditure projects in order to ensure supply for larger projects.

2.6 Land use

The relationship between land use and water quality varies across a catchment as pollution sources and a river's physical characteristics change. In the Lower Orange, a link between extensive land degradation, owing to overgrazing and overstocking, and its influence on the availability and quality of water resources has not yet been adequately determined. The impact of the development of large agricultural activity on natural ground and its associated impact on the erodability of the soil and underlying geology can be significant in such areas (Malan & Day, 2002; Woli *et al*., 2004; Stutter *et al*., 2007; ORASECOM, 2008; Tu, 2011). The Orange-Vaal River Catchment includes the major urban and industrial parts of South Africa. This includes the main gold mining areas, parts of the Highveld coal fields and power stations and large areas of dryland and irrigated agriculture in the arid part near the town of Upington (DWS, 2004b; ORASECOM, 2008).

Figure 2-9 shows the land cover found in the Northern Cape. Although most of the land is covered by shrub land, the most extensive man-made land use near the Orange River is irrigated agricultural activities. These activities, with their associated irrigation runoff, can alter the quality of the water in the river through return flows into the river. Land use changes can also alter the erodability of river banks (Woli *et al*., 2004; Stutter *et al.,* 2007; Tu, 2011). The monitoring of these areas can greatly aid the management of the water resources.

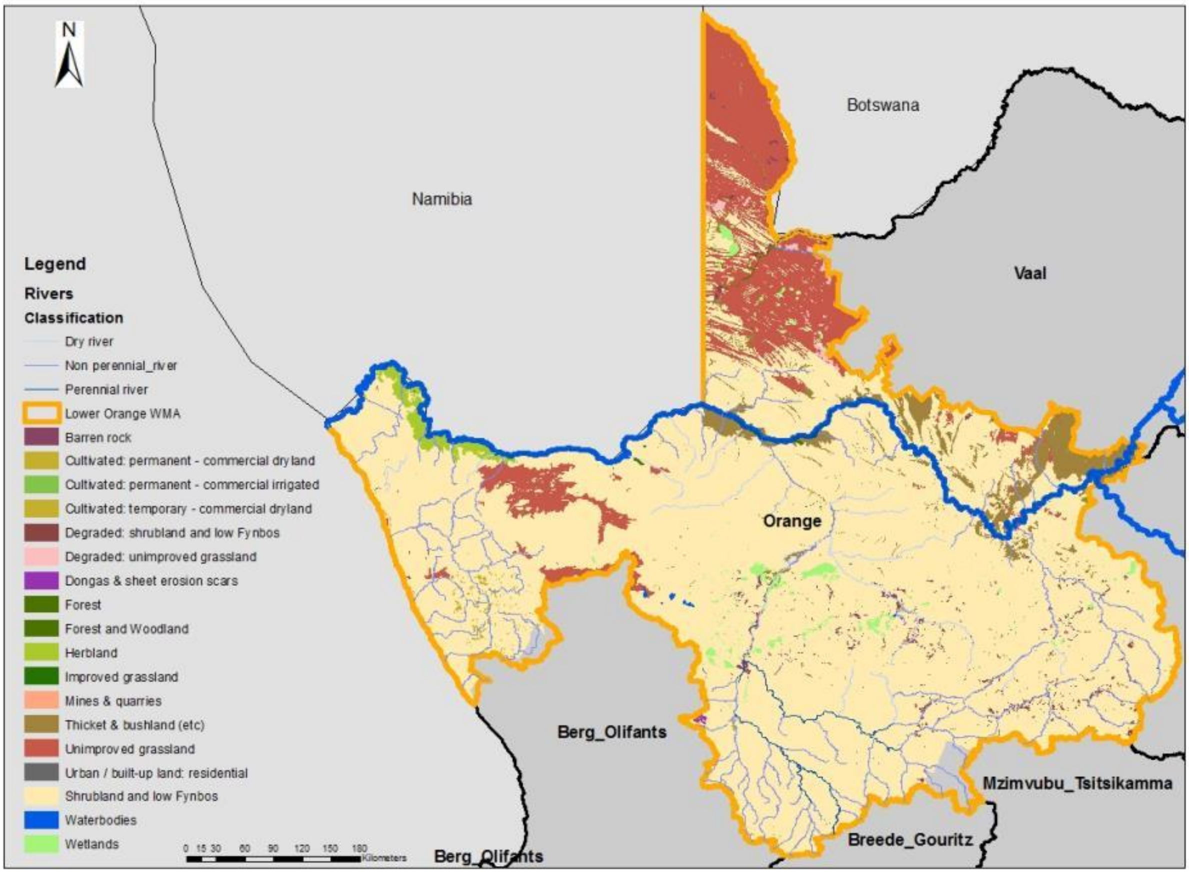

Figure 2-9: Land cover of the Lower Orange

2.6.1 Agricultural activities

The Lower Orange, with lower socio-economic development than the rest of the country, relies heavily on the Orange River for irrigation practices (DWS, 2004b; ORASECOM, 2008). Agriculture is one of the biggest employment sectors in the Lower Orange.

Water demand for agriculture, as summarised in Tables 7 and 8, is in future likely to increase in the Catchment. South Africa is already demanding 95% of the water available (approximately 60% mostly for agriculture) from the Orange River (ORASECOM, 2008). The demand for water in the Lower Orange has multiple water use sectors with agriculture registering at least 80% of the total volume.

Table 7: Annual water demand in the SADC region (Mm^3/a) (ORASECOM, 2008)

	2005	2010	2015	2025 (Projected)
South Africa	5389	5531	5647	5729
Namibia	76	134	197	244
Lesotho	21	23	24	26
Total	**5687**	**5867**	**5997**	**6168**

Table 8: Registered water users in the Lower Orange

Water Use Sector	Registered Volume (m^3/a)	%
Agricultural	282 348 737	82,05
Municipal	41 196 000	11,97
Industry	13 977 473	4,06
Mining	5 292 045	1,54
Power Generation	1 300 000	0,38
Total Registered Volume	**344 114 255**	

The construction of the Gariep and Vanderkloof Dams in the upper parts of the Catchment contributes greatly to the irrigation practices in the Orange River. In the Lower Orange the Boegoeberg Dam and the river itself are used for irrigation of crops such as grapes and citrus (DWS, 2004b). Return flows would be expected to have an impact on the overall quality of water in the Orange River due to the wide spread practice of flood-plain farming and use of fertilizers, pesticides and herbicides.

2.6.2 Recreation and tourism

Recreational use is one of the major water use activities in the Lower Orange. Viewing of the Augrabies Falls and white water rafting near Onseepkans are some of the major tourism contributors. Other big tourist attractions include nature reserves such as the Kalahari Gemsbok National Park and a portion of the Kgalagadi

Transfrontier Park, the Wonderwerk Cave near Kuruman and the world famous Namaqualand daisies (DWS, 2004b). Their proximity to the rivers means their impact cannot be disregarded. This is mostly due to increased effluent releases by waste water treatment works and domestic users. The impact of these water uses on the river can significantly alter the water quality of the Orange River (Malan & Day, 2002; Deksissa *et al.,* 2003).

2.6.3 Industrial activities

Industrial activities in the Lower Orange are very limited as there are very few urban developments. Only the town of Upington represents a large urban settlement. Waste water treatment works from such settlements and their associated discharges into the Orange River represent a potential source of pollution (Malan & Day, 2002; Deksissa *et al.,* 2003). In addition, the current solar power-generation projects earmarked for the region may add to this scenario in the near future as technologies such concentrated solar power can be very water intensive. The brine effluent from these plants can alter the water quality of the Orange River (DWS, 2004b; DWS, 2013b). The impact on the water quality by the Upper Orange industries and the main industrial hub of South Africa in the main tributary, the Vaal River, should also be considered as one of the main contributors (DWS, 2004b). The downstream position of the Lower Orange makes it more susceptible to these impacts.

2.6.4 Mining

Mining is essential for economic development in the Lower Orange. The discovery of diamonds in 1866 on the banks of the Orange River, and copper in 1850 near Springbok resulted in some of the first commercial mines in South Africa (DWS, 2004b). Diamond alluvial mining is the most common method of mining in the Lower Orange River.

Alluvial diamond mining requires the use of water in classifiers to sort and expose diamonds. Untreated discharged effluent may contaminate the adjacent Orange River through increasing the sediment load and the addition of chemicals, if any are added to the process, into the river (Deksissa *et al.,* 2003).

2.7 Climatic conditions

The Orange River Catchment covers several climatic regions due to its large surface area. Furthermore, there is the characteristic distribution of rainfall from east to west (ORASECOM, 2008). From the wet upper Catchment to the extremely dry lower parts towards the Orange River mouth, the climate affecting the Orange River may be described as ranging from temperate to extremely hot. Temperatures may fall below -10°C (at night) during the winter months (June and July) in the higher altitudes while rising as high as the mid 40°C heading westward in the summer months (ORASECOM, 2008).

The seasonality, quantity and distribution of rainfall and resulting runoff can affect the quality of the Orange River in terms of its ability to 'clean' itself through natural processes such as dilution. These processes are shown in Figures 2-10 and 2-11 and Table 9.

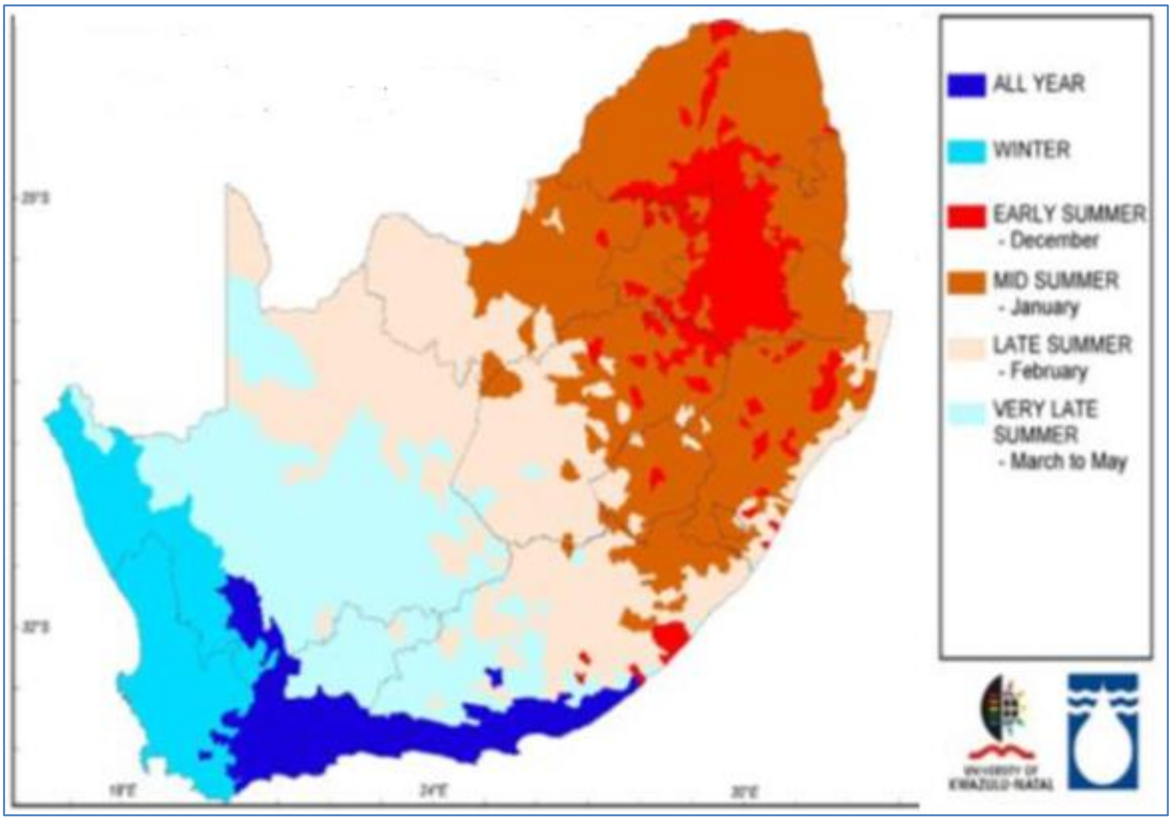

Figure 2-10: Rainfall seasonality of South Africa (Schulze, 2008)

Most of the Lower Orange receives its rainfall during the very late summer period. Although some of the areas in the region receive their rain during the winter season, there is however not sufficient quantity to contribute greatly to the overall rainfall quantity and runoff in the Catchment as indicated previously. This results in a situation where natural cleaning processes are only active during certain time of the year, while most of the Catchment is reliant on the upper Catchment in terms of water quantity and thus improved quality (ORASECOM, 2008).

The mean annual precipitation ranges from 1 600 mm to 1 800 mm in the upper Catchment to as little as 45 mm at the river mouth (Swanevelder, 1981; DWS, 2004a; ORASECOM, 2008).

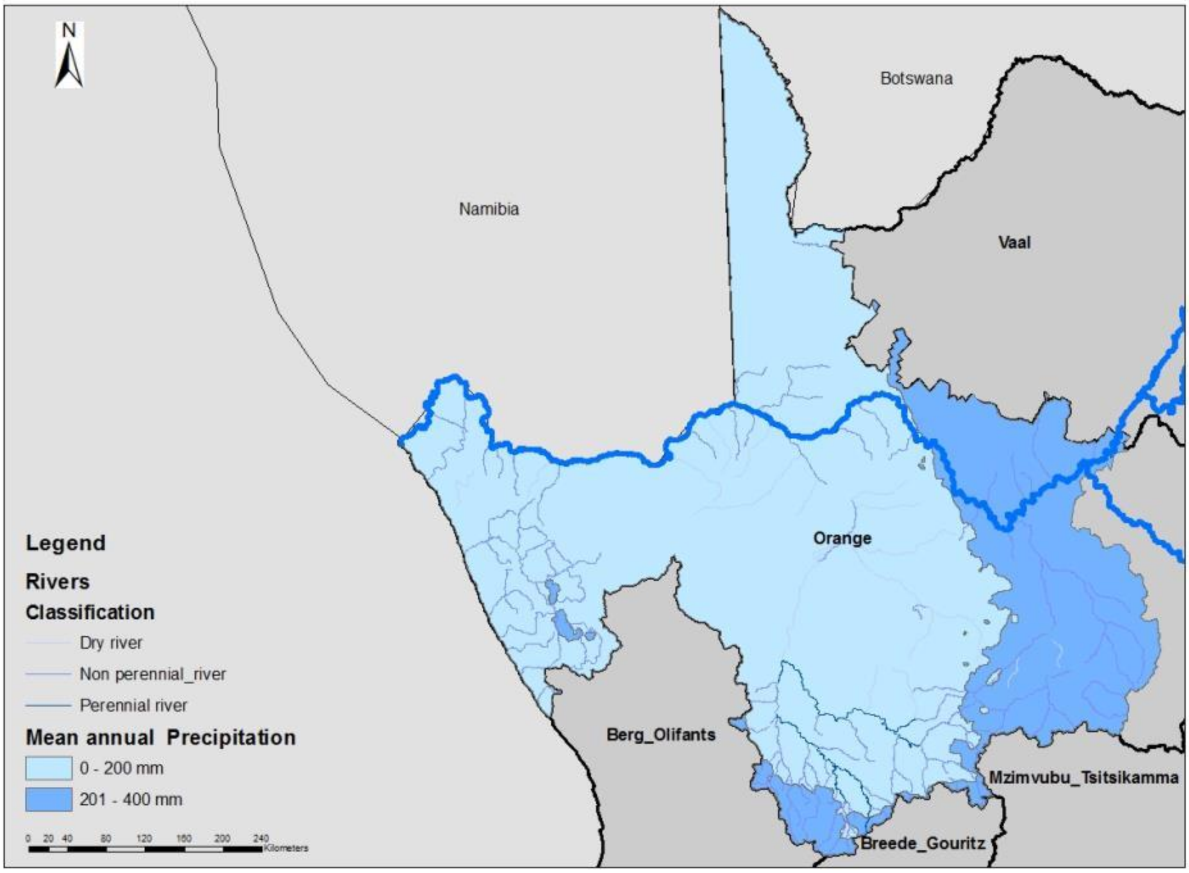

Figure 2-11: Lower Orange mean annual precipitation

Table 9: Annual average precipitation in the Orange River Catchment

Average Annual Rainfall (mm)	% Distribution
Above 1 000	1.49 (East)
750 – 1 000	6.69
500 – 750	26.95
250 – 500	30
Less than 250	35 (West)
Average for Total Catchment	**398.67 mm**

Except for the Lesotho Highlands, for the rest of the Orange River Catchment (more severe in the Lower Orange), the evaporation rates in the Orange River System far exceed annual precipitation rates and the region is categorized as arid to 'hyper-arid' as shown in Figure 2-12 (ORASECOM, 2008).

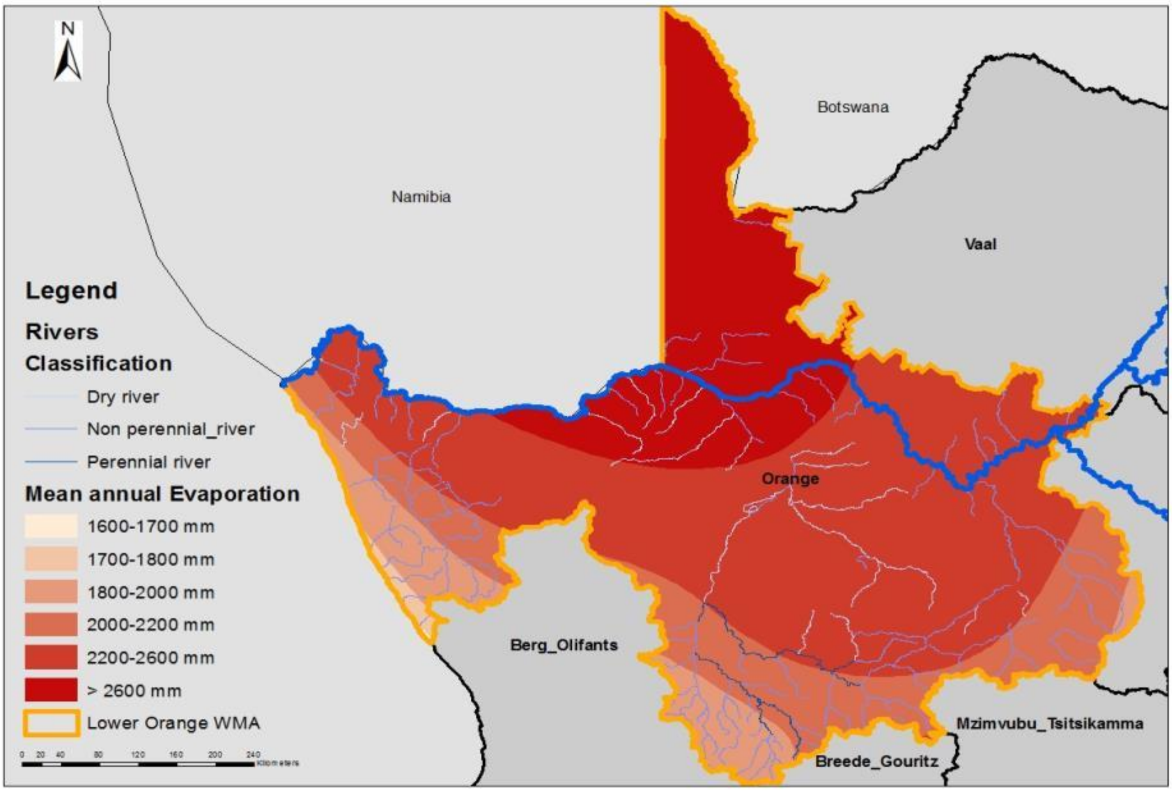

Figure 2-12: Potential mean annual evaporation

2.8 Vegetation

The Lower Orange is dominated by the Nama-Karoo Biome which, together with the Savannah and Succulent Karoo biomes, forms more than 90% of the vegetation type in the Lower Orange (Figure 2-13). Only the desert, Nama-Karoo and the Savannah biomes are of any significance to the Orange River itself. The Savannah biome is the largest biome in South Africa and is located in the Kalahari and low-veld regions of the country. It is associated with a grassy bottom layer and woody upper layers. The vegetation is termed 'shrubland' in areas where the upper layer is close to the ground and 'woodland' where it is dense, otherwise termed 'bushveld' (SANBI, 2013).

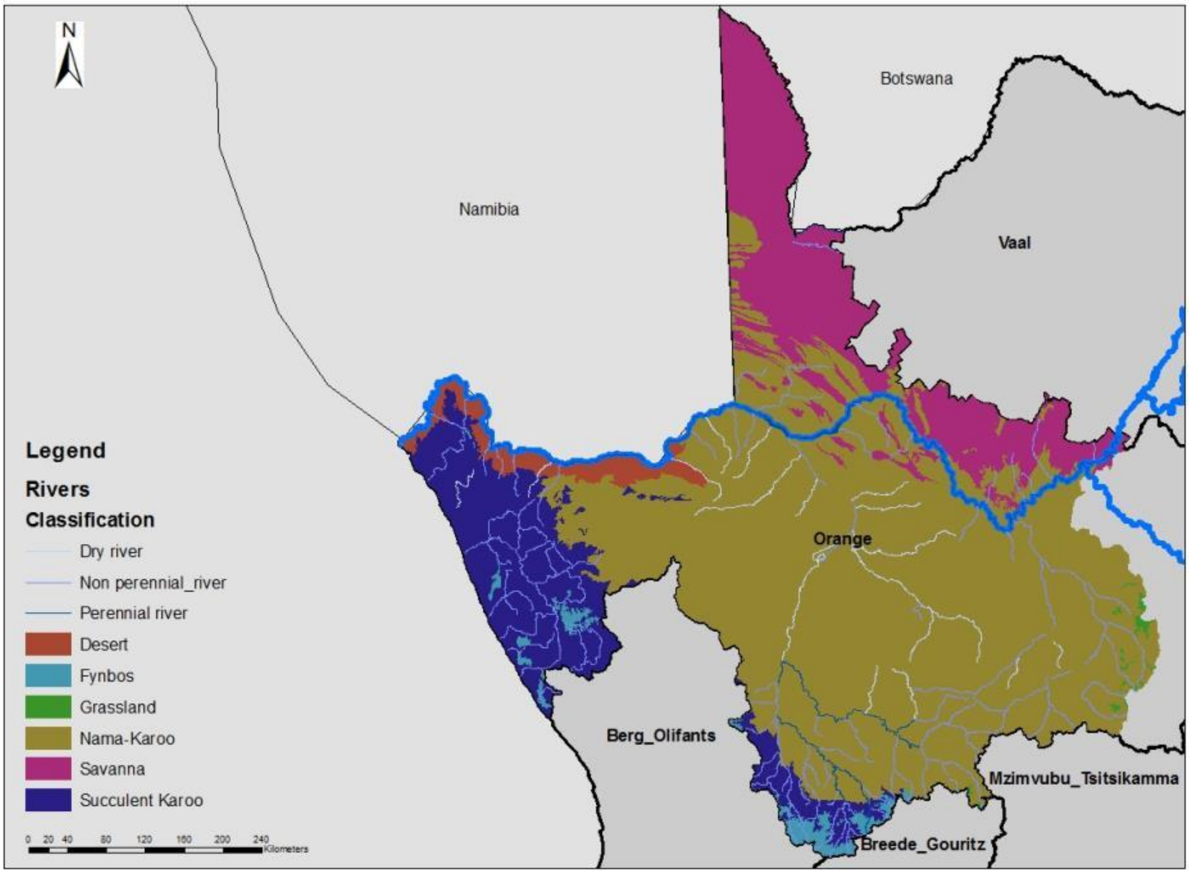

Figure 2-13: Biomes of the Lower Orange

The Nama-Karoo is the third largest biome in South Africa and is located throughout the central plateau of the western side of the country. It is associated with semi-arid conditions and low shrubs and grasses (Dean and Milton, 1999; SANBI, 2013). Most of its plant types are deciduous and situated along the Orange River and rocky hills. Not only do they reduce potential runoff, they also keep the bank and flood plain stable thereby reducing erosion.

The impact of alien invasive species should also not be neglected. They have the potential to erode the spatial extent of indigenous vegetation which may be part of the natural ecosystem of the River (SANBI, 2013). Alien trees and bushes increase over the ground biomass and evapotranspiration and in this manner diminish both surface water runoff and groundwater recharge. The increased biomass and evapotranspiration rates related with prominent alien plants emerge due to their more significant stature, root profundity and senescence, contrasted with the local species that they supplant (Chamier *et al*., 2012).

CHAPTER 3: LITERATURE REVIEW

3.1 Background

The water quality of a catchment can be impacted and influenced by many variables including dam construction, bridges and other man-made structures that may add to the increased velocity of water, and thus the rate of erosion and sediment carrying capabilities of water in a river. This plays a significant role in the quality of water flowing in a river (Malan & Day, 2002; Gregory, 2006; Ludwig *et al*., 2013).

In the Lower Orange River, high water usage in the upper Catchment, particularly the Vaal River Catchment, has significantly reduced the annual flow in the Catchment (Viljoen & Armour, 2002; ORASECOM, 2008). The high abstraction levels and low flow have also severely impacted the water quantity available in the Lower Orange. This has created a situation where, except for when the Vanderkloof Dam overflows, for most times it is difficult to notice any discernible flood season in the river (ORASECOM, 2008). This can have an impact on ability of the river to 'flush clean' itself naturally and therefore reduce the overall water quality in the river system.

The changing land use also plays a significant role in the Orange River water quality. The quality of runoff generated from changing land use into rivers would thus undergo significant change. This has been termed river-metamorphosis by Gregory (2006). Land use activities, and their associated land degradation, therefore increase the sediment load of tributaries and ultimately of the Orange River itself. The associated impact of these high usage levels on the water quality downstream should not be overlooked. Urban, industrial and farming point source discharge, together with seepage and runoff from these sources, significantly impact on the quality of water resources in the Lower Orange (Malan & Day, 2002; Deksissa *et al.,* 2003*;* ORASECOM, 2008). The Lower Orange, by virtue of its downstream position, bears the brunt of most of these impacts.

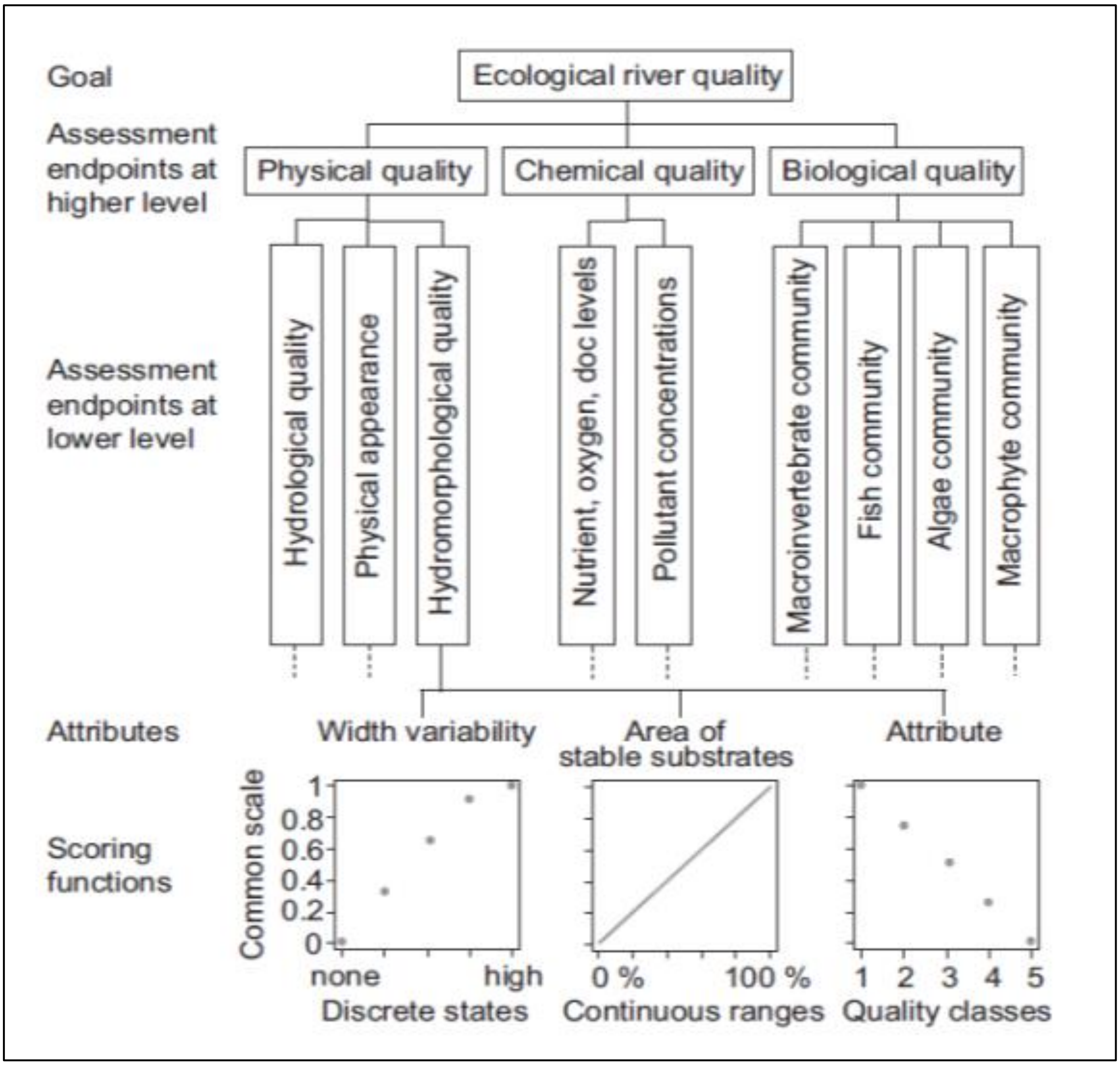

Figure 3-1: Water quality monitoring assessment hierarchy (Langhans *et al.*, 2013)

A coordinated approach that integrates all water use sectors is needed to manage and monitor this catchment adequately as past knowledge shows that single-sector focus is not the answer to good water resource management (ORASECOM, 2008). Figure 3-1 illustrates sustainable socio-economic and environmental development requirements which can only be achieved by inclusive planning that recognizes all stake holders and their water needs together with their potential impacts into planning and implementation of water resource management can greatly enhance aquatic river water quality.

A coordinated approach to water quality monitoring can ensure that physical, chemical and biological parameters of water quality are accurate and can be presented graphically for improved understanding. These graphs may represent their quality classes or classify them in discrete states or continuous ranges (i.e. as distinct and separate values or as intervals over time or depth).

The value of good, accurate and reliable data in water resource management should never be underestimated. Early detection, together with pro-active management decisions, can aid with the protection of sensitive water resources. The rendition of this data into understandable and representative graphical information can assist all stakeholders in interpreting the data and actively engaging in the conservation and protection of water resources (ORASECOM, 2008; Langhans *et al*., 2013). Thus the management of water quality monitoring in the Lower Orange River is of utmost importance.

3.2 The Orange River as a resource

As the largest catchment base of the Orange-Senqu River system, South Africa relies heavily on the support of the Orange River Catchment in terms of water supply to most of the activities that contribute towards GDP (ORASECOM, 2008). This includes both the Orange River itself and its biggest tributary, the Vaal River, which also supplies the main economic hub of the country. The main land-use activities responsible for the declining water quality in the Orange River are described by ORASECOM (2008) as follows:

- Urban discharges from waste water treatment works. The unmonitored release of effluent into rivers is one of the major causes of the declining water quality in rivers.
- Pollution from mining activities through dewatering of aquifers and the disposal of the final effluent. The runoff and seepage of water from its waste dumps, slimes dams and stockpiles should also be considered. These have the potential to be an unseen pollution source.
- Domestic, usually urban, runoff and seepage. Storm water channels can be major transporters of effluent from urban runoff.
- Return flow and runoff from agricultural activities. Irrigation near rivers or along banks can greatly influence the water quality downstream of the activities.

- Pollution from industrial undertakings through direct discharge, stormwater runoff and seepage.
- Overgrazing and inadequate terrain management. These may lead to increased runoff and thus increased pollution or sediment load in nearby rivers.

With the exception of some localised areas when the river runs through some towns, the water of the Orange River is generally considered to be of good quality compared to other rivers with similar high usage in South Africa (ORASECOM, 2008). However, constant and accurate monitoring of the river is required in order to ensure its state is maintained by management practices. This is especially more relevant during periods of low or high flows in the system as these may dramatically alter the value of most parameters.

3.3 The role of the Department of Water and Sanitation (DWS)

The history of South Africa has seen a highly distorted management of natural resources, including water and land. The majority of the country does not have access to water resources and legislation has been changed to ensure the fair distribution of this resource. Control, protection and use of water resources have been centralised by the DWS according to the NWRS (Nastar & Ramasar, 2012; Movik, 2013; Bourblanc & Blanchon, 2013). The water status of the country has reached a dire point and the supervision of this scarce resource has reached a "crossroads" (DWS, 2013a). The National Water Policy (DWS, 1997) states that:

> Water resources shall be developed, apportioned and managed in such a manner as to enable all user sectors to gain equitable access to the desired quantity, quality and reliable water. Conservation and other measures to manage demand shall be actively promoted as preferred options to achieve this objective (p.61).

The NWA (No. 36 of 1998) aims to achieve these goals through the successful implementation of Water WCWDM. This involves in the protection, minimisation of loss or waste and effective use. In order to provide the required quantity and quality of water to the all user sectors and still honour international obligations and meet environmental requirements (Viljoen *et al.*, 2004; Braid & Görgens, 2010; DWS, 2013; Movik, 2013). The NWRS is the mechanism through which the NWA (No. 36 of 1998) can be implemented – with a review of the strategy scheduled for every 5 years. The DWS has been guided by the first NWRS of the country which promoted the equitable and sustainable socio-economic transformation and development of the country. It has also been guided by the new NWRS 2 which aims to achieve equitability and sustainability in growth, development and socio-economical needs of the Republic (DWS, 2004a; DWS, 2013b).

The Water Allocation Reform (WAR) Policy of 2006 aimed to redress the historic distribution and management of South Africa's water resources (DWS, 2006; Braid & Görgens, 2010; Movik, 2013; Bourblanc & Blanchon, 2013). This included the introduction of legislation that aimed to deal with water services backlog in order to alleviate inequalities of the past (Nastar & Ramasar, 2012; Movik, 2013). The Orange River system, including the Vaal River, is paramount to this policy considering its size, contribution and economic importance.

The NWA (No. 36 of 1998) further tasks the Department with the responsibility of instituting nation-wide monitoring programmes for the management of water resources. In order to meet this, the DWS has instituted the following programmes towards monitoring surface water quality for South African water resources:

River Eco-Status Monitoring Programme (REMP): It was formerly called the River Health Programme (RHP), which is a sub-programme of the National Aquatic Ecosystem Bio-monitoring Programme (NAEBP) and the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP). It was launched in 1996 when the DWS collaborated with other governmental departments, institutions of higher learning and various private sector partners. The programme primarily uses biological indicators such as riparian vegetation, geomorphology, aquatic invertebrates and fish to assess the health or state of a river system.

National Microbial Monitoring Programme: It involves the chemical, physical and microbiological collection and analysis of water samples in surface water bodies (rivers, dams and lakes) in order to determine its suitability for varying water uses (domestic, agricultural, etc.) and any potential associated risks.

This programme encompasses the microbial analysis of both surface and groundwater nationally and within the Northern Cape region.

The DWS also represents the country as a member of the Orange-Senqu River Commission which is a platform for Catchment wide management of the Orange River and its tributaries among member states. The Department, as the custodian of national water resources, is guided by the legislation summarised in Table 10 (DWS, 2016):

Table 10: South African Acts on water resource protection

Act	Application
Constitution of the Republic of South Africa Act No. 108 of 1996	Section 24 of the South African constitution states that: “Everyone has the right to an environment that is not harmful to their health or wellbeing”. This includes the protection and prevention of the environment (water) to ensure its sustainability and efficient use.
National Environmental Management Act (NEMA) (No. 107 of 1998)	This is the framework Act for all environmental legislation in the Republic. It promotes the establishment of environmental forums for environmental management coordination and protection. The Act further encourages Integrated Environmental Management by providing a structure for the cooperative governance by all sector specific environmental Acts. It further provides guidelines for dealing with international obligations of the country.

Act	Application
National Water Act (NWA) (No. 36 of 1998)	This is the sector specific Act for water management: " the purpose of this Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed, and controlled" sustainably. It promotes the establishment of strategies to aid suitable water resource management and grants the state the ultimate responsibility of being the custodian of the nation's water resources." In terms of section 19 and 20, dealing with pollution and emergency incidents, the responsibility for remediating the situation rests with the person responsible for the incident of failure which the DWS must take reasonable steps to mitigate the impact and then bill the polluter. Integrated Catchment Management is promoted through the establishment of Catchment Management Agencies and the Act further guides the country in terms of international obligations in the case of international waters. Chapter 3 of the Act makes the determination of the Reserve, which consists of the Ecological Reserve and the Basic Human Needs Reserve, a legal requirement in all of the country's catchments
Water Services Act (WSA) (No. 108 of 1997)	The Act provides conditions for access to basic water services. This includes access to water of good quality and quantity. The Act differentiates between and gives roles to: Water Service Providers; Water Service Authorities; Water Service Intermediaries; and Water Service Committees. This is to ensure water services are coordinated for efficient and sustainable use.

According to the DWS (2016), the management of water quality is organised as follows: the national office which is responsible for the development of "policy development, capacity building, specialist support, authorization and audit services at a strategic level"; regional offices that are responsible for "policy implementation, operation, control and monitoring services at an operational level" as well as the Department's own water quality research unit which provides scientific support services.

The DWS also has multiple data storage platforms some of which were used in this study:

- Water Management System (WMS): the platforms contain data from water various water quality monitoring programs of the DWS. It entails both surface and groundwater data.

- National Integrated Water Information System (NIWIS): the platform was created to provide widespread, unified, manageable water information. All the information from all the various business units of the DWS is incorporated into the system.

3.4 Water quality monitoring

The monitoring of water quality in rivers is critical for water resource management. Continuous monitoring of rivers can lead to early detection of water quality fluctuations. In addition, accurate, reliable and accessible data from such monitoring practices can be useful as a management support tool to ensure proactive management of river water quality (Chapman, 1996). South Africa finds itself in a privileged position of having water quality data for most of its rivers from the early 1950’s. The availability of this data has led to a good understanding of the difference between good water quality and poor water quality with regards to the normal river environment (Malan & Day, 2012).

Understanding the interaction between water quality, water use, land use changes, various water use sectors and their impact on the receiving river system is part of the benefits of efficient water quality monitoring. Good water resource management (Figure 3-2) requires a reliable monitoring programme in combination with adaptive management practices that is proactive rather than reactive (USGS, 2016; Malan & Day, 2012).

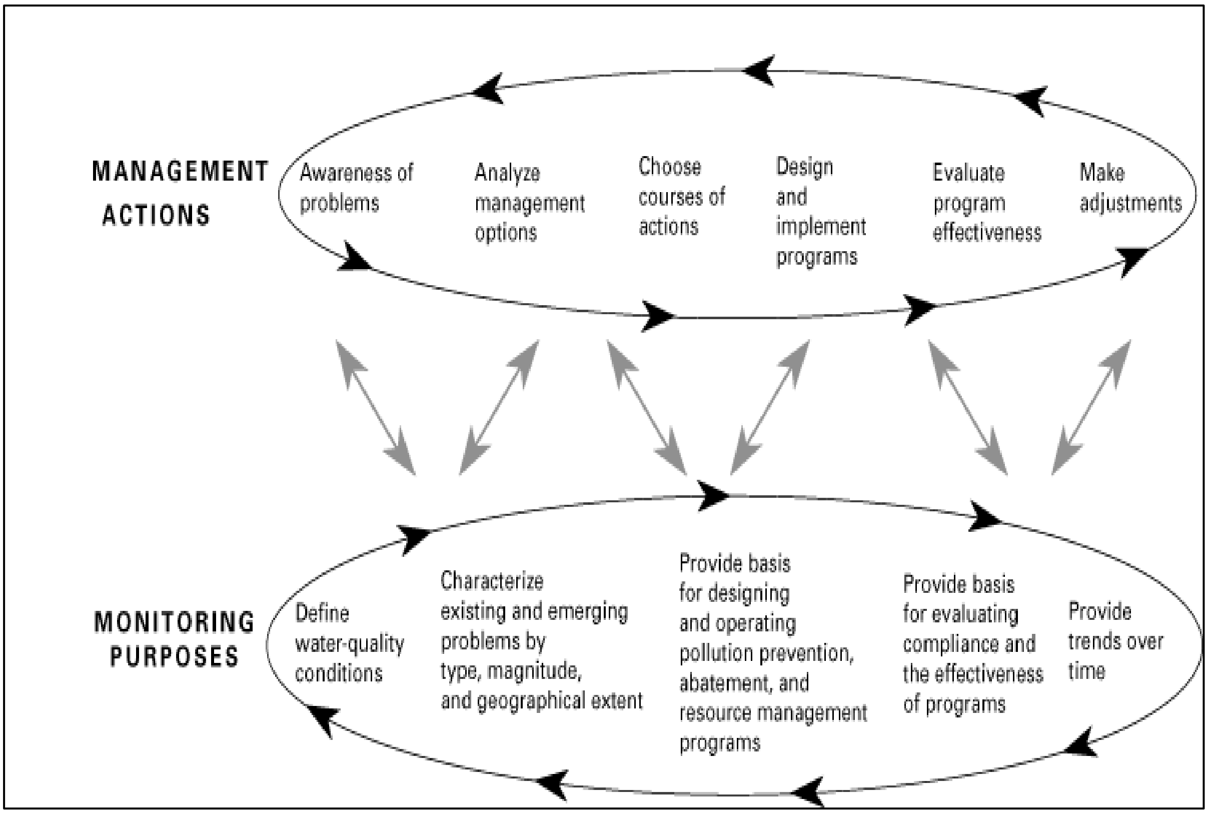

Figure 3-2: Identification and correction of water quality problems (USGS, 2016)

The involvement of all water use stakeholders and the awareness of their respective water quality and quantity responsibilities are important in this regard. Good water resource management of the Lower Orange River would require adequate planning, implementation and constant review of the management and monitoring methods. A reliable and accurate monitoring programme is required for appropriate management actions (Malan & Day, 2012).

3.5 Trans-boundary Diagnostic Analysis of the Orange River

A 2008 Trans-boundary Diagnostic Analysis (TDA) for the Orange-Senqu River Basin commissioned by the United Nation Development Programme – Global Environment Facility (UNDP-GEF) aimed to address socio-economic development needs in the Catchment. This was tasked to ensure that the water quality and quantity within the Catchment are able to meet current and future needs of the region.

According to ORASECOM (2008), the main objectives of the project included:

- “encouraging regional cooperation;
- increasing capacity to address water quality and quantity problems;
- demonstrating water quality/quantity improvements;
- initiating required policy and legal reforms;
- identifying and preparing priority investments;
- and developing sustainable management and financial arrangements” (p.8).

Cooperation between the SADC countries in terms of river management has seen DWS being solely responsible for water use authorisation in the Orange River section that forms part of the boundary between South Africa and Namibia. This requires trust and cooperation between the two states. The main outcomes of the TDA in terms of the water quality of the Orange River are summarised in Table 11 and include the following observations (ORASECOM, 2008):

- Poor quality of the water flowing from the Vaal River into the Orange River, at the start of the Lower Orange, has huge consequences for the quality of the water resources in the Lower Orange River downstream.
- The Orange River, and all its tributaries, is a major concern in terms of localised micro-biological pollution entering the river as it flows through villages, towns and cities by raw and semi-treated sewage entering the river and posing a health risk to downstream communities.
- Household, farming and industrial water use is put at great risk by increased concentrations of Total Dissolved Solids (TDS), chloride and sulphate.
- Although not proven by studies or monitoring data, the impact of radio-nuclides, heavy metals and Persistent Organic Pollutants (POPs) across national boundaries is suspected.
- Human impacts, such as eutrophication, are a significant problem across the whole Catchment but more severe in the Vaal Catchment.

Proactive water quality management are vital to sustain the Lower Orange River system. In addition, participation of all stakeholders is necessary for its conservation.

Table 11: Priority transboundary concerns (ORASECOM, 2008)

Major Concern 1	Stress on surface and groundwater – Over abstraction
Major Concern 2	Altered water flow regime – Impoundments (dams)
Major Concern 3	Deteriorating water quality – Pollution from agriculture, mines and urban areas
Major Concern 4	Land degradation – Poor mine rehabilitation – Poor range management – Poor cropping practice
Major Concern 5	Spread of Alien invasive plants and animals – Deliberate or accidental introductions

3.6 Relationship between water quantity and water quality

According to Malan & Day (2002), information from South African water quality lags behind that of water quantity in terms of data availability. Much work needs to be done in this regard. The monitoring of both water quantity and water quality is essential for the early detection of river ecosystem changes over time (Langhans *et al.*, 2013; DWS 2016).

Man-made structures, such as dams and inter-basin transfers, have greatly altered the quantity of water flowing in rivers globally and not only in South Africa (Malan & Day, 2002; Gregory, 2006). Land use changes and demands have also put great strain on already stressed water resources. Domestic, industrial and agricultural water uses have also increased dramatically over the years (DST, 2010; Ludwig *et al*., 2013; DWS, 2013a; DWS, 2016).

For the Lower Orange, large changes in demand and development have occurred mostly in the upper parts of the Orange Catchment (ORASECOM, 2008). The three largest dams in South Africa are found within the system while some of the largest historical gold mines are also present. The coordination and management of water demands from all water sectors is essential for good water resource management. Proper water resource management should incorporate both water quantity and quality. The integration of both legislation and policies is essential for the implementation of ICM/IWRM and thus the achievement of sustainable water resource usage and protection (Seyam *et al.*, 2003; Viljoen *et al.*, 2004; Savenije & Van der Zaag, 2008; GWP, 2014).

The implementation of WAR in South Africa was designed to deal with historical injustices that left a large part of the population without reliable water resources (Movik, 2013). The successful implementation of WCWDM is essential in this regard in order to ensure proper distribution and protection of scarce water resources for social, economic and ecological needs.

Domestic, agricultural and industrial water uses impact the river through the abstraction of raw cleaner water and the discharge or return flow of effluent back into the system (Deksissa *et al.,* 2003; Schulze, 2008;). Agricultural water use is the largest water sector in the system and return flows associated with fertilised crops can alter the quality of water in adjacent river systems.

The uncertainty brought by climate change also adds to concerns over water quantity and quality in the Catchment (ORASECOM, 2008; Ludwig *et al*., 2013). These changes may increase water quantity by increasing precipitation or vice versa.

3.7 Water impoundment and water quality

Due to the aridity of South Africa’s climate, the major rivers of the country are heavily dependent upon dams for the storage of an increasing quantity of the mean annual runoff (MAR). As a result, the discharge of water from these rivers is controlled. The Orange River system consists some of the biggest dams in South Africa: Gariep Dam; Van der Kloof Dam; and the Vaal Dam (Figure 3-3). These are all found upstream of the Lower Orange with discharge and flows in the Catchment regulated through the Van der Kloof Dam (DWS, 2004b; Ludwig *et al*., 2013).

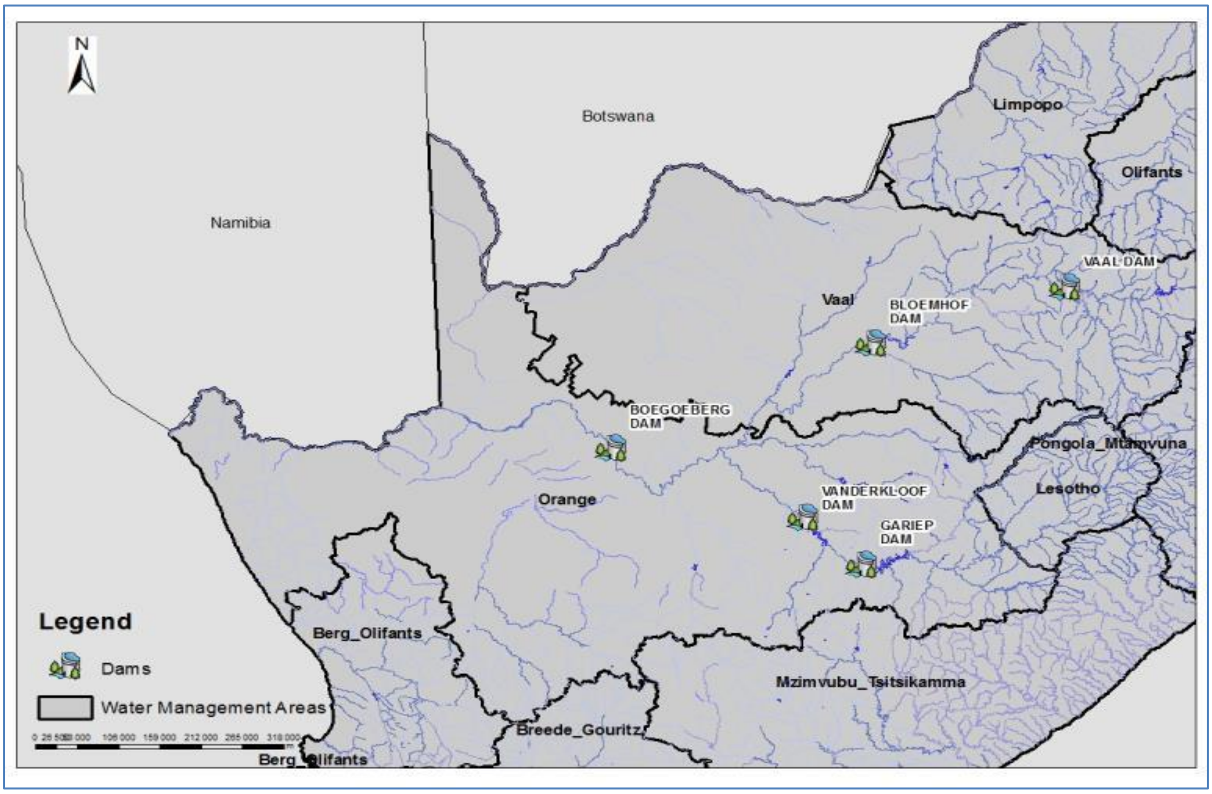

Figure 3-3: Dams in the Orange River System

The chemistry of water discharged from a dam is largely dependent on processes that occur within the reservoir. The complex nature of the relations of such processes and their driving forces ultimately make the water quality in the system difficult to determine (Malan & Day, 2002). Water quality in such structures would differ according to depth, temperature and the distribution of oxygen. These changes determine the type of habitat provided to aquatic organisms and ultimately effects the water quality in the river system. Each dam would be expected to have its own unique biological, chemical, physical and hydrological characteristics and thus the discharged downstream water quality varies (Malan & Day, 2002; Ludwig *et al*., 2013).

Due to the limited rainfall season in South Africa, most of the dams can be regarded as stratified for most of the year. Morphology also plays an important role in that the depth and the volume of the water determine its thermal and chemical stratification. This results in the water quality depending on whether it was released from the top (epi-limnetic discharges), bottom (hypo-limnetic discharges) or middle levels. The dams may also act as settling pools and trap sediments as well as affect the transportation of nutrients downstream. Also of importance is the impact they have on seasonal variation of water levels in rivers (Malan & Day, 2002). Therefore, the type of release and the management of the dams determine the quality of the water discharged downstream into the Orange River.

3.8 Alien invasive species

Alien invasive species may impact on the quantity and quality of water by their uptake of large quantities of water and degradation of the aquatic ecosystem they invade (DWS, 2014). This is mostly problematic in the Upper Orange and Vaal Catchments. Alien species such as Silver Wattle *(acacia dealbata)*, Black Wattle *(acacia mearnsii)*, Blue Gum *(eucalyptus sp.)*, Syringa *(melia azedarach)*, Jacaranda *(jacaranda mimosifolia)* and the Grey Poplar *(populous canescens)* are widely found in these parts of the Catchment (ORASECOM, 2008). Species such as hyacinth, found predominately in the Vaal River, can alter the natural flow of water in a river and affect the quality downstream by lessening the amount of water available for dilution processes. Although they help reduce erosion, and thus TDS, their impact on natural vegetation is mostly detrimental.

The Lower Orange, as well as the Middle Orange, is generally affected by growing infestations of Port Jackson *(acacia saligna)*. This woody shrub is found in the riparian zone and can significantly reduce the flow of water in a river (ORASECOM, 2008).

Programmes, such as Working for Water, need to be more extensive and supported. Such programs use mechanical, chemical, biological methods in order to control and remove these species. The inclusion of such programs as part of IWRM can provide a platform to fight a winning battle against the impact of such species on the quantity and quality of water resources in the Lower Orange Water Management Area (DWS, 2014).

3.9 Climatic impacts on water quality

The Intergovernmental Panel on Climate Change (IPCC) in its fifth report has highlighted the following climatic impacts on freshwater resources (Cisneros *et al*., 2014):

- Reduction in fresh surface water and groundwater will increase competition for this already scarce resource amongst the different water use sectors.
- Widespread global increases in the frequency and magnitude of floods and droughts will endanger both social and economic goals.
- Water quality and quantity of surface water systems is changed due human interventions – dams and increased abstraction rates.
- Raw water quality is expected to deteriorate and thus increase the costs of treatment. Associated risks are increased temperatures, sediment loads, nutrients and pollutants due to high precipitation rates; while there is an expected drop in the dilution of pollutants during droughts and the interruption of treatment services during floods.
- Higher temperatures often result in an increase in eutrophication and algal blooms

The climate of an area regulates the availability, accessibility, quality and demand for water in its area of influence (Ngcobo *et al.*, 2013). According to Tyson & Preston-Whyte (2000), the Southern African weather circulation is dominated by anti-cyclonic trends and its position means the regional weather is influenced by both the tropics and the middle latitudes. The warm Indian Ocean, Westerly Waves and Easterly Waves provide most of the precipitation in the region.

Rainfall increases from the west of the subcontinent, where rainfall can be as low as 50mm around Northern Cape to above 1000mm towards the eastern seaboard due to ocean temperatures. This causes the arid conditions prevalent over the western sector, clearly marked by the presence of the Kalahari and Namib deserts (Tyson & Preston-Whyte, 2000; New *et al.*, 2006). Southern Africa is considered to be especially susceptible to the effects of global climate change due to its global position and current dry climate. Anthropological impacts as well as environmental changes are exaggerated by these changes. The impact of these changes on water resources has necessitated the need to review current local land use and socio-economic development together with their interactions with global economic drivers (New *et al.*, 2006; Lange *et al.*, 2007; Morishima & Akasaka 2010; DWS, 2013; Ludwig *et al*., 2013; Ngcobo *et al.*, 2013). This susceptibility to climatic changes makes integrative and adaptive management of resources towards development imperative.

Changes in the climate may also affect runoff and the variability of flow in rivers. The intensity, distribution, duration and frequency of precipitation are some of the components of an area's climate that may have a direct impact on water in a river (Tyson & Preston-Whyte, 2000). The understanding that climate change has substantial impact on water availability and quality, as well as flood and drought risks, has shaped recent research and policy making in terms of adaptation methods (ORASECOM, 2008; Risk and Vulnerability Atlas, 2013; Ludwig *et al*., 2013; DWA, 2013).

Current climate change predictions include increased evaporation; less but higher intensity precipitation; reduced runoff per mm of rain; higher irrigation demands; reduction of the average water availability (New *et al.*, 2006; Ngcobo *et al.*, 2013; DWS, 2013). All sectors are anticipated to be affected by these changes (ORASECOM, 2008).

The associated increase in 'erosivity' and denudation rates due to increased rainfall will also increase sedimentation in the river and its dams (Rouby *et al*., 2009). This invariably impacts on the quality of water in natural water cleaning processes such as dilution are reduced in efficiency.

The sensitivity of a catchment to changes in the magnitude and distribution of precipitation, evapotranspiration and temperatures will ultimately determine the overall impact of climate change on the catchment (Cisneros *et al*., 2014). The changes in climatic conditions across the country will result extended periods of dryness in the Lower Orange River System (Figure 3-4) and the associated impact of low water levels on water quality. However, an increase in flash floods is expected as the upper parts of the Catchment experiences heavy rainfall events. In terms of water quality, this would increase cases in which the river 'flushes' out. This might result in a change in the averages of certain water quality parameters.

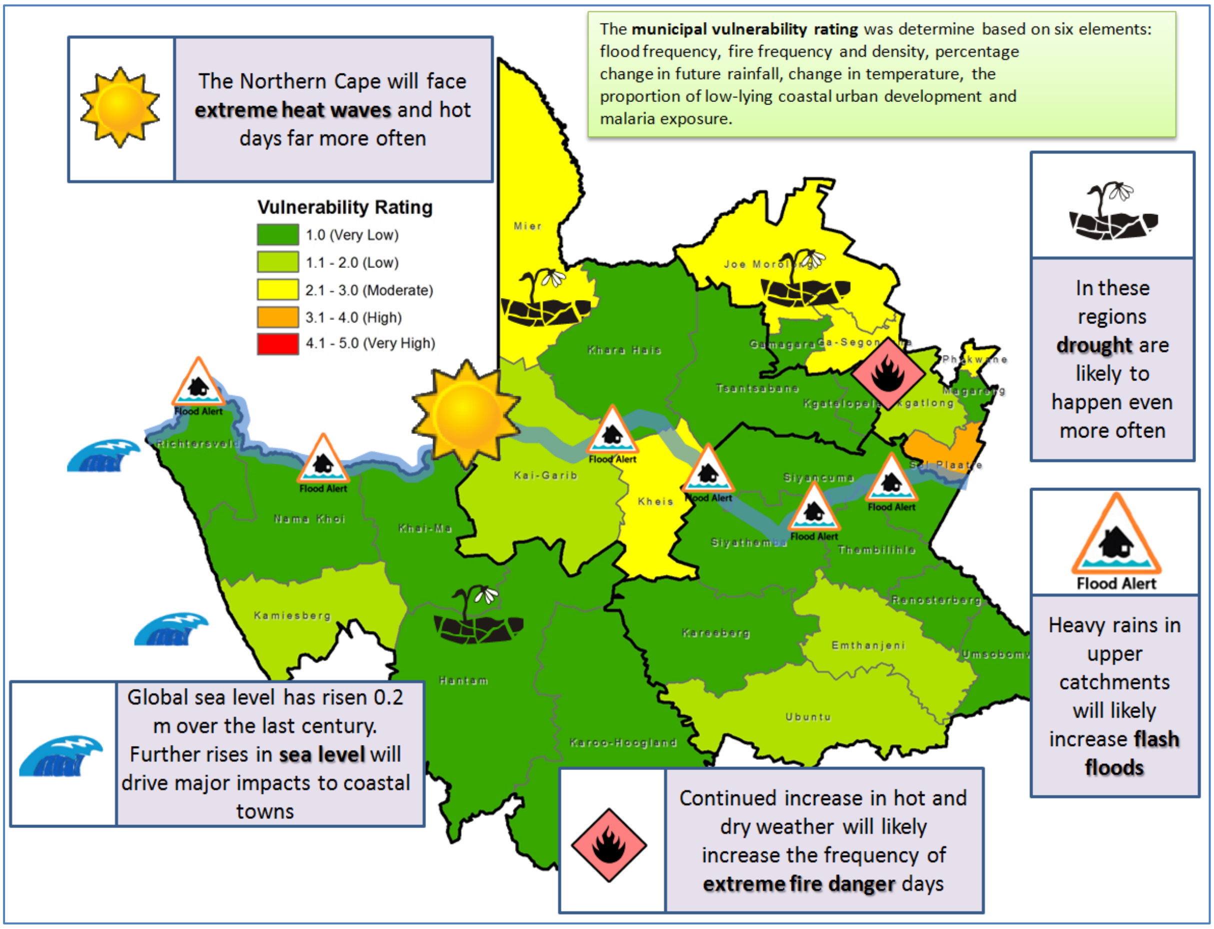

Figure 3-4: Climatic changes and their expected impact on the Northern Cape

3.10 Land use impacts

As Ngcobo *et al*. (2013) have shown, the current and probable rate of socio-economic development for Southern Africa is expected to increase. This will result in land use changes and thus the degradation of the natural environment. Water resources and water quality require adequate management in order to remain sustainable and reliable and the maintenance and distribution of water quality trends informs all users of their collective responsibility for the sustainability of the system with this growth.

Rapid expansion in population and economic development in the past years has resulted in widespread degradation of land in order to ensure continued socio-economic growth (Ngcobo *et al*., 2013). The sustainability of this relies on the consideration of both the bio-physical and the socio-economic linkages to direct the developmental requirements of the region.

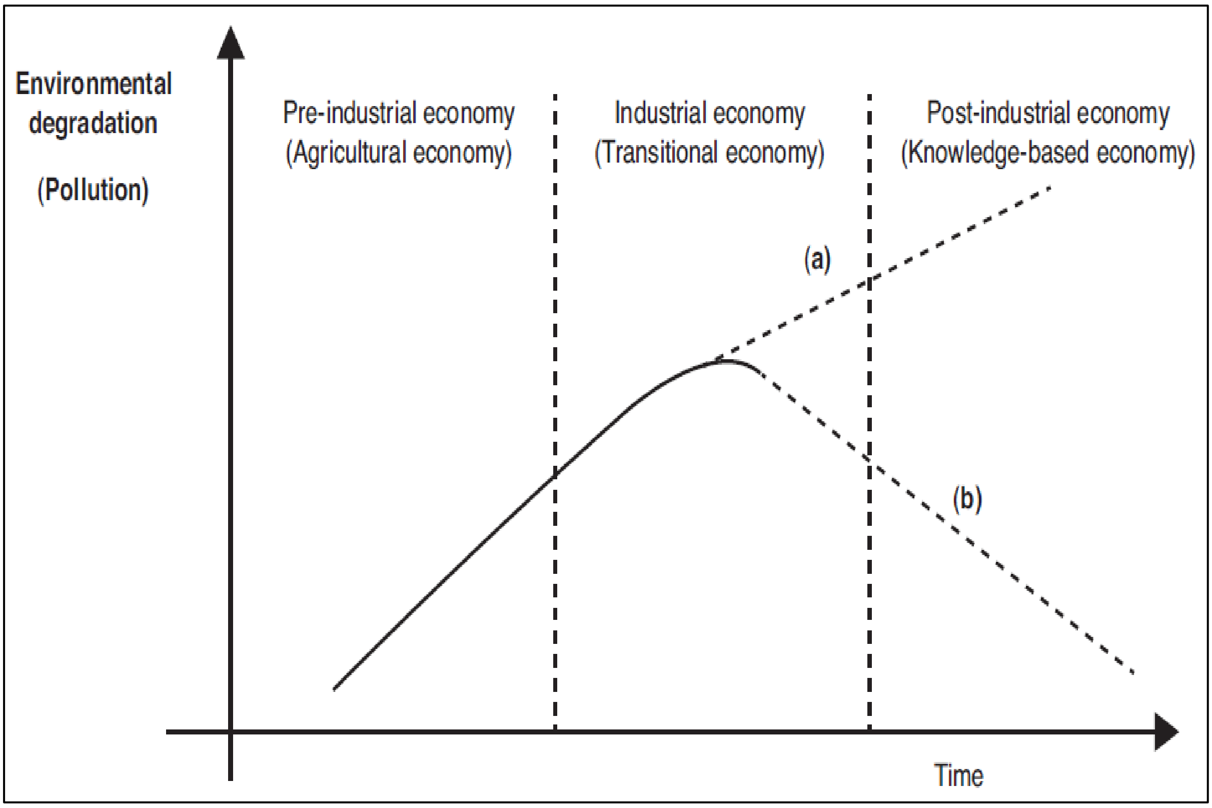

Figure 3-5: Adapted environmental Kuznets Curve for South Africa (Ngcobo *et al*., 2013)

According to the Kuznets Curve theory (Figure 3-5) the early stages of economic development produce an increase in environmental degradation and pollution. The trend begins to reverse when a certain level of income per capita is reached. Higher income levels equal improved environmental protection and an improved state of natural resources. Unfortunately, the degradation level is dependent on whether the threshold of the system has been exceeded or not.

CHAPTER 4: METHODOLOGY

This chapter describes the datasets and methods of analysis used in the study. In order to achieve the objectives of the Lower Orange River Study, land use, current monitoring programme, historical water quality data from DWS archives and current water quality data were sourced, assessed and displayed. The identification of water quality trends in the Lower Orange River was derived from these datasets.

4.1 Data collection

The main datasets used included historical water quality data, current water quality data and land use data. These datasets were analysed for trends and the evaluation of the effectiveness of the current monitoring networks. The data was also used to identify the potential increase in pollution of the Lower Orange River.

4.2 Monitoring data

This study used the following water quality monitoring data:

a) Existing water quality data from monitoring networks of the Department of Water and Sanitation (Resource Quality Services) database. The internet based software programs WMS and NIWIS were utilised for this purpose.
b) Regional Lower Orange water quality data sampled by the region for the national monitoring programme.

4.3 Data analysis

a) Temporal and spatial water quality trends, upstream and downstream of the Orange-Vaal River confluence, were analysed using time series plots.
b) GIS was used to display monitoring points and show water quality spatially.
c) Maucha diagrams were used to plot the chemical data and identify water type changes over time:

Table 12 shows water quality parameters that were used to indicate the major cations and anions through a Maucha diagram. Figure 4-1 shows the schematic layout of the ions in a typical diagram. The Maucha diagram can be used to show the temporal change of the concentration of ions in Mg/L (Silberbauer and King, 1991).

Table 12: Ions used in the Maucha diagram

Cations	Anions
K^+	TAL (Total Alkalinity) (HCO_3^- and CO_3^-)
Na^+	$SO_4^=$
Ca^{++}	Cl^-
Mg^{++}	

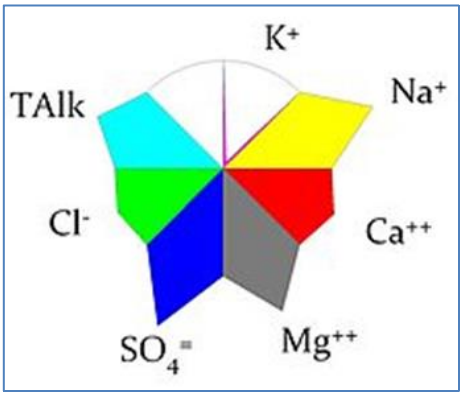

Figure 4-1: Illustration of a typical Maucha diagram (Silberbauer and King, 1991

4.4 Methods used in the study

Objective 1: To identify and understand the current water quality monitoring network and chemical parameters measured in the Lower Orange.

a) Data from the beginning of the water quality monitoring programme (1950s) was analysed in order to evaluate the water quality trend downstream in the Catchment. This data was sourced from the DWS archives and databases in the national office.

b) The software programs, WMS and NIWIS, were utilised for this purpose. These were designed by the DWS to provide a database and management platform for water quality results. The WMS software is made up of the following core subsystems that were used for determining the objective:

i. Monitoring Management Subsystem: This is used to manage water resource quality monitoring. Every monitoring network, together with its monitoring positions, is registered on this system. It provides a platform for the auditing of monitoring programmes and data capturing. Monitoring and analysis requirements can be specified on this subsystem which can be used as a management decision making tool and as an early detection device for the efficiency of the monitoring programmes.

ii. Water Resource Management Subsystem: This subsystem is used to support the sustainable use and protection of water resources by creating a water user network through the reporting and supply of data while setting objectives and standards. It connects both stakeholders and management by providing a platform for access to water quality data and information. The Water Resource Management Subsystem is used by DWS and its stakeholders (including municipalities, the agricultural sector and the mining industry) to export water quality data. This is to ensure the proper sharing of up to date and informative water quality information as it is uploaded onto the system.

iii. Geographic Information System (GIS): GIS is a tool that supports the interpretation and determination of the water quality status of a resource by visually and spatially displaying water quality information.

c) The data relevant for the purposes of this study is as follows:

   i. Data was collected, organised and classified according to quality data parameters using the South African Water Quality Guidelines (1996).

   ii. Time series graphs for the data were plotted as part of the trend analysis.

iii. Past monitoring station data was evaluated for the number of parameters analysed; missing data; and anomalies.

d) A low cost survey of a stretch of the Lower Orange River: As part of this study, a boat survey was conducted in the Orange River between the towns of Prieska and Douglas during the week of 24 – 28 April 2017. Due to the drought conditions from 2014, the river flow levels were deemed insufficient to conduct such a survey. The period chosen was deemed sufficient to acquire a reasonable outlook of river conditions after the drought and the subsequent floods that followed. The survey area was between the town of Prieska and the Irene Weir in the Lower Orange River. The survey conducted made use of a motorised small boat. The survey direction was upstream. Probes attached to the boat and suspended in the water continuously measured various physical water parameters. The area was selected for its ease of access as the water levels in the river were dropping quickly (Figure 4-2).

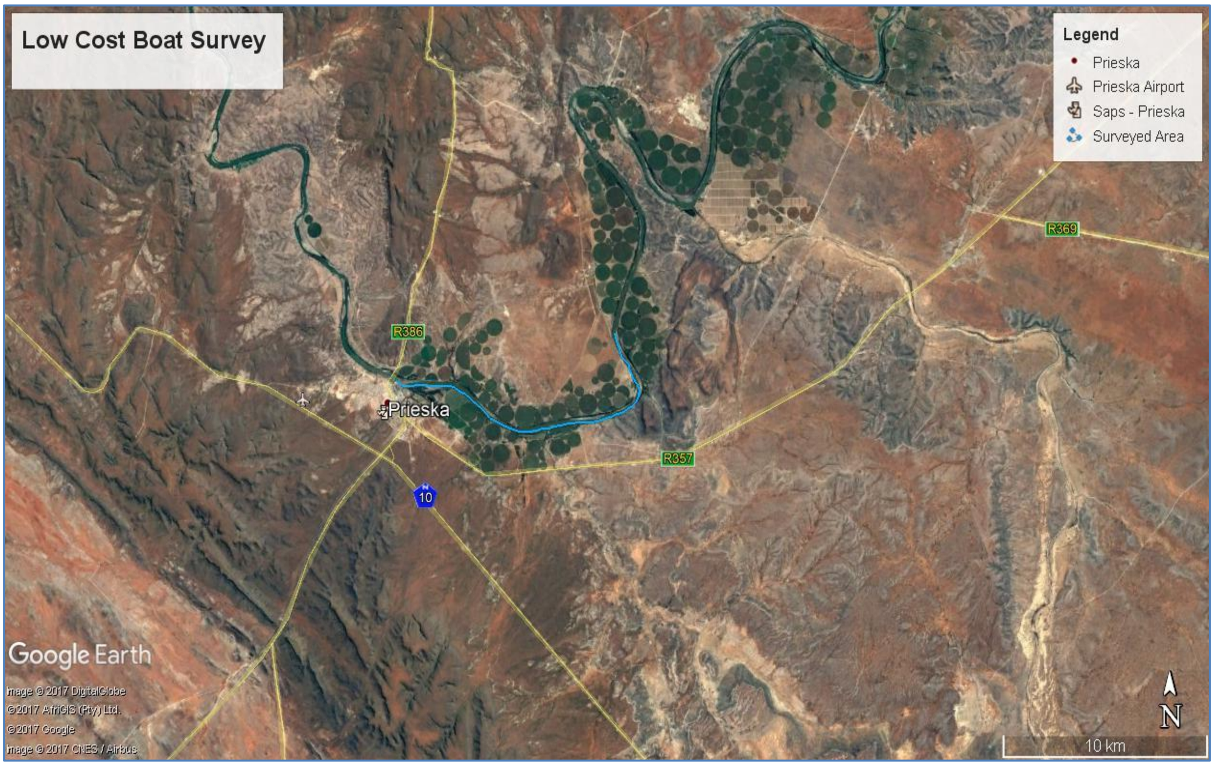

Figure 4-2: Boat survey section near the town of Prieska

The probe used was able to measure the following parameters: pH; Temperature; Electrical Conductivity; Salinity; Total Dissolved Solids; Dissolved Oxygen and Turbidity. Figure 4-3 shows the preparations for the beginning of the boat survey, probe installation and the actual survey of the river.

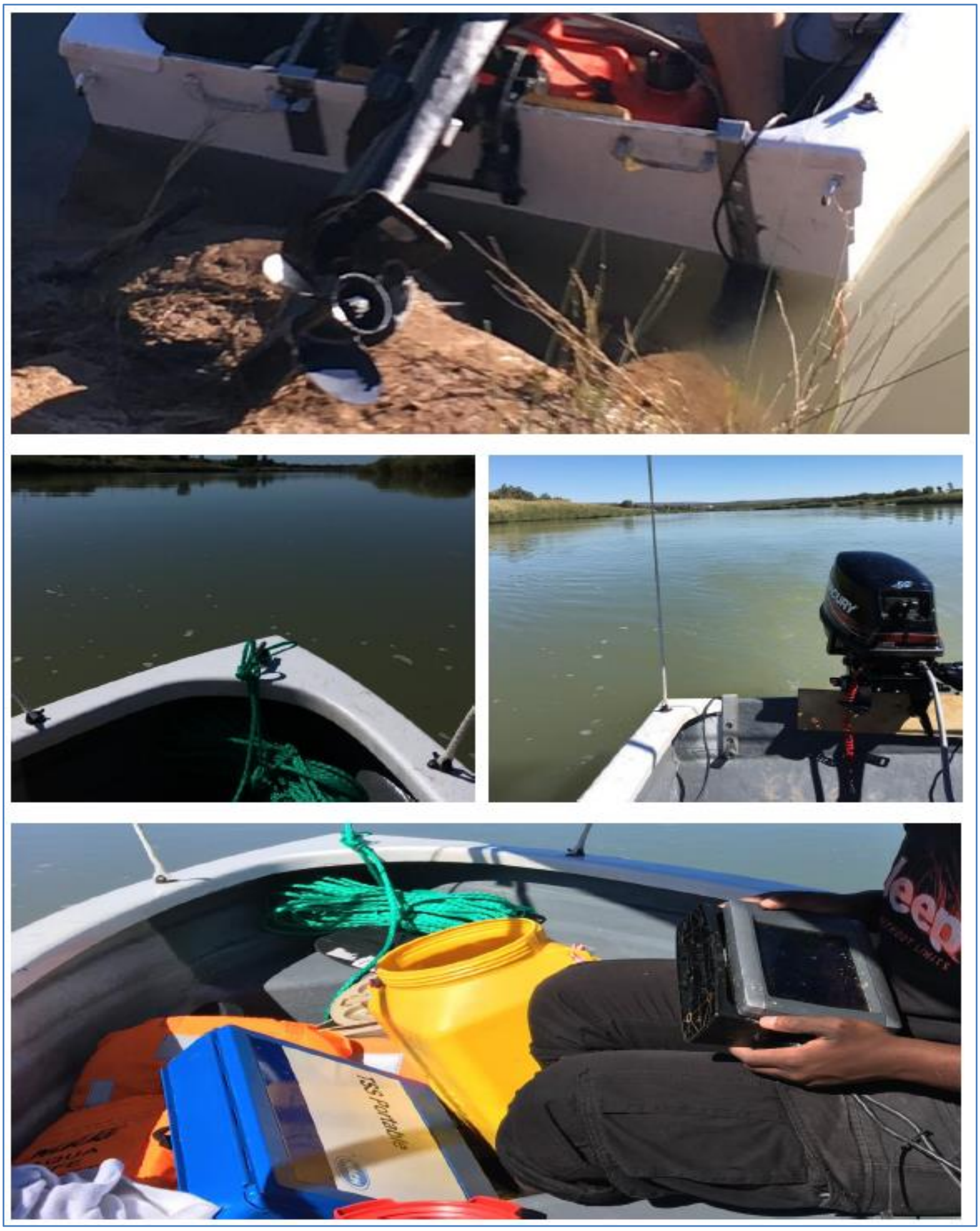

Figure 4-3: Boat survey conducted in the Orange River

The results of the surveys were used to provide real time data for water quality management. The survey also provided visual check of all legal and illegal abstraction and discharge points. In future such a quick survey can be used to adapt the monitoring network to suit change in water use patterns.

e) The ORASECOM has, under Theme 5 of its programmes, conducted studies on water quality and degradation issues of the Catchment. These studies should have enabled monitoring, management and compliance enforcement in the Catchment. The failure of these assessments to yield results (in terms of capacity building; communication and shared information systems) was investigated.

Objective 2: To compare the current water quality status to historic records and regulatory requirements

a) South African Water Quality Guidelines (1996) were used to compare the quality of the water in the Orange River against regulatory requirements. These are the standards currently utilised by the DWS and empowers all stakeholders associated with such a dynamic resource to act in a coordinated effort.

b) Historic, current and surveyed water quality data were compared to the guidelines in order to assess the water quality trends of the Orange River.

Objective 3: To suggest improved monitoring and mitigation measures necessary for the Lower Orange and to provide a management tool

a) The current monitoring system was evaluated for its effectiveness in terms of pollution detection. This compared the advantages and disadvantages of existing monitoring methods and schemes.

b) Suitable methods were identified for presenting and converting water quality data into accurate information for decision making. This information should be accessible to all water use sectors – which in turn provide a good water management decision support tool.

c) Stricter measures against polluters were recommended as part of this objective. According to the NWA (No. 36 of 1998) Sections 19 and 20, when dealing with pollution incidents, the ultimate responsibility of remediating the situation rests with the responsible party. The full implementation of this section of the Act would help maintain the integrity of the Orange River and its tributaries.

CHAPTER 5: RESULTS AND DISCUSSION

This study analysed the water quality trends, and monitoring networks deployed by the DWS, of the Lower Orange River in the Northern Cape. Historic data from DWS WMS and NIWIS was utilised to illustrate the changes in the water quality temporarily and spatially.

A comparative analysis of the two (historic and results of the survey) sets of data was conducted in order to gauge the accuracy of the current water quality monitoring systems. The efficiency of the data received ensures that adequate pro-active and responsive measures are taken in the management of water resource quality in the Catchments.

The legislative requirement of water quality in South Africa, according to the South African Water Quality Guidelines, was applied to the data sets. The Orange River's water quality status was then measured against these standards and guidelines and their respective Resource Quality Objectives.

5.1 Identifying and understanding of the current water quality monitoring programmes and their chemical parameters

The DWS has various water quality monitoring programmes throughout the country. Three surface water programmes run concurrently in the Lower Orange. These are:

I. National Chemical Monitoring Programme (NCMP)

The programme gives information and data on the chemical water quality of South Africa's surface water resources. The NCMP is the longest running of the national monitoring programmes, with some sample areas having information stretching back to the 1950s.

The monitoring is conducted by the regional office while the national office does the consolidation and verification of the data. The data is then stored on the WMS system of the DWS and then displayed through the web based

NIWIS system internally and externally. The programme covers stretch of the river outlined in Figure 2-5 previously.

II. National Microbiological Monitoring Programme for Surface Water

The programme was established in 1990 to provide information on the status and patterns of the degree of pathogenic bacteria contamination (as far as the microbial quality of surface water resources in priority regions). To provide data for determining the potential health risks to people related with the potential utilization of pathogenically polluted water resources.

The national programme has identified hotspots in the Lower Orange as shown in Figure 5-1.

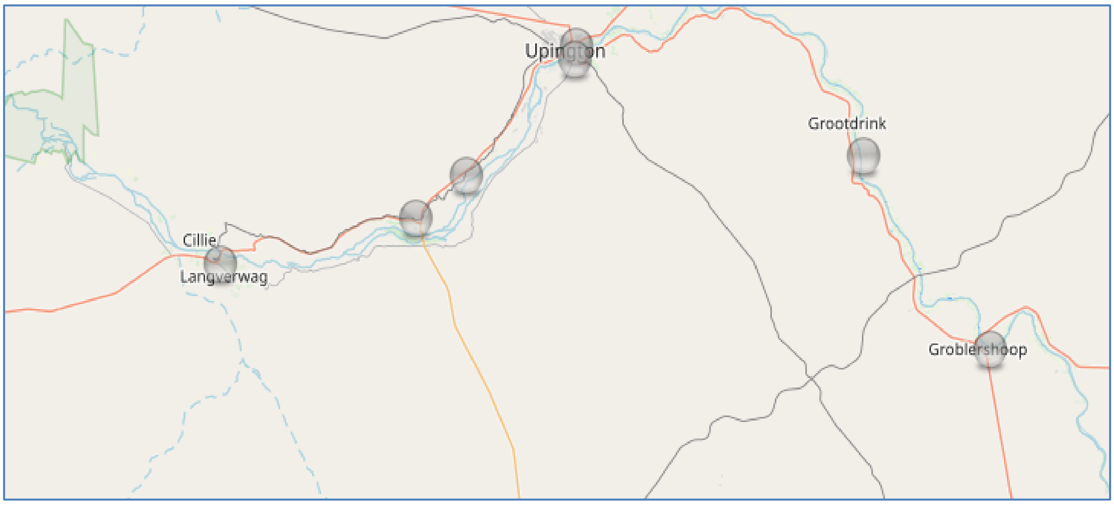

Figure 5-1: Lower Orange national microbial monitoring programme "hotspots"

III. National Aquatic Ecosystem Health Monitoring Programme

The National Aquatic Ecosystem Health Monitoring Program is a national program overseen by Resource Quality Services with help from the Water Research Commission, CSIR and different local and provincial experts. The oldest part of the National Aquatic Ecosystem Health Monitoring Program is the River Eco-status Monitoring Program, once in the past known as the River

Health Program. The REMP centres around the monitoring of the environmental conditions in river biological systems as they are reflected by the system drivers and natural reactions (instream and riparian).

The data from this programme was not utilised for this study due to the sporadic nature of the data in the Lower Orange River.

5.2 Trend analysis of the current water quality status to historic records and regulatory requirements

I. Analysis of the Microbiological Monitoring data in the Lower Orange

Elevated levels of coliforms (MPN/100 ml) give warnings of failure in the water treatment process, a break in the integrity of the water distribution network, or possible contamination with pathogens. This then increases the potential for waterborne diseases.

The monitoring of microbiological organisms in the Lower Orange has been sporadic at best. The earliest data collected is from 2001. Upington, being the largest development along the river, contains the largest dataset. However, the data was only collected up until 31 December 2011. This is a major course for concern due to the health implications of such a lack of information for management intervention.

As Figure 5-1 indicates, 6 sites have been identified as national hotspot areas in the Lower Orange by the national programme. The town of Upington has two monitoring points due to its regional importance. All the sites indicate the presence of coliforms (E. coli). They indicate fluctuating levels of the bacteria year to year. Upington shows the most concerning levels while Kanoneiland also shows very high levels. The levels in Kanoneiland can be associated with the levels in Upington as the site is less than 20 km downstream of Upington. The common attribute amongst the identified hotspots is that they all represent the biggest human settlements along the Lower Orange River. The town of Prieska represents the largest development not identified as a potential hotspot. This is illustrated in Figures 5-2, 5-3, 5-4, 5-5, 5-6, 5-7, and 5-8.

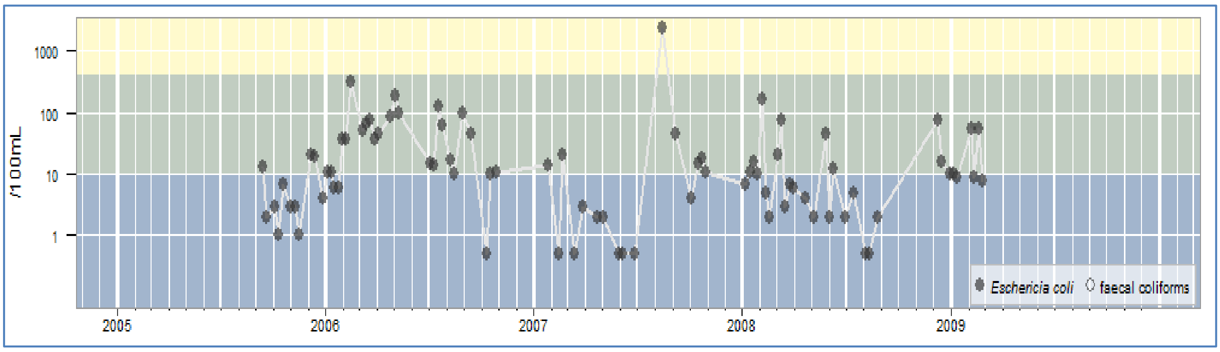

Figure 5-2: Groblershoop E. coli monitoring data

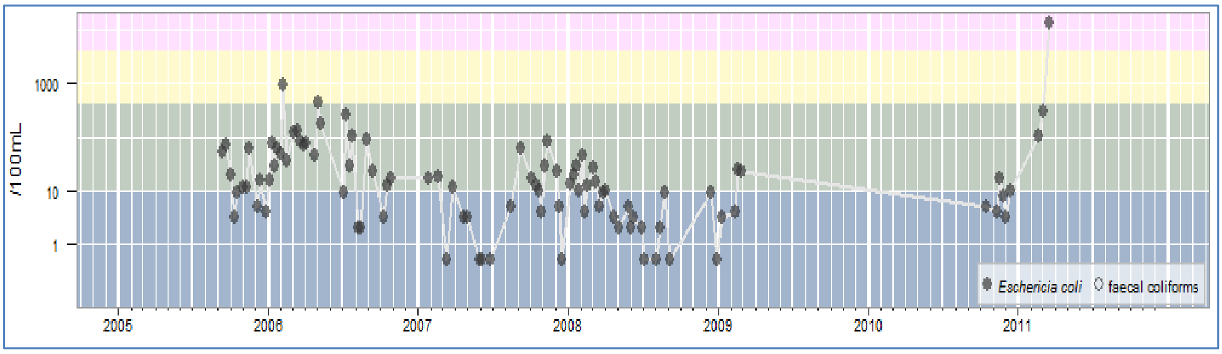

Figure 5-3: Gariep

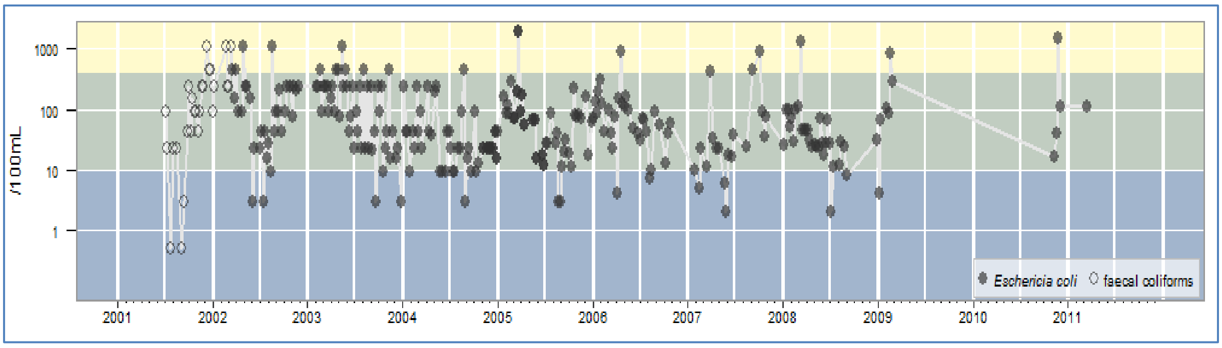

Figure 5-4: Upington Water Works

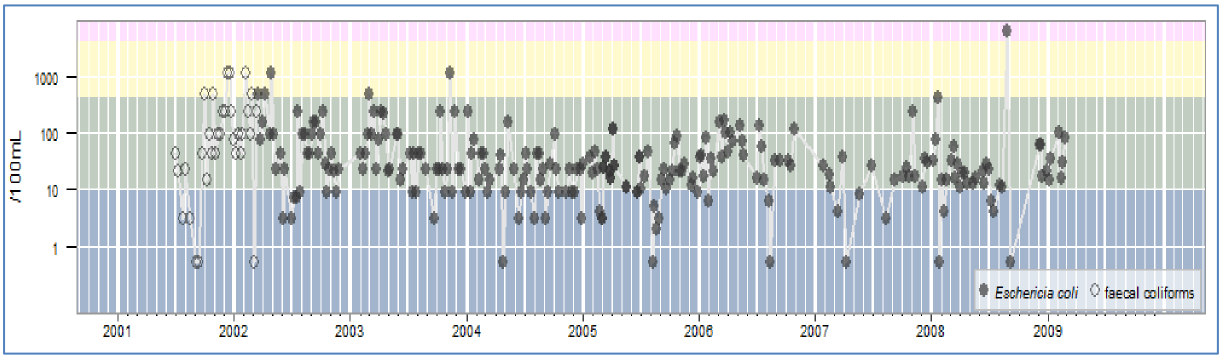

Figure 5-5: Upington Canal

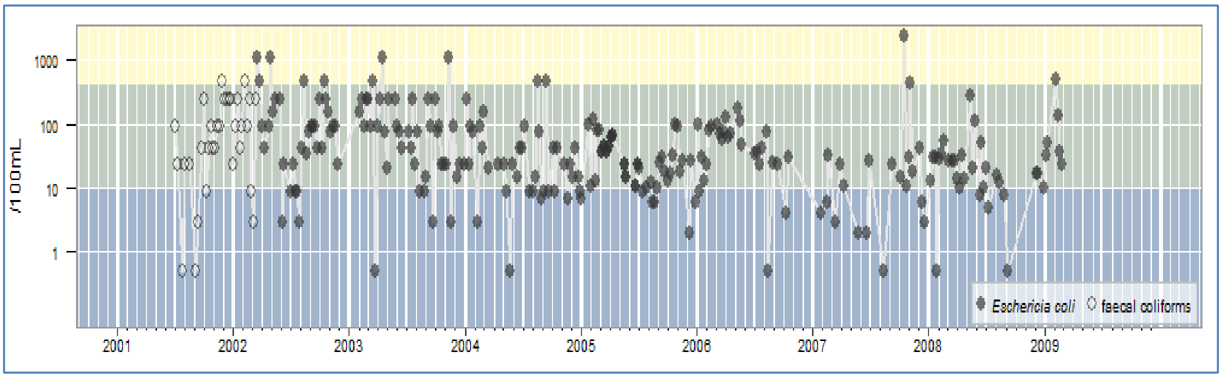

Figure 5-6: Kanoneiland Canal

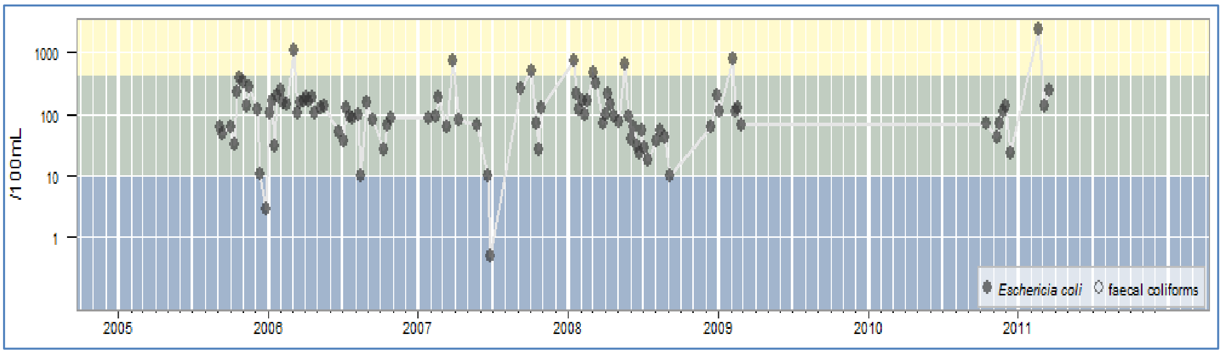

Figure 5-7: Keimoes

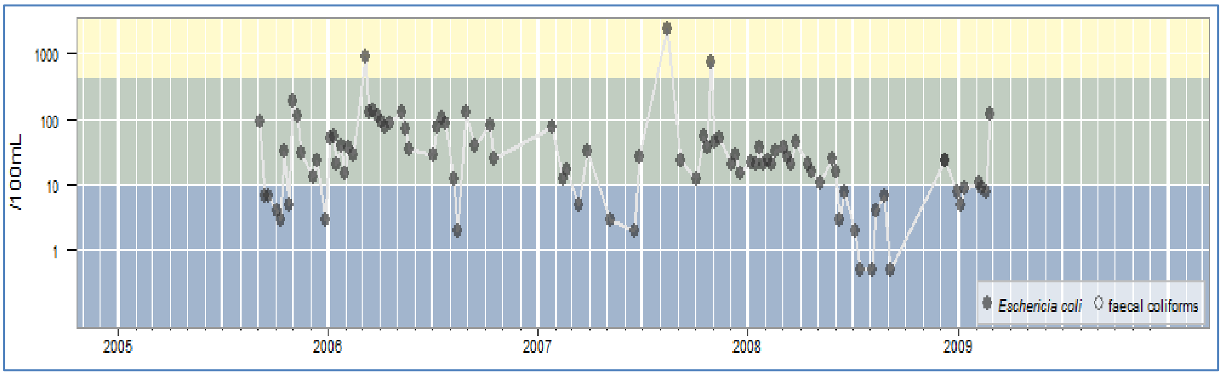

Figure 5-8: Kakamas

Potable water should not have detectable E. coli levels at all according to the South African Water Quality Guidelines (1996). Their presence not only implies poor infrastructure management but also increased costs of water purification of supply. Water quality monitoring requires the monitoring of both the chemical and microbiological composition the water resource. Therefore, potable on the basis of its chemical composition may not necessarily be safe bacteriologically.

II. National Chemical Monitoring Programme (NCMP)

The water quality for the Lower Orange River shows a general increase in total alkalinity. This is illustrated in the combined Maucha diagrams for the 10 monitoring sites in Figure 5-9. Only the Vaal River site shows a lower increase, the St. Clair. Bucklands Canal site indicates a slightly more balanced diagram with slight increases in total salinity and sodium.

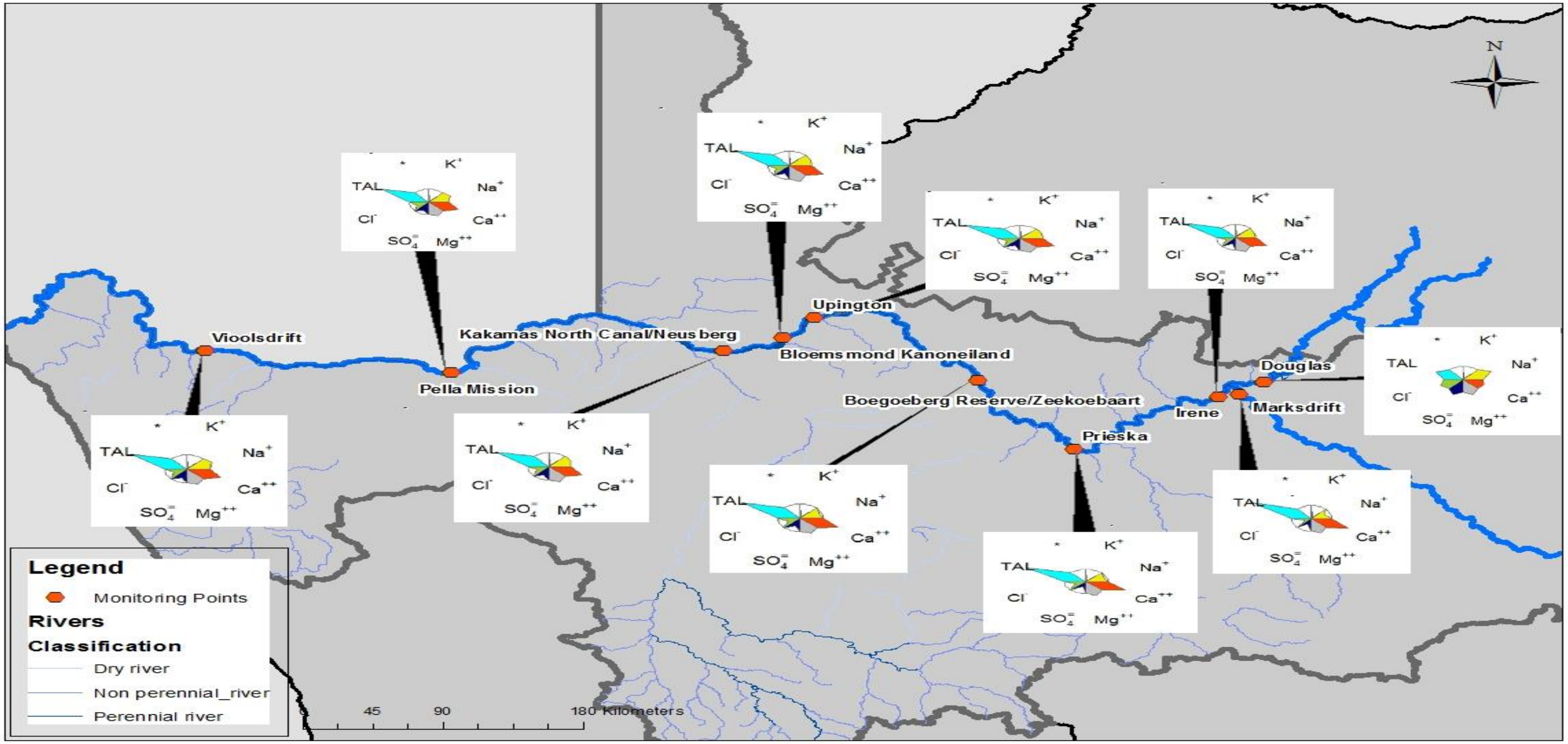

Figure 5-9: Maucha diagram water quality change for the period 1952 - 2018

5.2.1 Marksdrift

This is the last point in the Orange River (the highest point in the Lower Orange) ~15 km before the confluence with the Vaal River. This is one of the more recent sites in terms of historical data as shown in Table 13.

Table 13: Marksdrift station information

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS101824 / D3H008Q01	1905	29/03/1996	12/09/2018

The chemistry of the water at the Marksdrift monitoring station is shown in Figure 5-10. The plot indicates that the river water is a calcium bicarbonate type indicating the presence of alkaline.

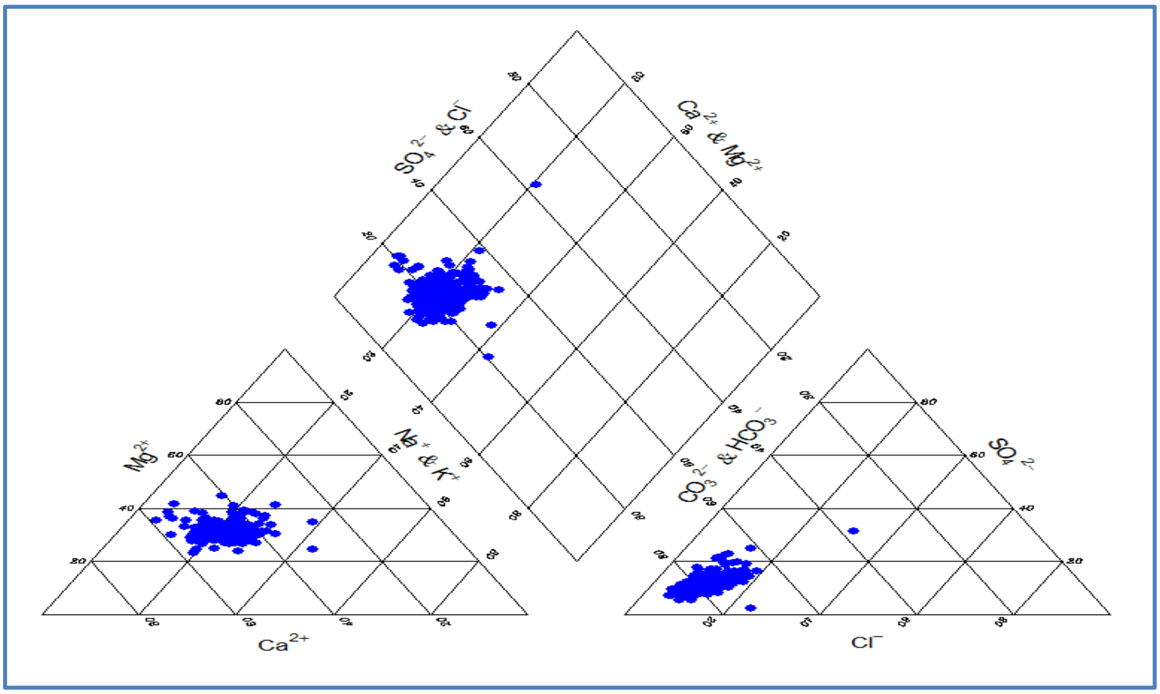

Figure 5-10: Piper diagram for Marksdrift monitoring station

Table 14 provides the statistical analysis based on yearly values for the Marksdrift monitoring station with the average for the period of time.

Table 14: Statistical analysis for Marksdrift

	Ca	Cl	EC	K	Mg	Na	pH	SO_4	TAL
Mean	20,94	7,21	22,16	1,71	8,11	9,21	8,17	12,23	85,40
Median	20,65	7,22	22,27	1,55	7,90	8,96	8,16	12,00	83,83
Std. Dev.	1,85	1,67	2,21	0,47	1,12	1,86	0,11	1,13	9,98

Figure 5-11 shows the concentration of the total solute per 5 year cycle since 1991 in milli-equivalents per litre. The height of the bar is proportional to the concentration of anions or cations. The left half of the bars represents cations and the right anions.

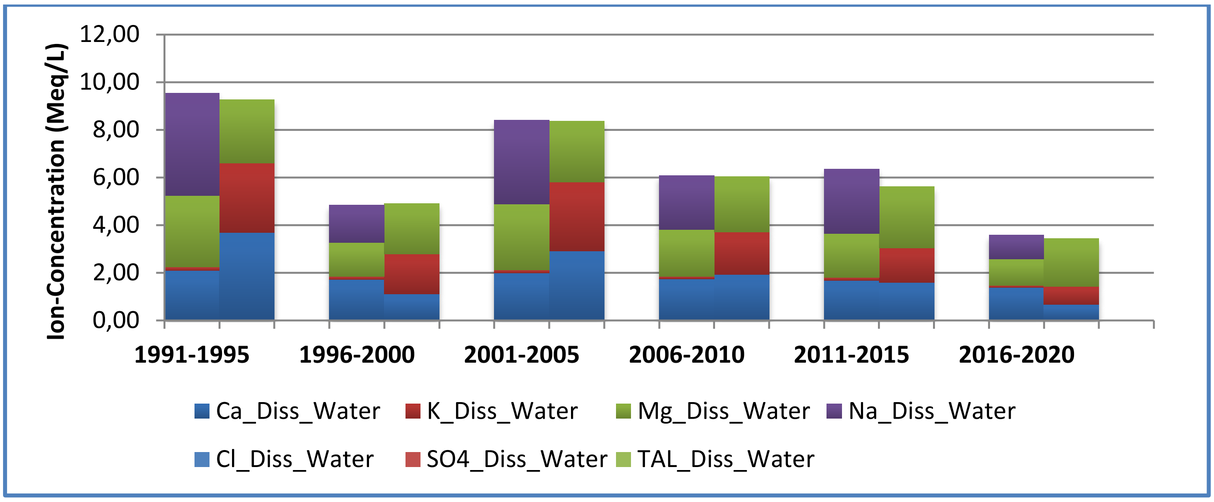

Figure 5-11: Ion-Concentration diagram for Marksdrift

4 sites have been chosen (according to priority) for ion concentration analysis. 2 sites are for the 2 rivers (Orange River and Vaal River); 1 site downstream of the confluence; and 1 site at the largest development along the river (Upington).

The trend analysis used for all the sites indicates the various parameters sampled and analysed throughout the monitoring years. The South African Water Quality Guidelines (1996) were used as a baseline for water quality limits and the legend (according to colour) is as shown in Figure 5-12 below. Orange cross hatch indicate periods of unreliable data.

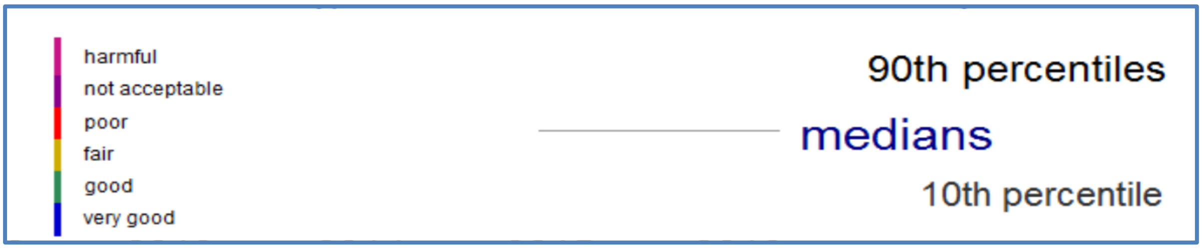

Figure 5-12: Legend for colour coding in trend analysis

The results indicate an increase in the concentration of total alkalinity and calcium over the years of sampling. There are years where sampling was not done at all. There were concerns for the concentration of total phosphates and the nitrogen load. These may be due to the high number of agricultural activities upstream of the sampling point. The trend for the Marksdrift station is shown in Figure 5-13.

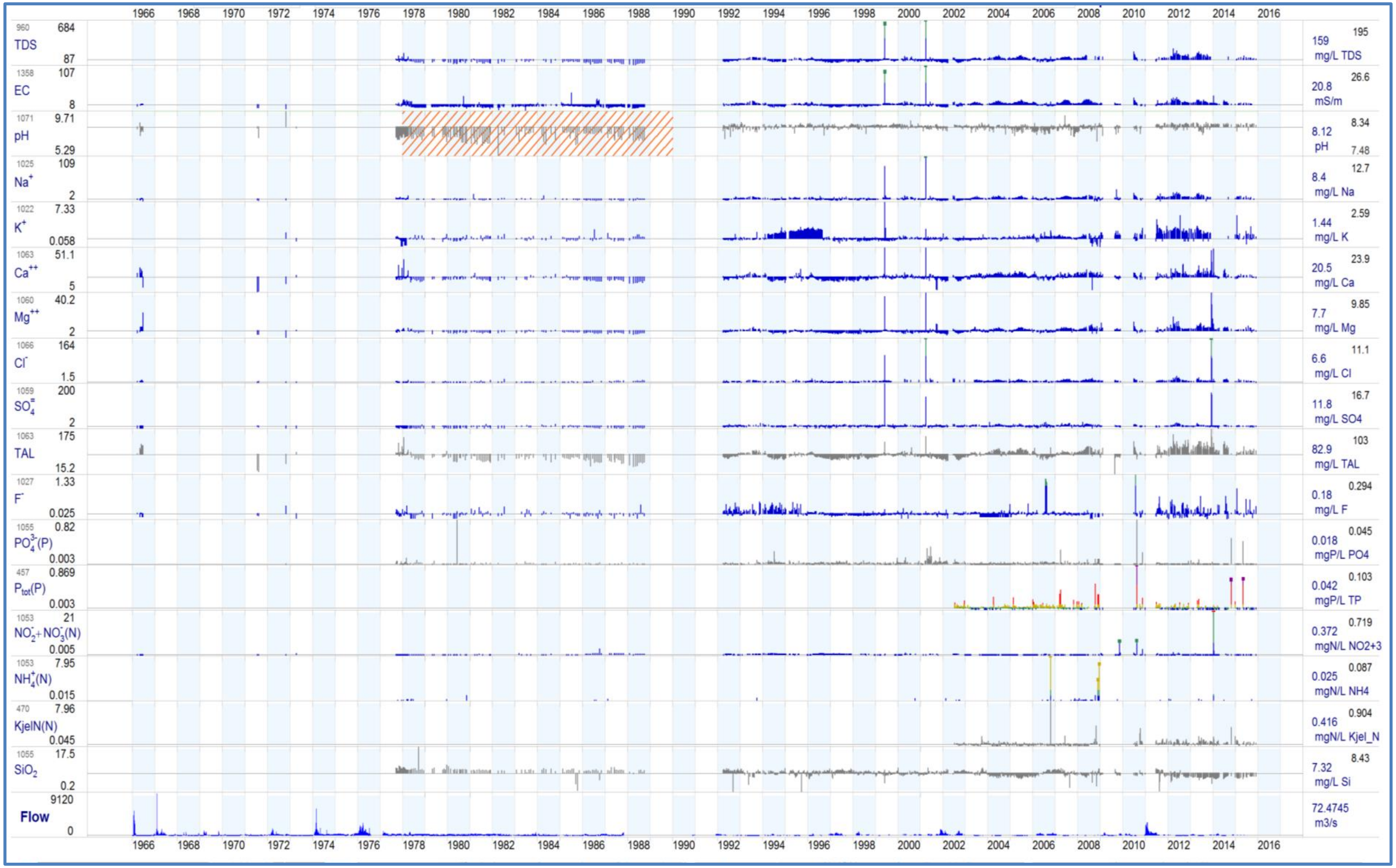

Figure 5-13: Trend analysis for the Marksdrift monitoring station

5.2.2 St. Clair Douglas Bucklands Canal

This is the last point before the confluence (of the Orange and Vaal River) ~23 km upstream. The point is marked as Douglas in Figure 5-9. The station has been active since 1992 as shown in Table 15.

Table 15: Bucklands

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS90905 / C9H017Q01	987	10/12/1992	19/06/2018

The chemistry of the water at the St. Clair Douglas Bucklands Canal monitoring station is shown in Figure 5-14. The plot indicates that the river water has a history of fluctuation between calcium bicarbonate and calcium sulphate type. This may be a result of the mixture between the Orange and Vaal River waters through the Barrage.

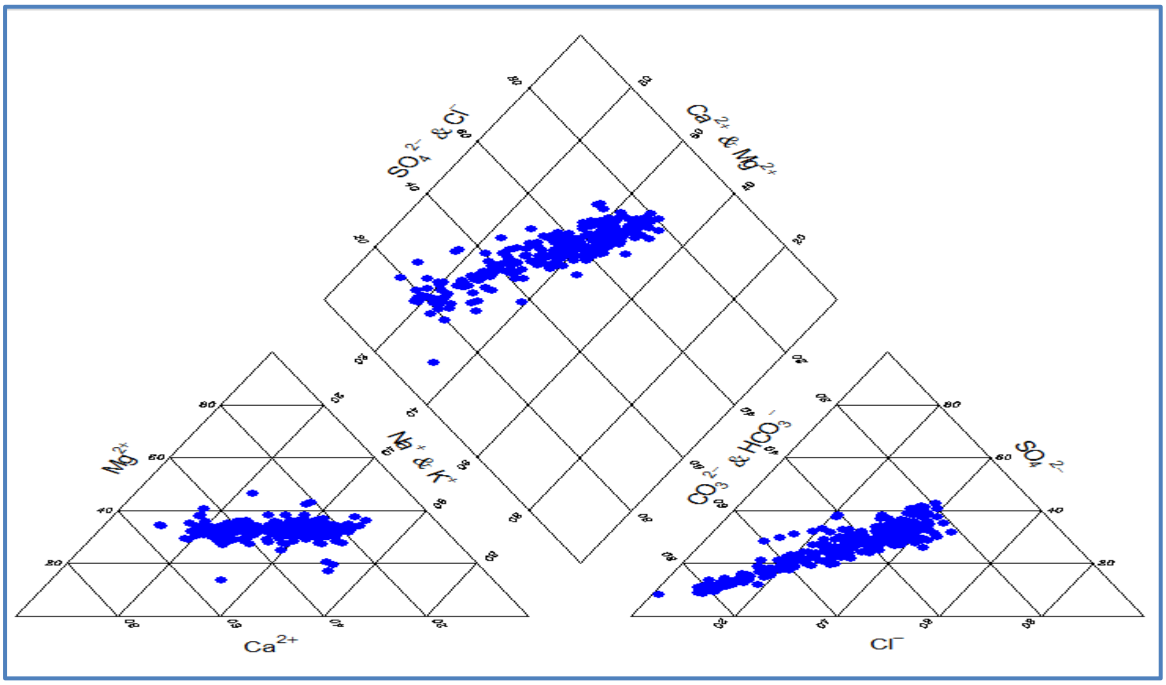

Figure 5-14: Piper diagram for St. Clair Douglas Bucklands Canal

Table 16 shows the statistical analysis of the station from 1991 to 2018.

Table 16: Statistical analysis for St. Clair Douglas Bucklands Canal

	Ca	Cl	EC	K	Mg	Na	pH	SO_4	TAL
Mean	35,87	70,81	65,92	4,80	24,83	58,09	8,27	96,00	119,84
Median	36,00	64,46	61,85	4,78	23,28	55,53	8,29	85,63	119,90
Std. Dev.	6,69	45,24	25,93	1,28	10,44	32,49	0,11	51,15	17,17

Figure 5-15 is an illustration of the ion concentration of the site through 5 year cycles. There has been a steady decline in the concentration volumes from the years.

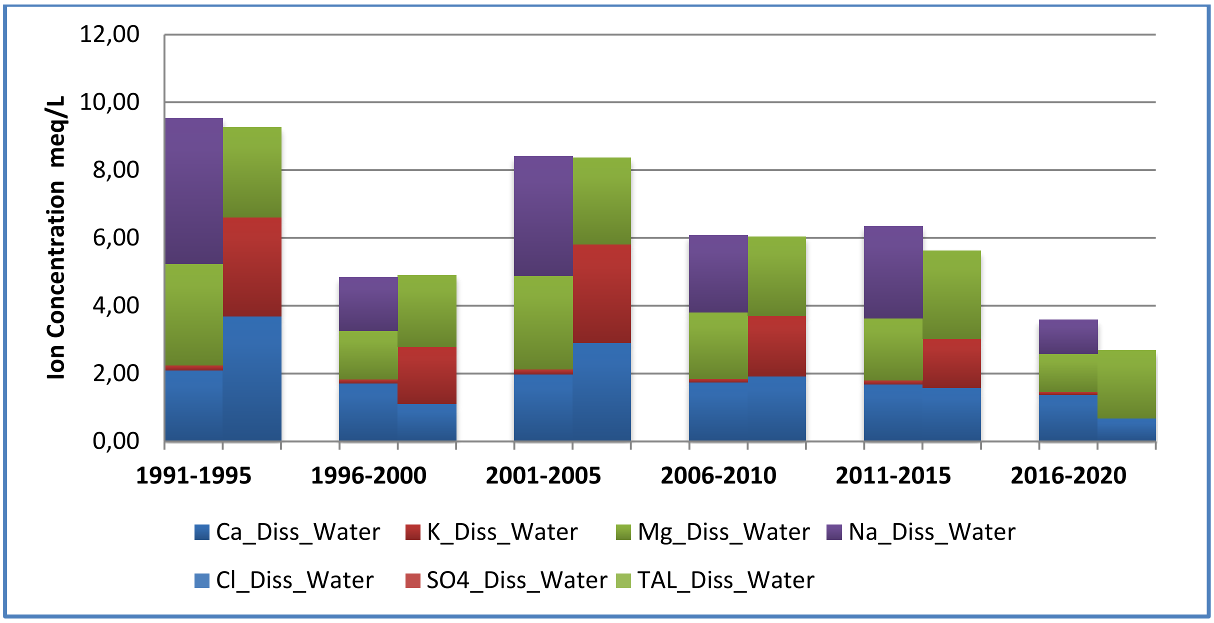

Figure 5-15: Ion concentration diagram for St. Clair Douglas Bucklands Canal

There has been a general increase in concentration volumes of both anions and cations with a more prominent increase in total alkalinity and sodium over the years of sampling (Figure 5-16). There are also months in 2009 and 2011 where sampling was not done. There are concerns for the concentrations of total phosphates during the periods were it was sampled. This may also be due to the high number of agricultural activities in the area upstream of the sampling point.

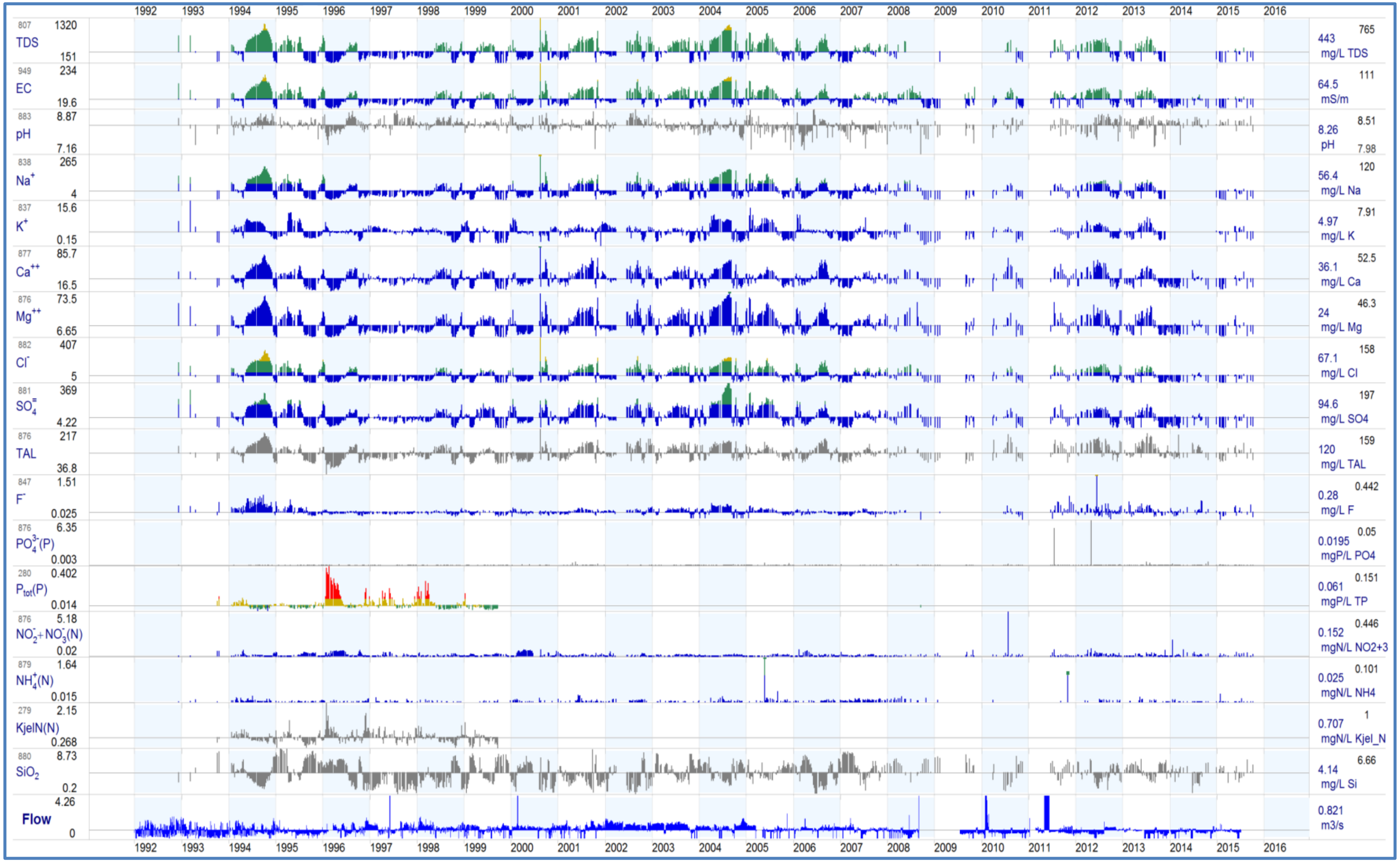

Figure 5-16: Trend analysis for the St. Clair Douglas Bucklands Canal monitoring station

5.2.3 Irene

This is the first point after the confluence between the Orange and Vaal Rivers ~15 km downstream, shown as Irene in Figure 5-9. Table 17 summarises the site information.

Table 17: Irene

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS101881 / D7H012Q01	98	27/02/1986	19/06/2018

The chemistry of the water at the Irene monitoring station is shown in Figure 5-17. The plot indicates that the river water is a calcium bicarbonate type with outliers of calcium sulphate.

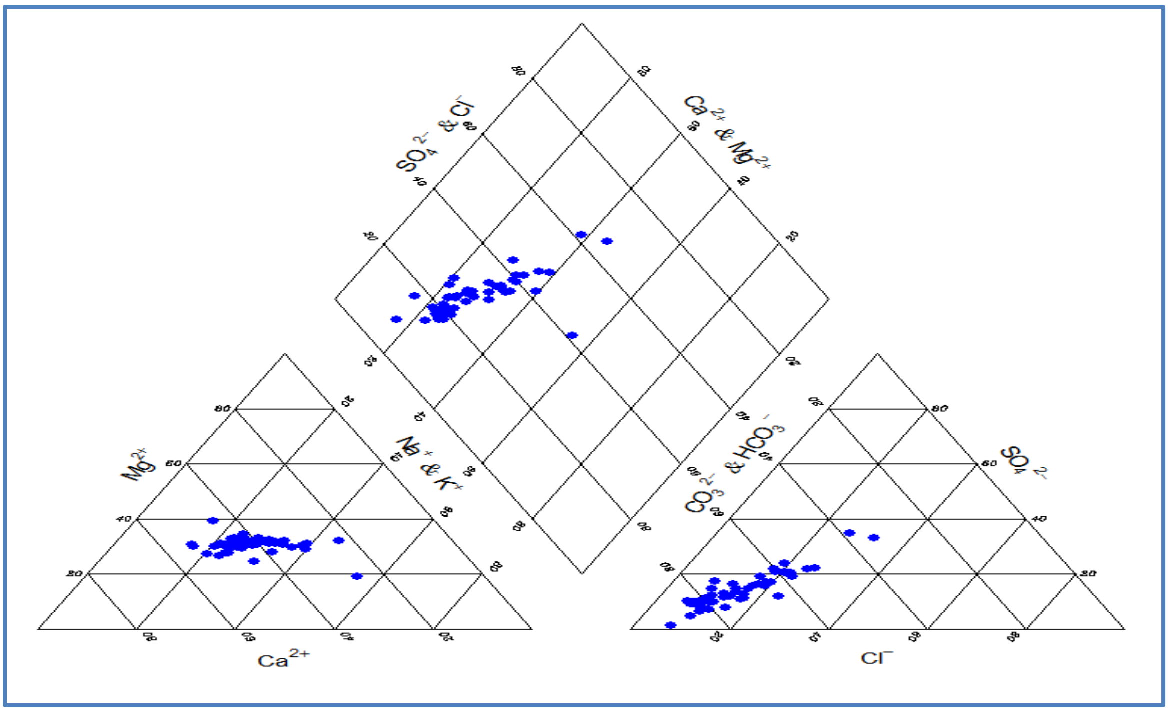

Figure 5-17: Piper diagram for Irene

There were an alarming number of years where sampling was not done due to lack of access to site and personnel. The region relied on the local Water User Association for the collection of the data and during this period, it did not have the capacity for constant monitoring. The cross-hatching orange lines are used to show a period of unreliable data (Figure 5-18). There are concerns in recent years (2014) over the high concentrations of electrical conductivity, magnesium, chloride and sulphates concentrations.

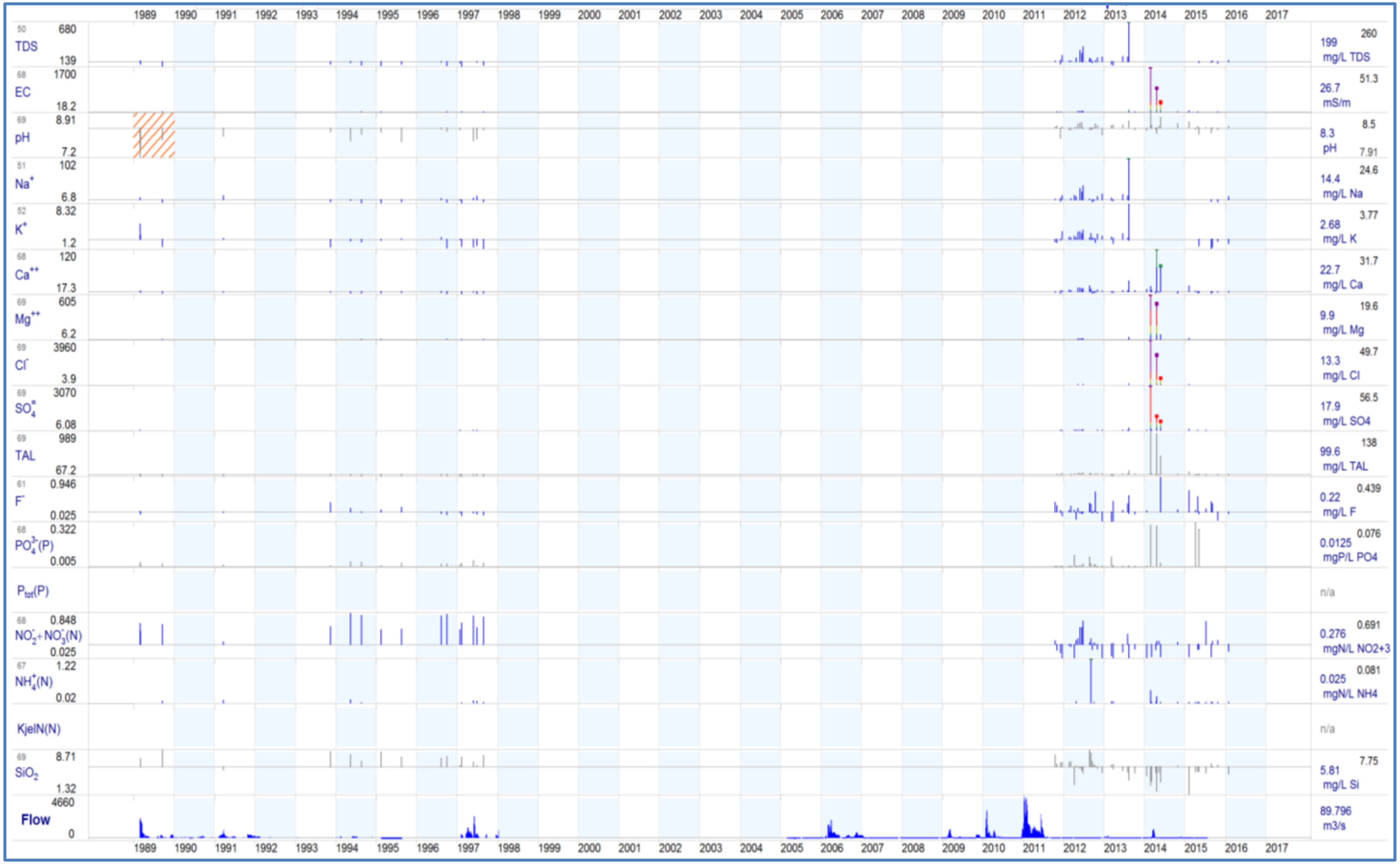

Figure 5-18: Trend analysis for the Irene monitoring station

5.2.4 Prieska

This is the second point after the confluence between the Orange and Vaal Rivers and found on the Orange River near the town of Prieska ~150 km downstream of the Irene Monitoring Station. Information about the site is summarised in Table 18.

Table 18: Prieska

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS101874 / D7H002Q01	1468	24/10/1952	17/04/2018

The chemistry of the water at the Prieska monitoring station is shown in Figure 5-19. The plot indicates that the river water is a calcium bicarbonate type with calcium sulphate outliers.

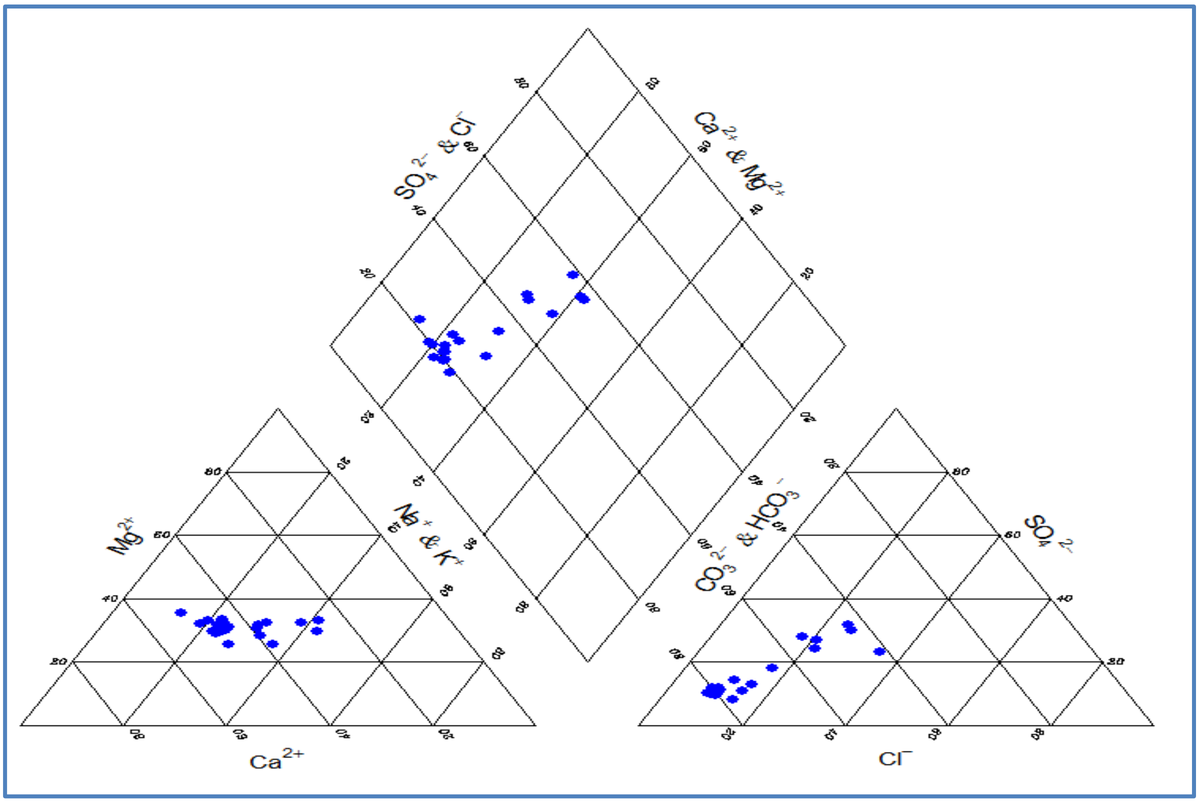

Figure 5-19: Piper diagram for Prieska

Table 19 provides that statistical analysis from 1991 to 2018.

Table 19: Statistical analysis for Prieska

	Ca	Cl	EC	K	Mg	Na	pH	SO_4	TAL
Mean	24,21	18,16	30,95	2,44	11,16	15,56	8,22	21,24	98,20
Median	23,20	12,93	26,43	2,41	10,10	13,29	8,30	16,83	92,90
Std. Dev.	4,12	12,54	10,06	0,81	4,17	6,05	0,22	12,83	20,89

The ion concentration levels of the Upington site are illustrated in Figure 5-20. The levels show missing data between the 2006 and 2010 5 year cycle. This was a result of a lack of capacity to sample the site as there was no dedicated official for river sampling from the regional office.

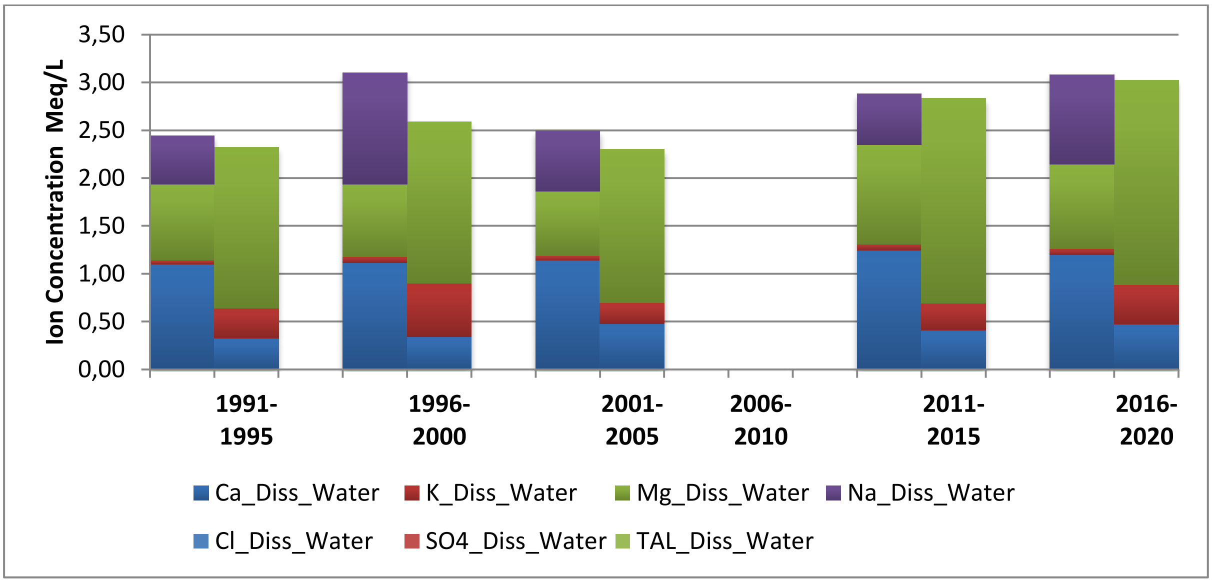

Figure 5-20: Ion concentration for Prieska

Figure 5-21 shows an increase in the concentration of total alkalinity and calcium over the years of sampling. There is also an extensive period (between 1967 – 1977 and 1997 – 2013) when sampling was not done while the cross-hatching orange lines are used to show a period of unreliable data. The major concern in recent years (2015) would have been the sudden increase in the EC and TDS. However, this proved to be an outlier as the data returned quickly to the average concentration.

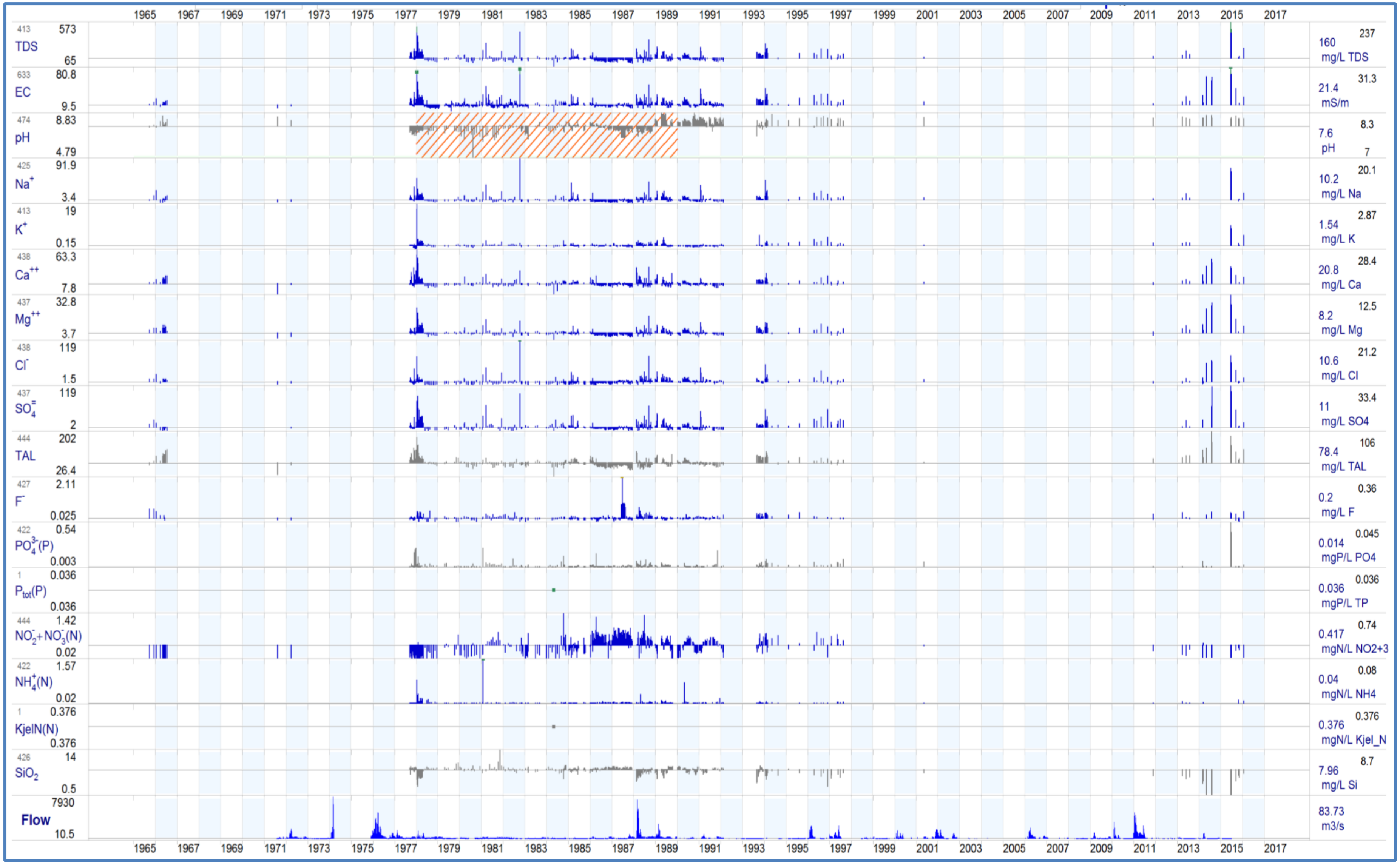

Figure 5-21: Trend analysis for the Prieska monitoring station

5.2.5 Boegoeberg Reserve/ Zeekoebaart

This site if found ~117 km downstream of the Prieska monitoring station. The site has been active from 1 April 1966 as shown in Table 20.

Table 20: Boegoeberg

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS101878 / D7H008Q01	1111	01/04/1966	18/04/2017

The chemistry of the water at the Boegoeberg Reserve/ Zeekoebaart monitoring station is shown in Figure 5-22. The plot indicates that the river water is a calcium bicarbonate type.

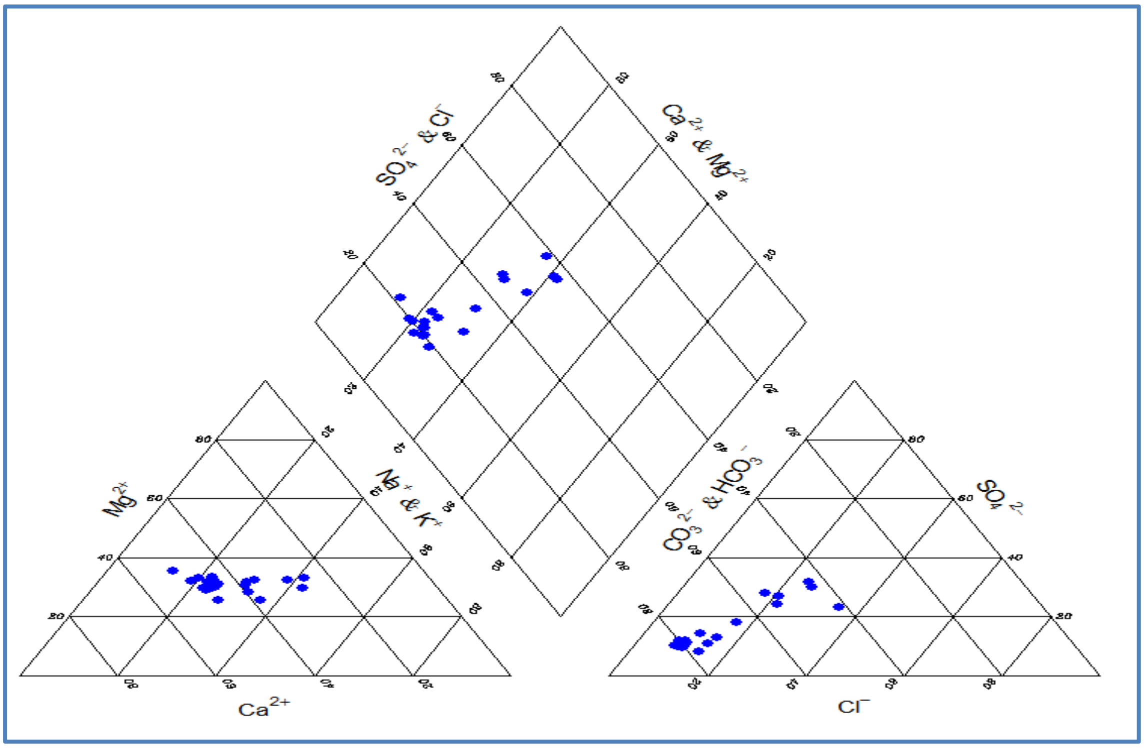

Figure 5-22: Piper diagram for Boegoeberg Reserve/ Zeekoebaart

Figure 5-23 indicates an increase in the concentration of total alkalinity and calcium over the years of sampling. There are several years (between 1972 – 1977 and after 2010) when sampling was not done while the cross-hatching orange lines are used to show a period of unreliable data. The major concern in the sampling years would have been the sudden increase in the chloride content around 1996 and 2000. The large gaps in data make it difficult of establish a clear trend in water quality from the data, however the piper diagram provides a better analysis.

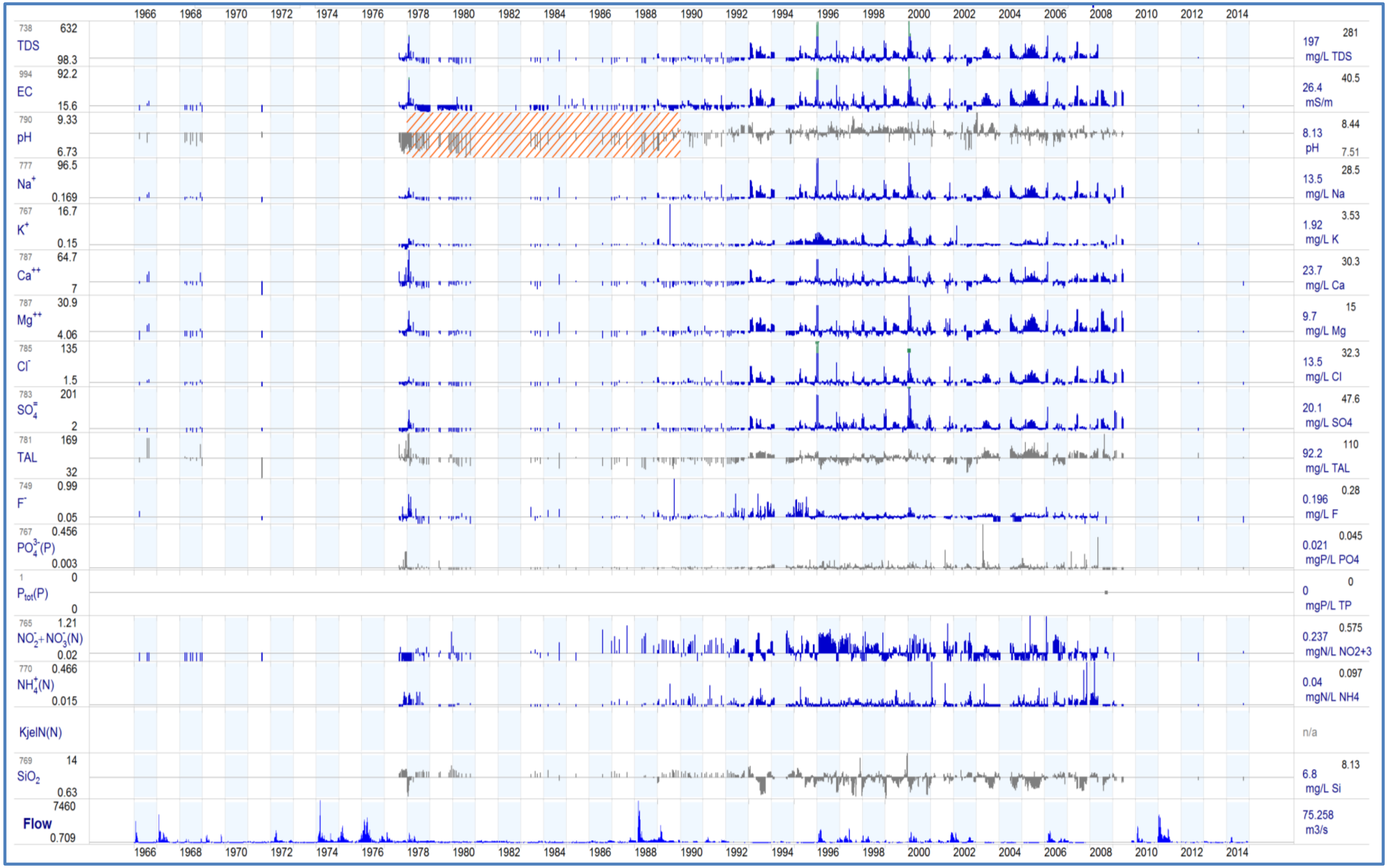

Figure 5-23: Trend analysis for the Boegoeberg Reserve/ Zeekoebaart monitoring station

5.2.6 Upington

Table 21 summarises information on the Upington site. The site is found ~160 km downstream of the Boegoeberg Reserve/ Zeekoebaart monitoring station. Upington is the largest town along the river system.

Table 21: Upington

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS10187 / D7H005Q01	4211	03/10/1952	26/02/2016

The chemistry of the water at the Upington monitoring station is shown in Figure 5-24. The plot indicates that the river water is a calcium bicarbonate type with calcium sulphate outliers.

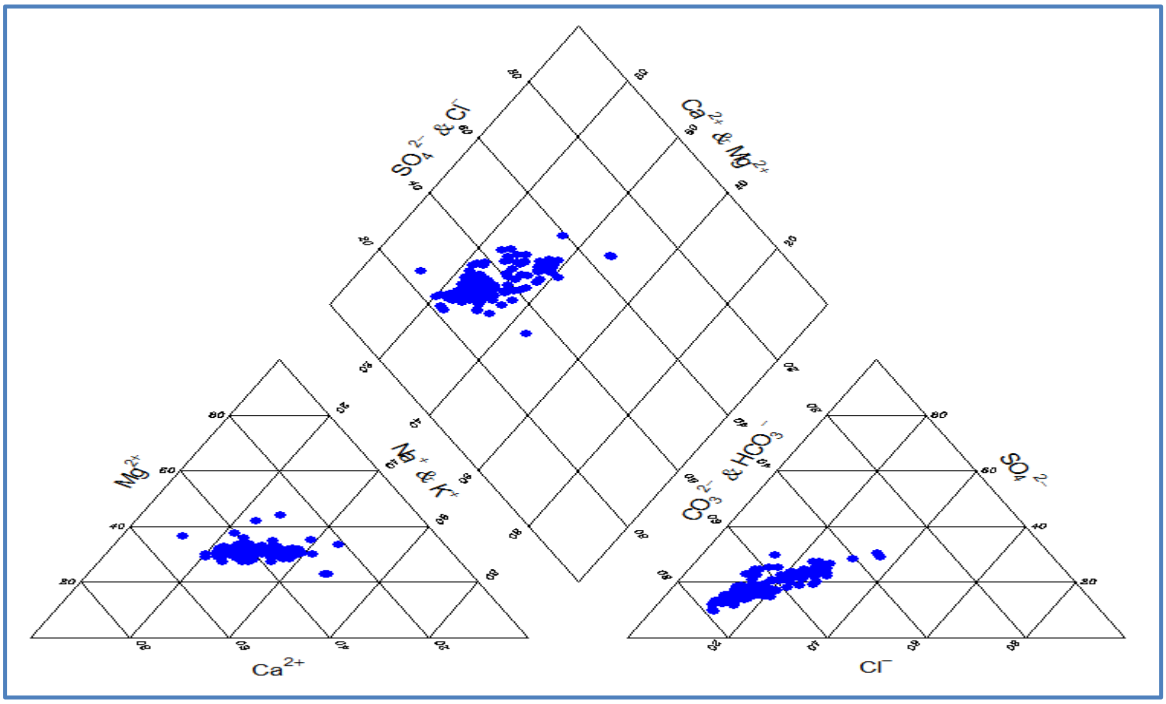

Figure 5-24: Piper diagram for Upington

Table 22 summarise the statistical analysis for the site.

Table 22: Statistical analysis for Upington

	Ca	Cl	EC	K	Mg	Na	pH	SO_4	TAL
Mean	27,04	21,00	35,30	2,53	12,54	20,86	8,17	29,98	107,29
Median	27,38	19,81	36,70	2,27	13,03	21,26	8,18	27,07	110,43
Std. Dev.	3,45	6,91	6,80	0,91	2,43	6,33	0,16	12,54	15,85

The ion concentration levels have remained relatively steady through the year. This is shown in Figure 5-25.

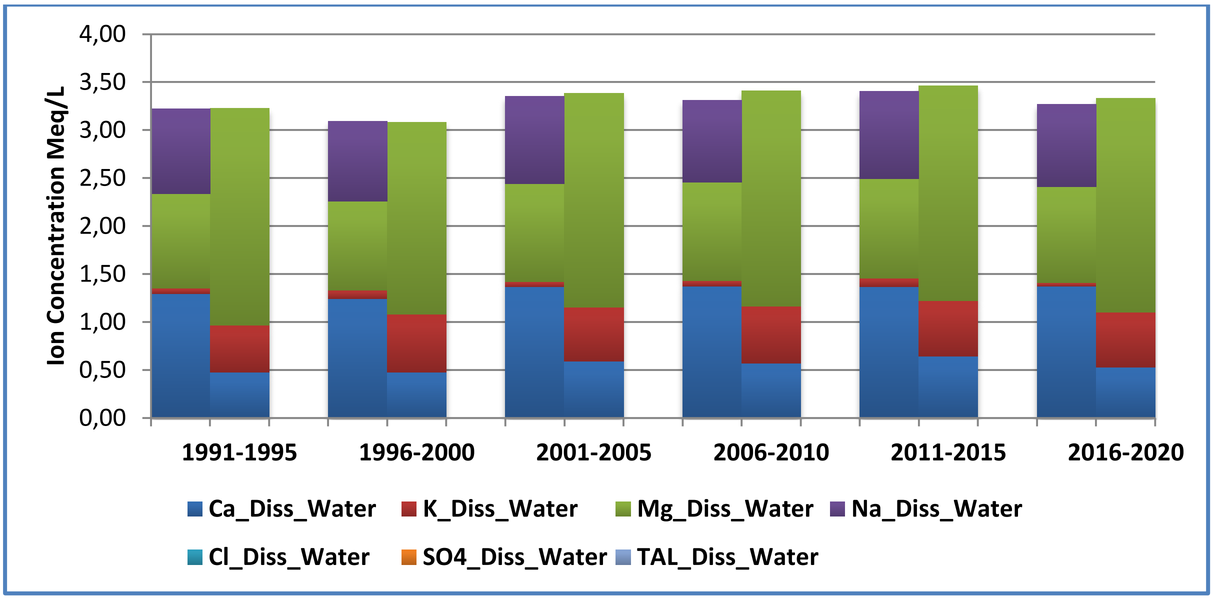

Figure 5-25-: Ion Concentration diagram for Upington

The trend indicates an increase in the concentration of total alkalinity and calcium over the years of sampling (Figure 5-26) The trend also indicates years (between 1969 – 1973; 1976 - 1983 and sporadic sampling after 2012) when sampling was not done while the cross hatch orange lines are used to show periods of unreliable data.

Concerns should be raised over the high levels of phosphates in the system at the point. The major agricultural activities taking place just upstream of the monitoring station may be the major reason behind this state.

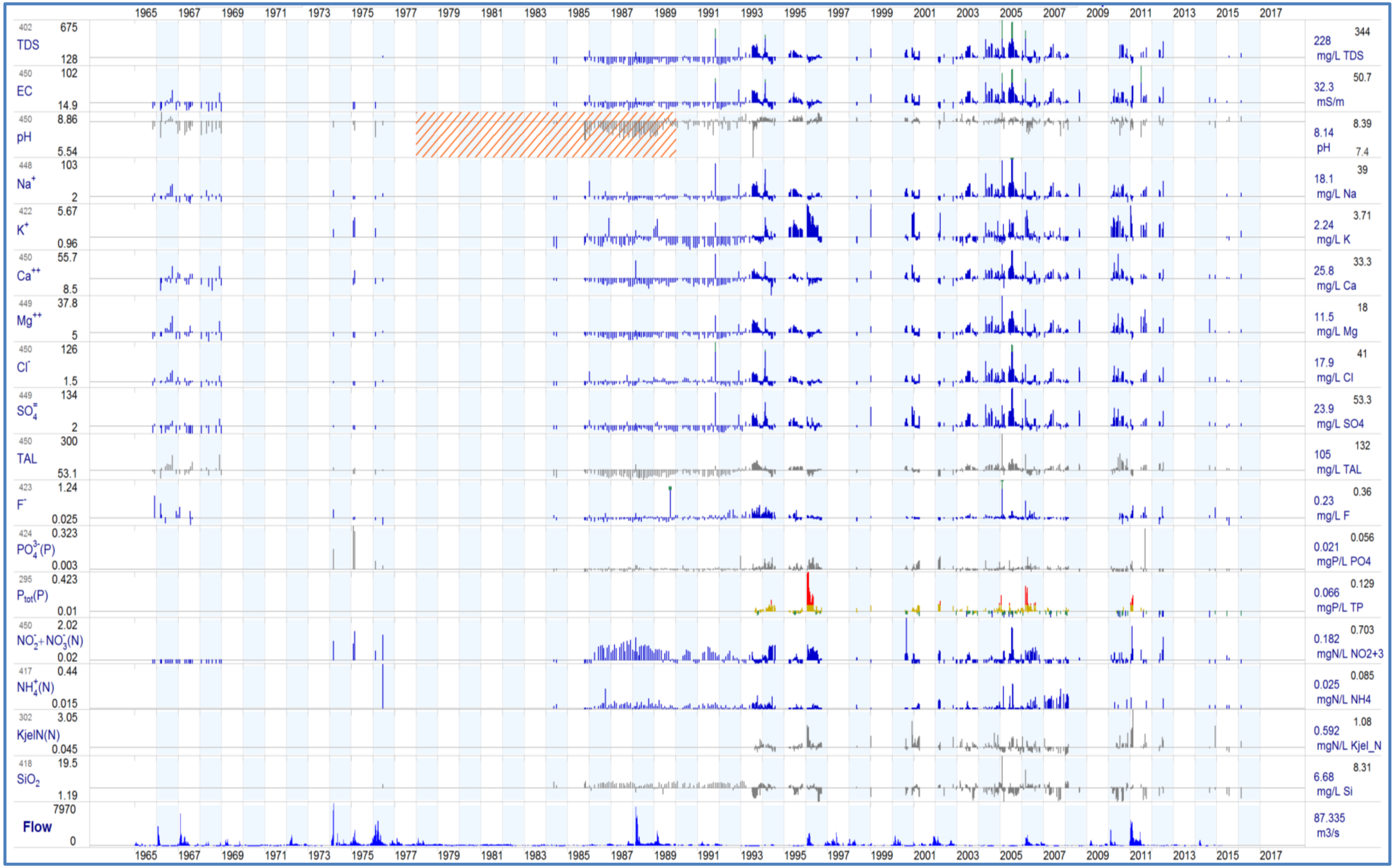

Figure 5-26: Trend analysis for the Upington monitoring station

5.2.7 Bloemsmond Konaneiland

The site is found along the famous Orange River Islands as the river fans out before the Augrabies Falls ~32 km downstream of the Upington monitoring station. Site information is summarised in Table 23.

Table 23: Bloemsmond Konaneiland

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS18756	153	08/03/2000	13/12/2015

The chemistry of the water at the Bloemsmond Konaneiland monitoring station is shown in Figure 5-27 below: The plot indicates that the river water is a calcium bicarbonate type with very little change over the period.

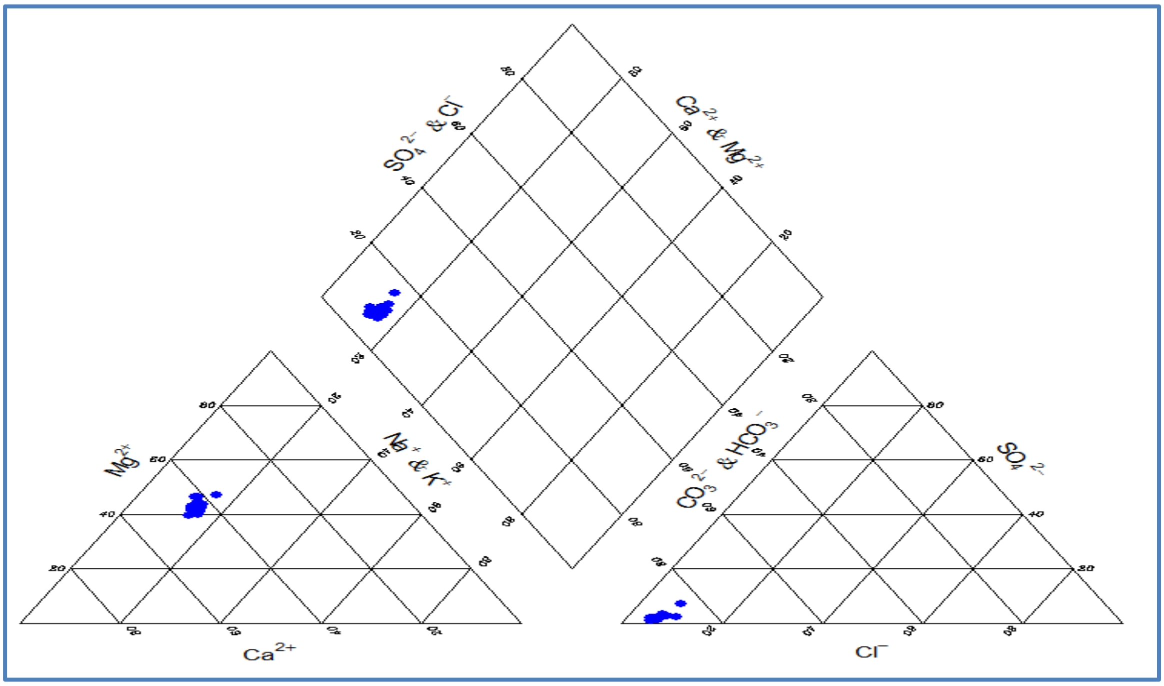

Figure 5-27: Piper diagram for Bloemsmond Konaneiland

The trend indicates an increase in the concentration of total alkalinity and calcium over the years of sampling. Figure 5-28 shows sporadic sampling throughout the years. The high phosphates levels can be attributed to the large agricultural activities that characterise this area of the Catchment. Although the large gaps in data make it difficult to establish a clear trend in the water quality, the piper diagram indicates little change in water quality.

Figure 5-28: Trend analysis for the Bloemsmond Kanoneiland monitoring station

5.2.8 Kakamas North Canal/ Neusberg

This is the last site (summarised in Table 24) before the Augrabies Falls and ~41 km downstream of the Bloemsmond Konaneiland Monitoring Station.

Table 24: Kakamas

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS101885 / D7H016Q01	861	25/08/1995	29/05/2015

The chemistry of the water at the Kakamas North Canal/ Neusberg Monitoring Station is shown in Figure 5-29 below: The plot indicates that the river water is a calcium bicarbonate type.

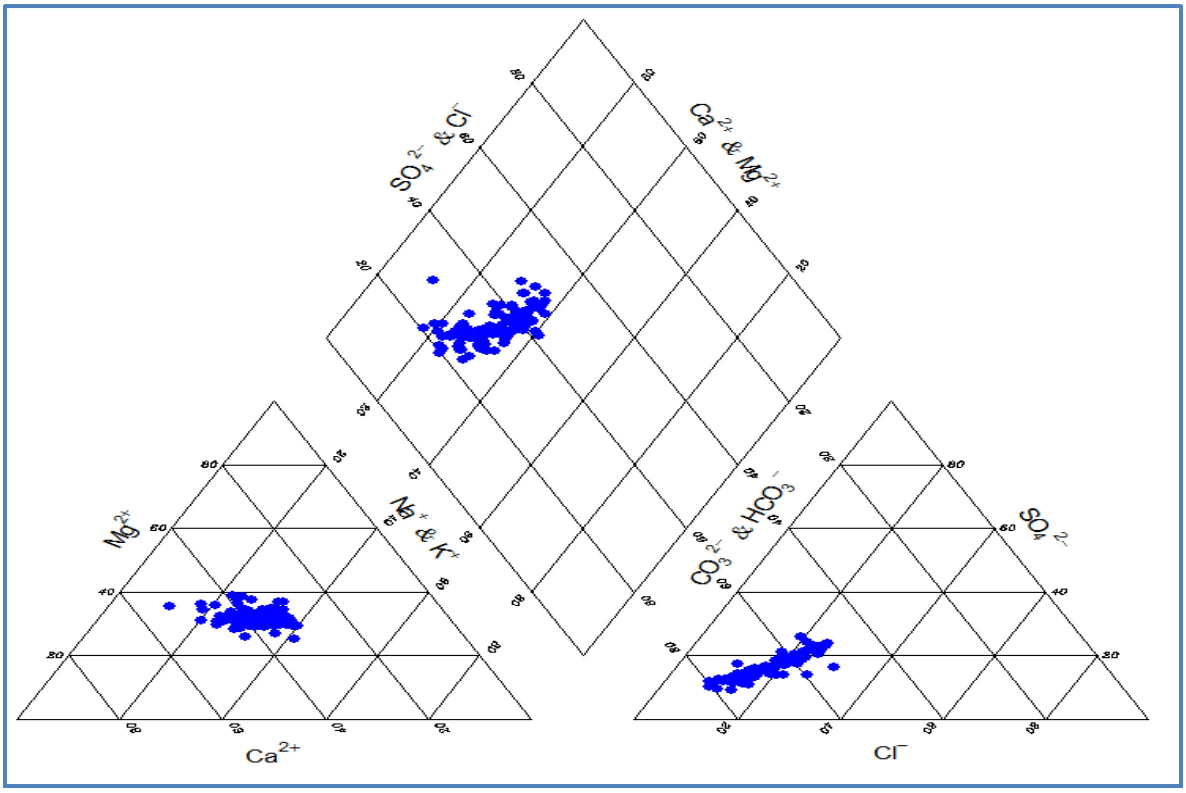

Figure 5-29: Piper diagram for Kakamas North Canal/ Neusberg

The trend in Figure 5-30 also shows an increase in the concentration of total alkalinity and calcium over the years of sampling. There are gaps in sampling through some of the years (2006, 2009 and 2011). The high phosphates levels can also be attributed to the large agricultural activities that characterise this area of the Catchment.

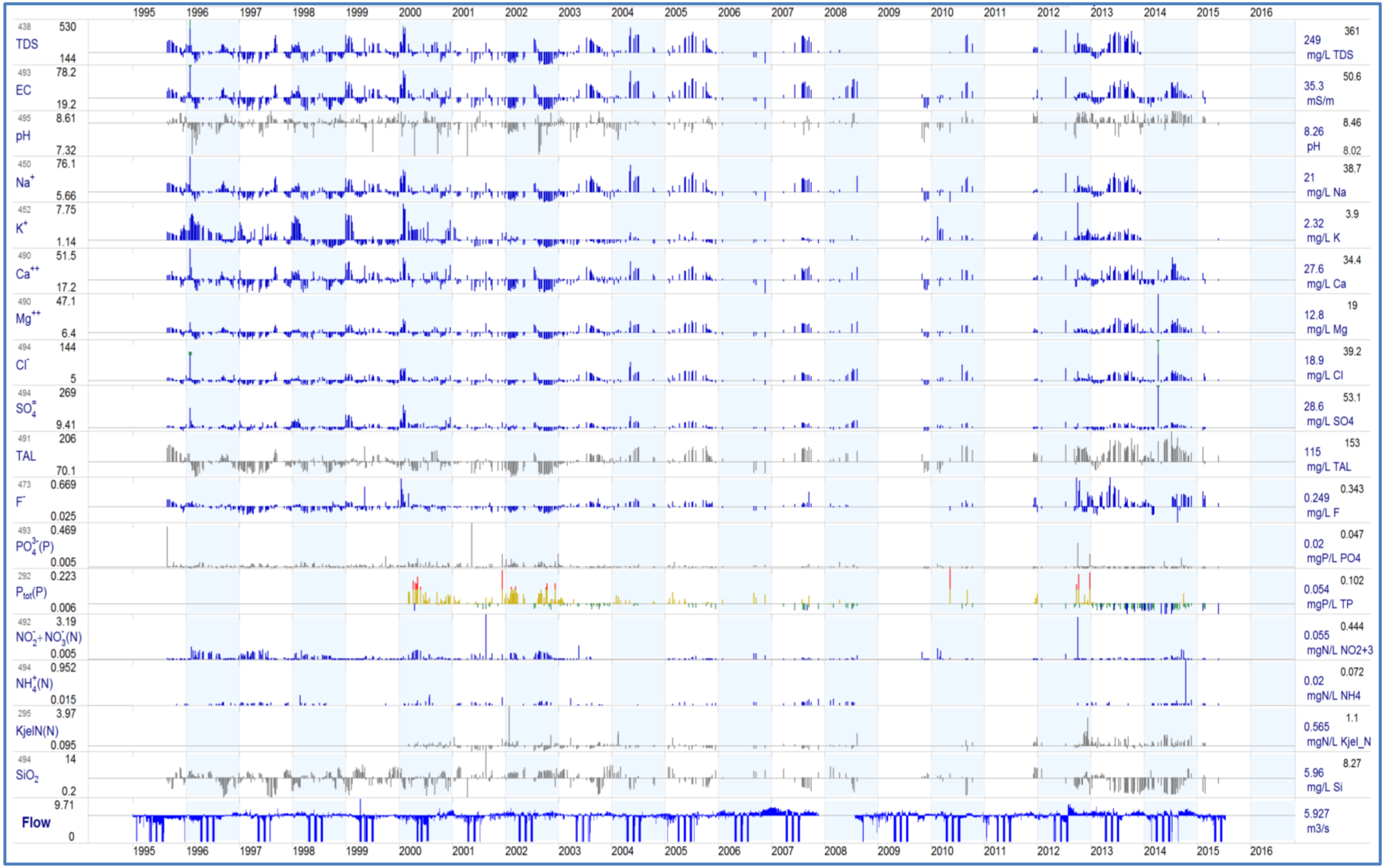

Figure 5-30: The Kakamas North Canal/ Neusberg monitoring station trend analysis

5.2.9 Pella Mission

The site is the first monitoring points after the Augrabies Falls ~220 km downstream of the Kakamas North Canal/ Neusberg Monitoring Station and is shown in Table 25.

Table 25: Pella

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS1011893 / D8H008Q01	1582	28/04/1980	20/05/2015

The chemistry of the water at the Pella Mission Monitoring Station is shown in Figure 5-31. The plot indicates that the river water is a calcium bicarbonate type with a calcium sulphate outlier.

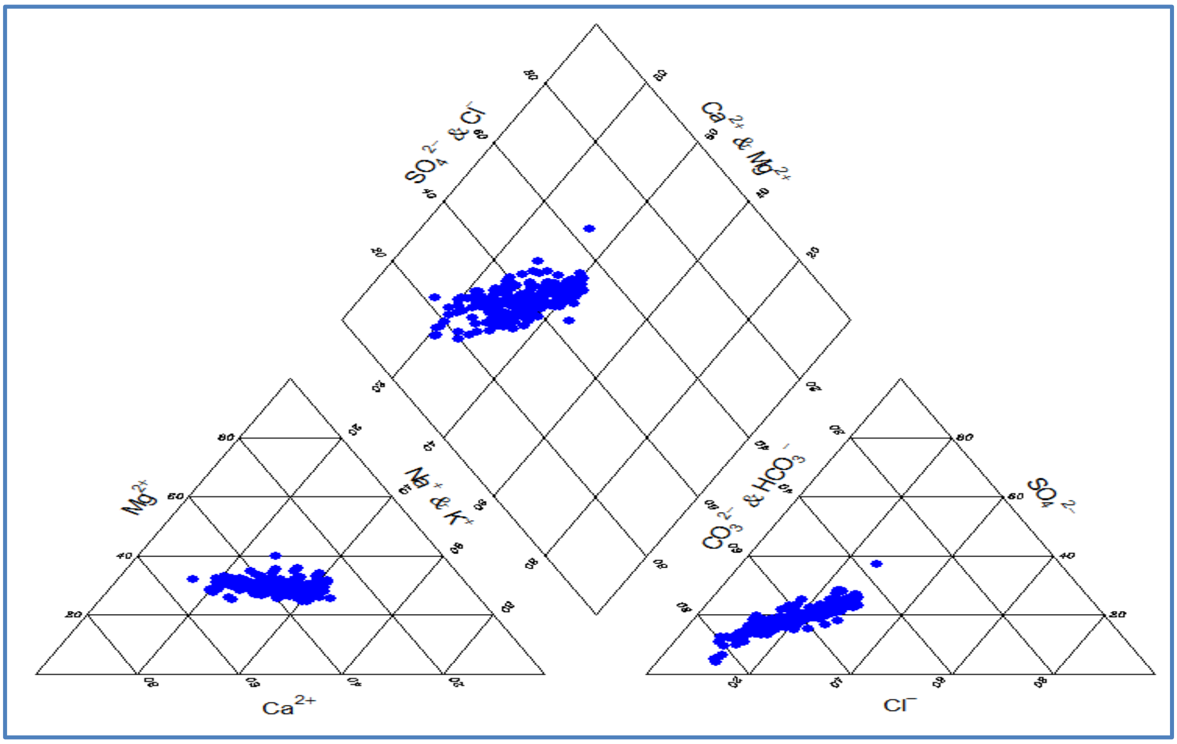

Figure 5-31: Piper diagram for Pella Mission

The trend in Figure 5-32 shows an increase in the concentration of total alkalinity and calcium over the years of sampling. There are large gaps in sampling during the early parts of the sampling period until 1995. The slanted orange lines are used to show periods of unreliable data. The high phosphates levels can be attributed to the large agricultural activities that take place upstream of the monitoring point.

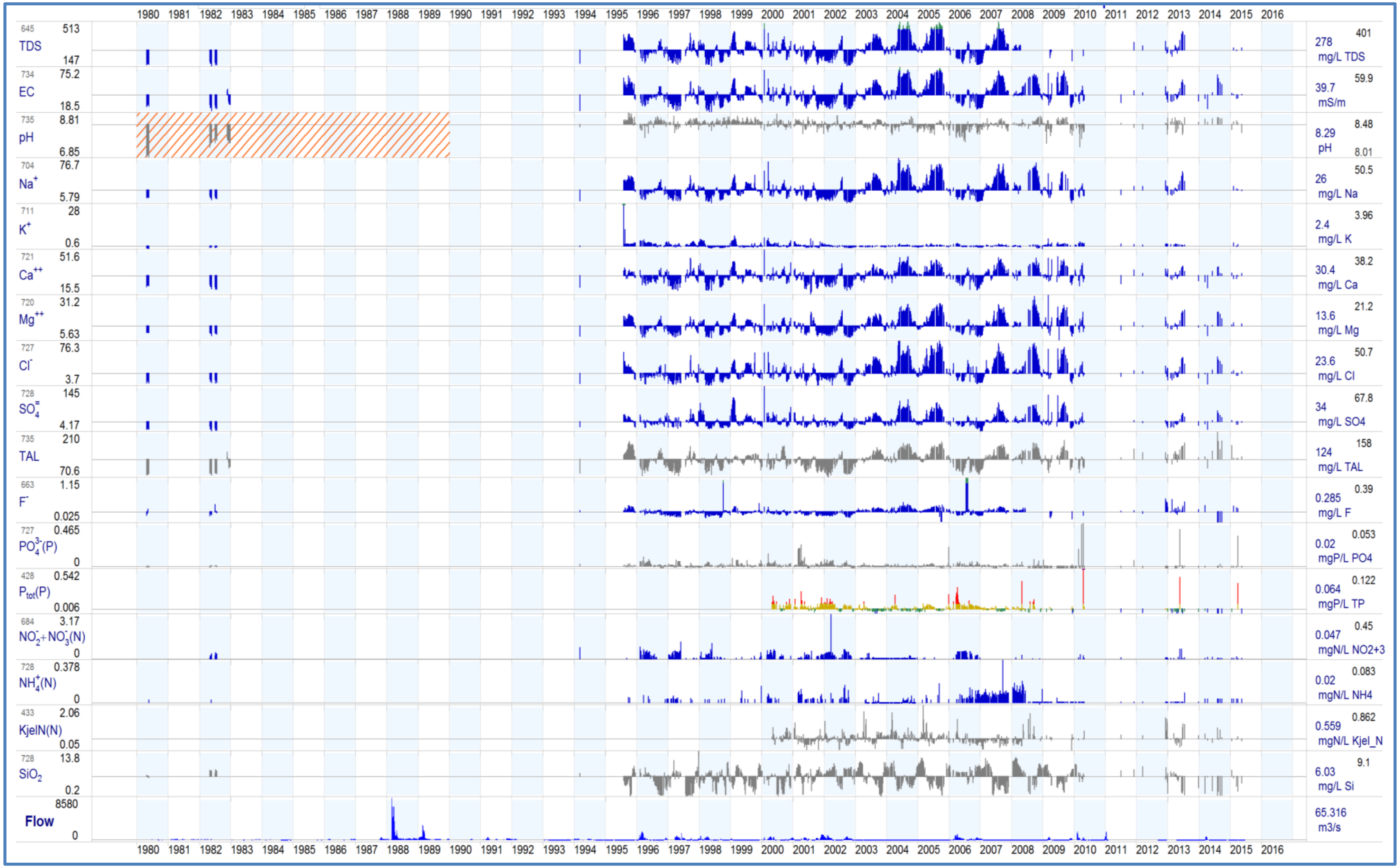

Figure 5-32: Trend analysis of the Pella Mission monitoring station

5.2.10 Vioolsdrift

This station is found Catchment ~160 km downstream of the Pella Mission Monitoring Station. The site is the last monitoring points before the mouth. Table 26 summarises the site information.

Table 26: Vioolsdrift

Site Code	No. of Samples	First Sample Date	Last Sample Date
WMS101888 / D8H003Q01	1893	16/02/1959	14/05/2018

The chemistry of the water at the Vioolsdrift Monitoring Station is shown in Figure 5-33. The plot indicates that the river water is a calcium bicarbonate type with calcium sulphate and sodium chloride outliers.

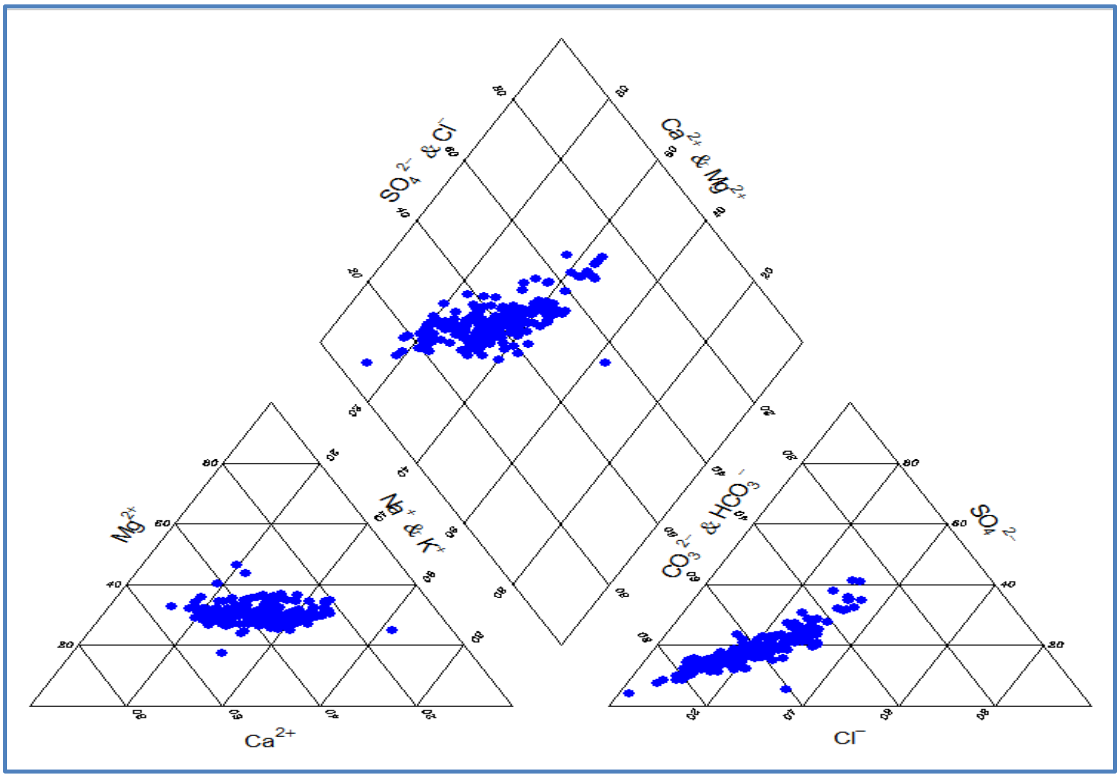

Figure 5-33: Piper diagram for Vioolsdrift

Figure 5-34 also indicates an increase in the concentration of total alkalinity and calcium over the years of sampling. There are also large gaps in sampling during the early parts of the sampling period until 1977. The cross-hatching orange lines are used to show periods of unreliable data. The high phosphates levels can be attributed to the large agricultural activities that take place upstream of the monitoring point along the river.

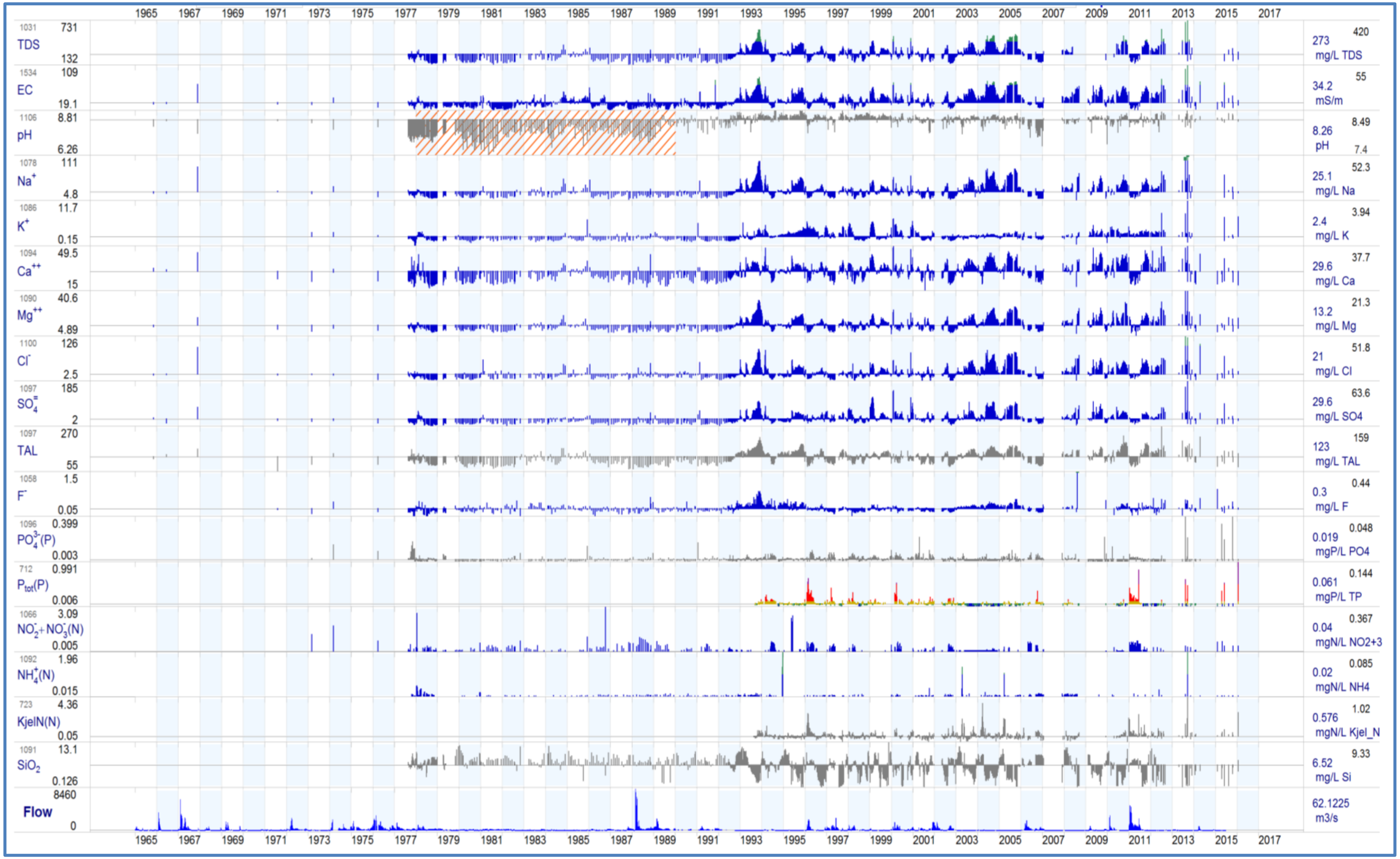

Figure 5-34: Trend analysis for the Vioolsdrift monitoring station

5.2.11 Summarized historic water quality status

There is a clearly distinct difference in water quality between the Vaal River and Orange River. The cumulative increase in the concentration levels of certain parameters over the monitoring years shows the impact of anthropogenic activities along the river. The Vaal River, being the most heavily used and impacted, shows the greatest increase in concentration amongst most parameters. Yet, the water quality downstream of the confluence shows the Orange River water trend being the more dominant.

The largest urban development along the Orange River is the town of Upington. However, there is no distinctive change in the water quality of the river downstream of Upington. This may be an indication of other activities (agricultural) impacting on the quality of water in the River or incorrect parameter selection for analysis.

The water quality displays consistent increase in the level of total alkalinity and calcium along the Orange River as it flows towards the mouth. Water quality high in these parameters reflects a high pH level. These parameters also increase the river's ability to neutralise acids entering the system. This could pose a long-term risk to aquatic organisms and potable water quality as the water becomes harder (more expensive) to clean as well as leading to a higher algae growth in the system.

In rivers, the main source of alkalinity is usually associated with soils and bedrocks that contain high levels of hydroxide compounds, bicarbonates, silicates and phosphates. Alkalinity and calcium are also related to hardness in water and also protect against rapid fluctuations in pH levels. This is most suitable for aquatic organisms which function best in ranges between 6.0 and 9.0 (DWS, 1996).

Thus the total alkalinity and calcium in the Orange River can be associated with lower acid levels in the soil adjacent to the river; bedrock and runoff entering the river. Agricultural fertilizers accelerate the rate of dissolution of surfaces that have high levels of alkaline minerals naturally. The chemical weathering that occurs would dissolve rocks (limestone and carbonate containing rocks) that runoff into the adjacent river. The Orange River, all the way to the mouth, has a large number of agricultural activities situated on the banks and adjacent to the riparian zone.

5.2.12 Field survey results

Figures 5-35 and 5-36 illustrate the results acquired by the multi-meter during the boat survey. The average results were then compared to the South African Water Quality Guidelines (1996).

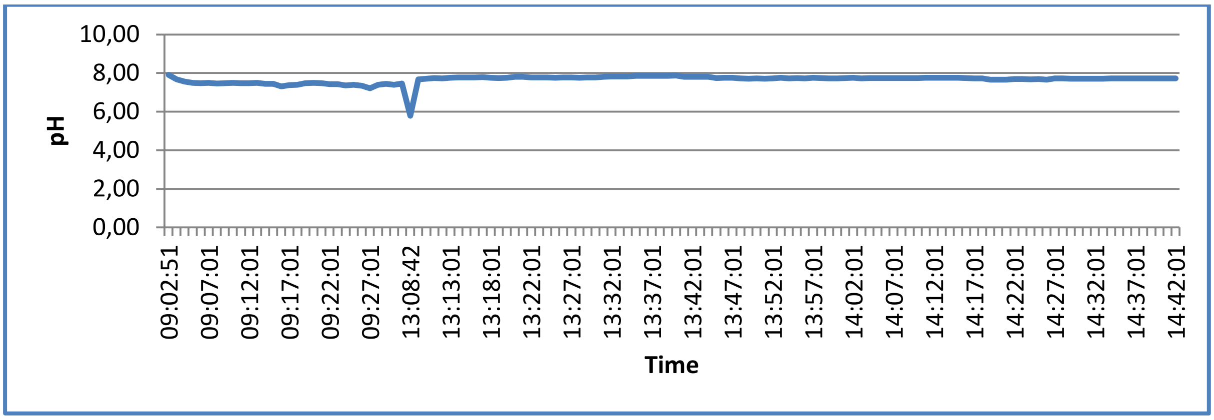

Figure 5-35: The pH of the surveyed section of the Orange River

The average pH at 7.7 is found in between the recommended lower levels and the higher levels. The guidelines recommend a pH of between 6.5 – 8.4 for optimum aquatic habitat preservation. The outlier in Figures 5-35 and 5-36 maybe a result of hard rocks that affected the boat in the river or potentially irrigation return flows.

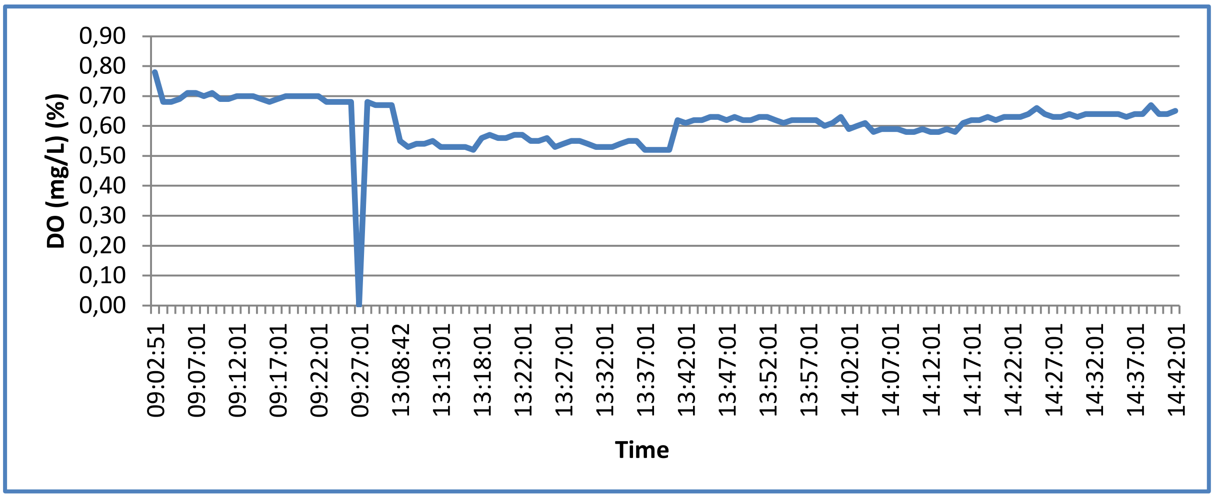

Figure 5-36: Dissolved oxygen of the surveyed section of the Orange River

The dissolved oxygen concentration is recommended for levels of between 80% - 120% of saturation by the guidelines. The average levels found during the survey were on average 61% of saturation levels (indicated in decimals). This can have the impact of changing the composition of aquatic communities since levels below 60% can favour more tolerant species while levels below 40% would be classified as lethal.

There is a relationship between salinity, electrical conductivity and the concentration of total dissolved solids (Figures 5-37, 5-38 and 5-39). While there is a proportional relationship between total dissolved solids and electrical dissolved solids, salt can also be used to determine the concentration of substances that can conduct an electrical charge according to the guidelines. Average total dissolved solids levels of 161 (mg/L) during the survey are enough to maintain a 90% yield of fairly salt tolerant crops.

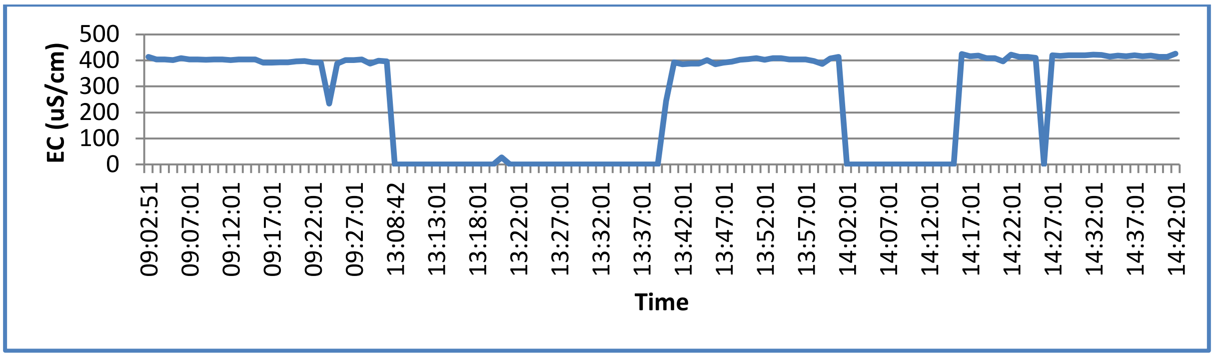

Figure 5-37: The EC of the surveyed section of the Orange River

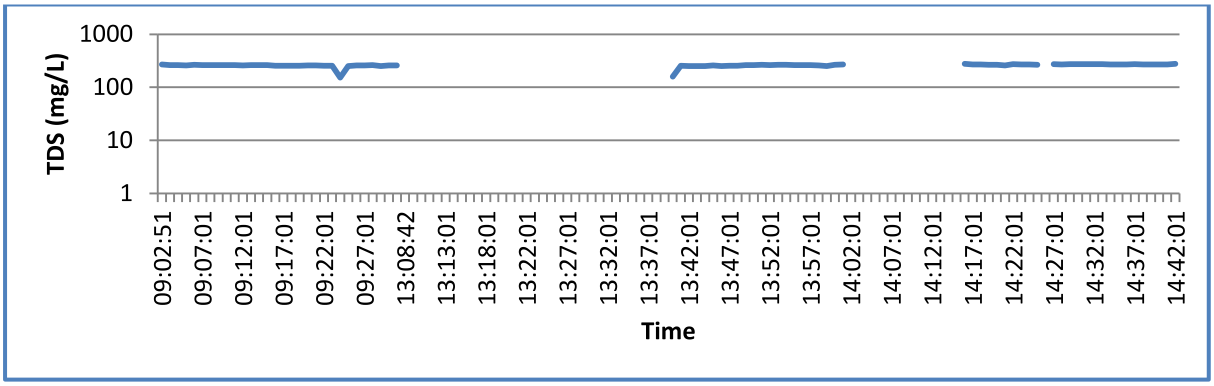

Figure 5-38: Total dissolved solids of the surveyed section of the Orange River

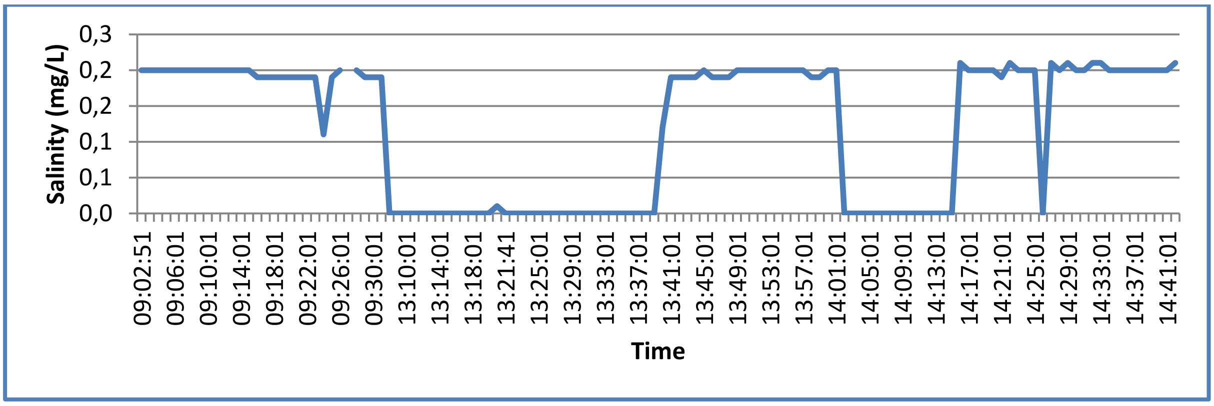

Figure 5-39: Salinity concentration levels of the surveyed section of the Orange River

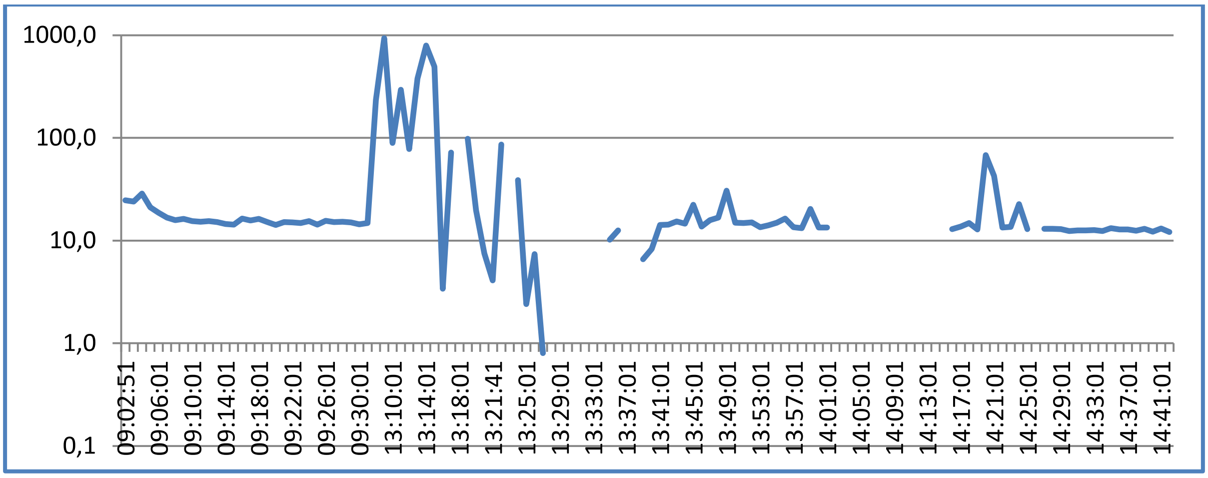

Figure 5-40: The turbidity of the surveyed section of the Orange River

The average turbidity level during the survey was found to be 34 NTU (Figure 5-40). This level is above the recommended level for aquatic ecosystems of <25 NTU. The higher levels after 13h00 are a result of abstractions that started around midday and their associated return flows into the river.

The survey obtained an average temperature of 19.5 ºC (Figure 5-34). However, the temperatures fluctuate according to time of day and season. The recommendation from the guidelines is fluctuations of > 2 ºC for the normal background average daily water temperature. The levels indicted above are a result of a regular rise in temperature though the course of the day.

5.3 Suggested improvements to monitoring inefficiencies and mitigation measures necessary for the Lower Orange.

The quality of water in a river system can be impacted by numerous anthropogenic and natural events. This makes IWRM vital for good water quality in rivers. The DWS, as the custodian of South African water resources, has to be at the forefront of sustainable water quality management.

There are a number of management techniques and control measures that the DWS can implement in order to ensure more effective and efficient water quality monitoring programmes. There are also mitigation methods that may be successfully applied to improve the quality of water in the Orange River. Measures that can be put in place to ensure proper water quality management in the Lower Orange River include:

i. Consistent monitoring

Water quality management requires the conversion of water quality data into clear water quality information. The results over the years indicate vast gaps in data probably due to results not being captured on the right databases or, in the worst case scenario, no monitoring being conducted.

Consistent, reliable and accurate monitoring of water quality in the Orange River is required in order to get a true picture of the water quality. The survey done as part of the study (although done only once) provided a viewpoint and potential for data that would otherwise not be available.

ii. Increased monitoring stations

The Orange River covers a long course through the Northern Cape and the border with Namibia. The stretch covers alluvial diamond, agricultural and some urban areas. The length of the Lower Orange needs the monitoring points to provide adequate coverage along its length. The number of points needs to adequately and efficiently (costs) cover the river. There are currently very large distances between the sites with certain large irrigation areas along the river not being adequately covered and monitored. The amount of inactive stations along the river should be reviewed in order to address this.

iii. Setting and utilising river-wide water quality objectives

There are Resource Quality Objectives set for the Orange River. However, they are currently not enforced and many water users are either unaware or not abiding by their guidelines. Different water use sectors need to be made aware of their responsibilities and roles in terms of maintaining the water quality integrity of the Orange River. The cooperation of all stakeholders is very important for good water quality management.

iv. Laboratory contracts in place

Although the national office of the DWS has laboratory facilities, the majority of provincial-based offices depend on private (external) professional service providers for the laboratory needs. These laboratories are also required to be accredited by their respective regulatory bodies in order to ensure a high standard of quality analysis. Due to the socio-economic and geographical status of the Northern Cape Province, there is a huge challenge in terms of accessibility to these facilities. They are usually located in major towns which are very far apart from each other and from the sampled site. Sample preservation procedure and equipment is thus of the utmost importance in the Lower Orange River.

v. More stakeholder involvement

The water quality monitoring data and databases need to incorporate monitoring that is conducted by local governments and the private sector. As part of IWRM, all stakeholders need to take responsibility for the water quality in water systems they consider as their resource. This means that there needs to be partnership between the users and the DWS that gives each the accountability they can handle. This collective 'ownership' of the Lower Orange River would help ensure early and adequate management response to fluctuations in water quality.

vi. Compliance monitoring enforcement

The compliance, monitoring and enforcement of water uses and their respective water quality discharge limits (parameters) is crucial for the prevention of pollution as enshrined in the NWA. The DWS needs capacity and expertise to identify and hold polluters accountable as rapidly as possible. This may be done in the form of audits, inspections or merely adequately responding to complaints summited to the DWS. In the long term, when water uses and users are being monitored competently and followed up with the appropriate enforcement procedures for those found wanting, there will be a natural inclination to comply with the water quality guidelines or water use licence conditions for the Lower Orange River. Regular monitoring of the river through the use of resources such as small boats (surveys) can also ensure that users are accurately monitored. The abstraction and disposal of water from and into the Orange River can at times not be picked up from main roads or farm holdings. The survey conducted as part of the study illustrated this point as Figure 5-35.

vii. Low cost field tests

The boat survey (Figure 5-41) has shown that surveys/snapshots can provide information that would otherwise not be available through other approaches. The survey can be utilised to plan and cost monitoring. It can provide information about water abstraction and discharge points as well as potential parameters that can be removed or added to the programme in order to adequately monitor the river. Probes can thus be added or procured in order to address any potential changes.

Figure 5-41: Water abstraction points in the Lower Orange River

viii. Integration and harmonisation of monitoring programmes

There are multiple water quality monitoring programmes within the DWS and private sector. The incorporation and integration of the data contained within the programmes together with the current programme would give a broader picture of the true status of the water quality in the Orange River. Programmes such as the REMP give a clearer long term picture than the instantaneous nature of the chemical and microbial monitoring.

ix. Management involvement

All successful projects and programmes need the involvement of the top management of an organisation. This ensures that employees receive adequate tools, equipment, training and other resources in order to ensure that accurate and reliable monitoring of the river continues unhindered. This includes management from CMAs, provincial operations and the national head office. The management can also hold the relevant officials responsible for any gaps or lack of adequate monitoring.

The effective water quality management of the Lower Orange River requires the principles of IWRM to be embraced by all stakeholders. The DWS needs to foster partnerships between the public and the private sectors to ensure sustainable water quality levels in the system for both ecological and human needs. There is a proposed Integrated Water Quality Management Strategy being developed by the DWS in support of the NWRS 2. The gaps identified and the implementation of the strategy is crucial for the sustainable use other the river.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

This study analysed the water quality trends of the Lower Orange River in the Northern Cape. Historic data from DWS WMS and NIWIS was used to illustrate changes in the water quality temporally and spatially. The accuracy of the data ensures that adequate pro-active and responsive measures are taken in the management of water resources in any catchment.

Anthropogenic impacts or interventions have accelerated what could otherwise be seen as a natural shift in water quality in river systems. The damming of water for irrigation use with dams or barrages has had an impact on the water quality of the affected Orange River. This is due to sediments and other pollutants being slowed down and settling to the bottom of such systems. Thus water samples, and the water quality results from these samples, would not necessarily be a true reflection of the water quality in the adjacent river. The quality of water in the canal systems would also not be a true reflection of the water quality in the river system. The water found in canals is not exposed to all the other environmental elements that the water-body in a river would be such as the movement and dissolution of rocks and gravel in and out of current; sediments in suspension; vegetation in and out of current; etc.

There is a new dam proposed for the Lower Orange River. The new dam will have a projected capacity of approximately 2800 million cubic metres and a height of 70m and it is envisaged to meet the water supply needs of the Lower Orange System up to 2045. It will be situated upstream of the towns of Vioolsdrift (South Africa) and Noordoewer (Namibia). There is currently a monitoring point for water quality in Vioolsdrift and the construction of the dam will greatly alter the proposed sample. The new dam may also necessitate the re-evaluation of monitoring points along the river. At the same time, the dam is predicted to inundate large irrigated areas along the banks of the river. Combined with the expected impact on the water quantity and its associated impact on the water quality, the dam can greatly alter the ecosystem of the Orange River both upstream and downstream.

In conclusion, the study found the following:

I. Identifying and understanding of the current water quality monitoring programmes and their chemical parameters:

The current water quality network of the Lower Orange is under-utilised. The various sites are not monitored on a consistent basis. A large number of sites have been left inactive and not monitored. Creating a situation where the latest data may not be available for management decisions.

The water quality monitoring network setup for the Orange River currently needs to be revised. Some of the points have been active for decades while others were setup within the last two decades. While these sites provide valuable data, it should be noted that land use, water uses and requirements have drastically changed and, in most cases, expanded throughout the years. The selection of parameters and sampling locations needs to be cost effective. The use of boat surveys by DWS personnel can greatly assist in this regard as data can be acquired in the field.

The network also needs to incorporate or work in conjunction with the neighbouring countries that also share the larger Orange-Senqu Catchment. The coordination of the monitoring network among all affected countries is important for the sustainability of the water quality in the Lower Orange River and may even lead to a shared database that is accessible to all stakeholders.

II. Trend analysis of the current water quality status to historic records and regulatory requirements:

The general trend of the river water quality indicates a general increase in the Total Alkalinity in the river. This potentially is the results of years of run off from irrigation practices into the river. The river also displays high levels of phosphate, nitrate and magnesium at some monitoring points.

There are large gaps in data, and thus limited information, in terms of water quality of the Lower Orange River. The management of water resources requires accurate, reliable and consistent data in order to inform management decisions. The gaps should be of major concern for the water quality management of the river as the lack of data implies a lack of knowledge and use during the unmonitored periods. This lack of knowledge also means management decisions taken at the time (or not taken) were unsupported by scientific data. Considering the importance of the river to the region, corrective actions should be taken to ensure that reliable monitoring is conducted consistently. Due to temporal changes in land use, monitoring points should change as changes occur.

Despite the observed gaps, the limited available data has been compared to the South African Water Quality Guidelines to gauge its suitability for the sustainability of aquatic ecosystems. The water quality in the Orange River displays a consistent increase in the level of total alkalinity and calcium through the years. This can be associated with the high irrigations levels and their associated runoff into the river. The river displays high levels of phosphate, nitrate and magnesium at some monitoring points.

Persistent Organic Pollutants, heavy metals and radio nuclides have not been monitored in the river. This potentially raises alarms about their levels and possible contamination. Planned monitoring (even if not as frequent as for other parameters) could provide information that could allow management to adapt monitoring requirements.

The impact of 'non-apparent' polluters such as alien invasive species and land degradation found along the banks and in the river should also be considered. These should be integrated into the current monitoring networks. Capacity and expertise should be integral to the works of programmes such a 'Working for Water' to eradicate plant species that impact on rivers. Vegetation is important for soil and bank stability. The removal of alien species, and the protection of indigenous riparian vegetation, is important for the preservation of the integrity of the water quality of the Lower Orange River. Protection of the land over which runoff flows into the Orange River is also important for the sediment load and hence water quality in the river. Further research into these impacts could also shed more light into any present and imminent consequences.

III. Suggested improvements to monitoring inefficiencies and mitigation measures necessary for the Lower Orange:

Studies conducted by organisations such as the ORASECOM also indicate a lack of information with regard to Persistent Organic Pollutants, heavy metals and radio nuclides. These potential major pollutants are currently not being given priority compared to other parameters. This is applicable for both the Orange River and its major tributary, the Vaal River. Good water quality management requires management systems that are adaptive and proactive. This implies that, for the sustainability of the Orange River water quality, it is important to not only manage current impacts but to also identify and mitigate against future impacts. These parameters should be added for analysis while unimportant parameters (after review) should be removed.

The engagement and involvement of all stakeholders (water users and the various sectors) is vital for good water quality management. The distribution (and access) to water quality data and information for all stakeholders helps maintain the protection of water resources by all. Timeous communication and interpretation of the data also aids the early adaptation to changing water quality or corrective actions to stabilise the quality. A culture of conservation and protection of water resources can be established through compliance monitoring of users and the enforcement of action against transgressors.

The use of boat surveys can greatly increase the amount of information that water services authorities can use. Surveys provide a view point of water abstraction and discharge points that would otherwise not be visible. The participation of all stakeholders and their practical roles in the management of the Lower Orange River water quality can assist authorities to make better management decisions.

The impact of adverse water quality in the Orange River has far reaching consequences on the sectors and communities that are completely reliant on the river for their daily water needs. The socio-economic status of the Northern Cape and the impact of poor water quality on the affected users would have major consequences for economic productivity and increase the burden on the provincial health services and their associated costs. Thus the importance of adequate water quality monitoring in the Orange River cannot be emphasised enough.

Recommendations for future work:

The study found a number of gaps in the monitoring programme and datasets in the Lower Orange River. These gaps would benefit from further research including the testing of theories and results from this particular study:

I. Water economics: The value of the Lower Orange River to its various sectors (mainly agriculture) needs further research. South Africa spends vast amounts of money to acquire water from Lesotho for the Vaal River System, While it is common knowledge that the river is vital to the agricultural sector in the Lower Orange, little has been done to quantify the value of the water to the farmers it supplies as it flows towards the mouth. This is applicable to both South Africa and Namibia.

II. Water usage monitoring: The Department of Water and Sanitation lacks capacity in terms of agricultural water usage monitoring. The current operational plan is to acquire data from farmers themselves through their self-installed water metres. This all depends on the reliability and honesty of the farmers affected. While there needs to be trust between stakeholders, the Department does need to have the capacity to verify data it receives from users.

III. State of the environment: The Department of Water and Sanitation currently compiles and distributes an annual “State of the Water” report. Although this is good, the state of the affected environment (human wellbeing and the state of major ecosystems) would need further research.

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