The applicability of a Water Quality Index (WQI) as an assessment tool for urban rivers: A Case Study in the Crocodile River

MN Kunene

orcid.org/0000-0003-2998-0471

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

Supervisor: Prof RJL Gerber

Co-Supervisor: Prof V Wepener

Graduation May 2022

25209469

PREFACE AND ACKNOWLEDGMENTS

This is the Masters dissertation in Environmental Management to test the applicability of a Water Quality Index (WQI) as an assessment tool for urban Rivers: A Case Study in the Crocodile-West River under the faculty of Natural and Agricultural Sciences in the University of the North-West and under the supervision of Dr Ruan Gerber. I would like to acknowledge my supervisor Dr Ruan Gerber. Thank you for the guidance and support and providing scientific knowledge and expertise during the process. It made the journey in writing this thesis easier. I would like to acknowledge my co-supervisor Dr Victor Wepener for his scientific knowledge and expertise which has shaped the thesis. I would like to acknowledge Dr Wynand Malherbe for designing the GIS maps that were used in the study and Dr Lizzaan De Necker for PCA analysis figures that that were used in the study. May God Bless you all.

I dedicate this Masters thesis to first and foremost Lord God for gift of life, wisdom, intellect and hard work to complete the thesis and make the contribution to the science field. Secondly, I dedicate the thesis to my late Father Michael Lulu Kunene and my late sister Nondumiso Promise Kunene. I still carry your teachings in my heart and mind. May your souls rest in peace. Thirdly, I dedicate this thesis to my mother Phumzile Lynette Kunene and my wife Nomonde Zikhundla and my son iNalayomusa Kunene. Thank you for your love, encouragement, and support during this milestone of my life. Lastly, I would like to dedicate this thesis to my friends and colleagues who have supported me throughout this journey.

ABSTACT

The water quality of the Crocodile-West River is deteriorating and has affected the ability of the water resource to be utilised adequately. Mining, urban, and agricultural run-off have negatively impacted the water quality of the Crocodile-West River catchment and has caused water quality issues in the catchment. The Crocodile-West River is monitored by the Department of Water and Sanitation where complex water quality data are collected and stored in the water quality database called the Water Management System (WMS). The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) was applied in the study to evaluate surface water quality data to protect aquatic ecosystems. In this study, the CCME WQI integrated physico-chemical variables collected in the Crocodile-West River to determine its applicability as an assessment tool for Department of Water and Sanitation (DWS) managers in evaluating the health of the catchment for decision-making purposes.

The water quality data was sourced from the Water Management System. The water quality data consisted of annual seasonal data of DWS monitoring sites 90194, 90167, 90203, 90204 and 90233 on the Crocodile-West River from 1976 to 2018. The water quality variables chosen in the study were ammonia (NH_3), nitrate/nitrite (NO_3^-/NO_2^-), phosphate (PO_4^{3-}), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), chloride (Cl^-), electrical conductivity (EC), sulphate (SO_4^{2-}) and pH. Each data set was organised into average seasonal data for summer, autumn, winter and spring. This was done for each water quality variable per year for each site. The average seasonal data for each water quality variable was organised into a series of data from 1976 to 2018. The seasonal data was used to calculate the CCME WQI values and plot PCA biplots for each site from 1976 to 2018. A box-and whisker graph was plotted to determine the spatial differences in the WQIs of each site. A principal component analysis (PCA) was used to evaluate the success of the CCME WQI as an appropriate tool to evaluate water quality data of the Crocodile-West River.

The overall status of the Crocodile-West River was good in the 1990s and early 2000s and deteriorated to marginal quality from 2010 to 2018. The CCME WQI was able to indicate the temporal and spatial water quality changes of the Crocodile-West River from 1976 to 2018. The trend in CCME WQI of sites situated upstream of Crocodile-West River deteriorated more than CCME WQI trends for sites situated downstream. The CCME WQI is sensitive to the changes in number (F_1) and magnitude (F_3) of water quality variables that exceeded the target water quality guidelines of the study. The years which have lower F_1 scores and F_3 scores have the highest CCME WQI scores than the years which have higher F_1 scores and F_3 scores.

The PCA results have indicated that the spatial distribution of the sites can influence the pollutants surveyed. The CCME WQI correlated with PCA biplot in flagging pH, PO_4^{3-} and NH_3 as problematic water variables that negatively impacted the water quality of each site for the period of 1976 to 2018. In addition, the PCA biplot showed that the contribution of pH, PO_4^{3-} and NH_3 to the pollution of each site was insignificant as compared to NO_3^-/NO_2^-, Cl^- and SO_4^{2-} other water quality variables in the study.

The CCME WQI and PCA were implemented successfully in the Crocodile-West River. CCME WQI was flexible in integrating the water quality data and the water quality guidelines sourced from different water quality guidelines to interpret the overall water quality status of the Crocodile-West River. The CCME WQI can be enhanced by incorporating scientific and local knowledge of the river to ensure that the correct water quality variables appropriate with Crocodile-West River are included in the calculation of CCME WQI of the Crocodile-West River.

Keywords: Water quality index (WQI), Crocodile, resource, variables, assessment, guidelines

ABBREVIATIONS AND ACRONYMS

BCWQI	British Columbia Water Quality Index
Ca^{2+}	Calcium
CCME	Canadian Council of Ministers of the Environment
CCME WQI	Canadian Council of Ministers of the Environment Water Quality Index
Cl^{-}	Chloride
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
ER	Ecological Reserve
EWR	Ecological Water Requirement
F_1	number of variables whose objectives are not met
F_2	number of times which objectives are not met
F_3	magnitude which the objectives are not met
FRAI	Fish Response Assessment Index
GAI	Geomorphological Assessment Index
HAI	Hydrological Assessment Index
K^{+}	Potassium
Mg^{2+}	Magnesium
NAEMP	National Aquatic Health Monitoring Programme
NCMP	National Chemical Monitoring Programme
NEMP	National Eutrophic Monitoring Programme
NFSWQI	US National Sanitation Foundation Water Quality Index

NH_3	Ammonia
NMMP	National Microbial Monitoring Programme
NO_3^-/NO_2^-	Nitrate/ Nitrite
NTMP	National Toxicity Monitoring Programme
OWQI	Oregon Water Quality Index
PAI	Physico-chemical Assessment Index
PCA	Principal Component Analysis
PO_4^{3-}	Phosphate
RHAM	Rapid Habitat Assessment Model
RQO	Resource Quality Objective
SO_4^{2-}	Sulphate
VEGRAI	Vegetation Response Assessment Index
WAWQI	Weighted Arithmetic Water Quality Index
WHO	World Health Organisation
WQI	Water Quality Index
WWTW	Wastewater Treatment Works

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1. Background

Water is a prime natural resource that supports aquatic ecosystems and economic sectors such as agriculture, livestock production, forestry, industrial activities, hydropower generation, fisheries, domestic, and human recreational activities (Tyagi et al., 2013). The availability and quality of water resources is declining due to influences such as industrialisation and urbanisation (Tyagi et al., 2013). Surface waters are polluted by domestic sewage, industrial waste and agricultural run-off, fertilisers, pesticides, and mining tailing dams which are sources of surface water pollution (Kankal et al., 2012).

The concern that water will in future become a scarce resource has prompted countries to establish comprehensive river water quality monitoring programmes to protect water resources (Kannel et al., 2007). The water quality of a site or source of water can be assessed using the chemical, physical and biological variables of a water resource by comparing the water quality variables to defined limits (Tyagi et al., 2013). Reporting critical information about water quality to stakeholders continues to be a challenge to water managers because technical water quality reports present variable-by-variable assessments and statistical summaries. This type of reporting is valuable to water experts but does not benefit the public because it is poorly understood (Davies, 2006).

Water quality indices (WQIs) transform several selected variables into a single qualitative variable (Kachroud et al., 2019). The WQI is a mathematical instrument that summarises large amounts of water quality data into a simplified numerical value to report to management and public in a consistent manner (Kannel et al., 2007). It is therefore the most useful and efficient method for assessing the suitability of water quality of a water resource. A WQI indicates if the overall water quality of the water resource is suitable to support aquatic organisms or for irrigation, recreation, and domestic purposes (Akoteyon et al., 2011; Kankal et al., 2013).

1.1.1. Water Quality Management of Water Resources

Developed and developing countries have implemented comprehensive river water quality monitoring programmes to protect freshwater resources (Kannel et al., 2007). Surface water monitoring programmes are effective in monitoring water quality for different purposes, but it is difficult to determine the overall water quality of surface water resources from the complex data collected (Kannel et al., 2007). The purpose of a water quality monitoring system of a water resource is to generate sufficient and timely information to enable water managers to make informed decisions on the management of water resources. Water quality monitoring assist in identifying pollution sources and to use the data collected to devise policy regulations improve conservation of water resources (Telci et al., 2009).

1.1.2. Legislative Framework Governing Water Quality Management in South Africa

The water resources of South Africa are in the custody of the Department of Water and Sanitation (DWS). The management of these water resources is mandated under the National Water Act. The National Water Act promotes the protection of water resources by conserving, developing, and controlling its use in a sustainable manner (Riemann et al., 2017) The National Water Act (Act 36 of 1998) describes water quality as a feature of water resource that results from conditions of in-stream flow, natural water quality, riparian habitat, and aquatic biota (DWAF, 1998).

Chapter 3 of the National Water Act makes provision for the protection of water resources by setting measures to be undertaken to prevent pollution of water resources and the rehabilitation of polluted water resources (Riemann et al., 2017). Part 1 of Chapter 3 of water resources makes provision for DWS to issue a classification system to classify water resources to promote effective water management (Riemann et al., 2017). Chapter 3 of the National Water Act makes provision to consider the reserve of a particular water resource which is defined as the volume and quality of the water resource that can sustain basic human needs and the aquatic biota Section 18 of the National Water Act prescribes that all water resources be classified (Riemann et al., 2017). The desired future state of the water resource for protection is achieved by classifying the water resource. This is done by developing the classification system, setting the management class, determining the Reserve, and setting the water resource quality objectives of the water resource (Pollard & Du Toit, 2008; Mosoa, 2013).

Section 19 of the National Water Act addresses the pollution and rehabilitation measure of polluted water resources and holds the owner of the land where the source of pollution occurs liable to intervene in rehabilitating the polluted water resources. Section 20 of the National Water Act makes provisions for DWS to issue directives to polluters to reduce pollution and minimise the degradation of water quality of water resources (Riemann et al., 2017).

Chapter 14 of the National Water Act mentions the importance of monitoring, recording, assessing, and disseminating of information of water resources and it is the duty of DWS to establish national monitoring systems (DWAF, 1998). The objective of the established monitoring systems was to provide a continuous monitoring of the water resources to collect data and provide information on the status of water resources to management institutions and water users (DWAF, 1998). The collected data should include information on quantity, quality, water use, compliance, and overall health of water resources (DWAF, 1998). The objectives of the established monitoring programs are to ensure protection, sustainable use and management of water resources, inform planning of water resources and indicate the safety for water resource for disaster management (DWAF, 1998).

The Resource Quality Monitoring section of the DWS has established number of monitoring programmes (Griffin et al., 2014). These monitoring programmes are: National Microbial Monitoring Programme (NMMP), National Aquatic Ecosystem Health Monitoring Programme (NAEMP), National Eutrophication Monitoring Programme (NEMP), National Toxicity Monitoring Programme (NTMP) and National Chemical Monitoring Programme (NCMP) (Griffin et al., 2014).

1.1.3. Water Quality Management Issues in South Africa

South Africa's freshwater resources are under stress due to population growth and economic expansion. Currently most of the water resources are allocated in terms of water uses, and they are experiencing a decline in quality due to pressures from urbanisation, industry, afforestation, mining, agriculture, power generation, eutrophication, acid mine drainage (AMD) and dysfunctional wastewater treatment works (Oberholster & Ashton, 2008).

Eutrophication is a threat to the water resources of the country. Eutrophication is caused by nutrient enrichment of water resources which leads to ecological changes such as algal blooms and macrophytes which uptake the nutrients to grow. The nutrient impacts on water resources are caused by effluent from wastewater treatment works, agricultural practices, mining, and industrial processes (Van Ginkel, 2011). Eutrophication lowers the potential of water resources to be used for agricultural, recreational, and domestic purposes (Griffin et al., 2014). The algal blooms that are a by-product of nutrient enrichment of water resources have ecological consequences. The most common cyanobacterial blooms found in water resources in South Africa produce toxins in water resources and modify the taste and odour of abstracted water. Macrophyte blooms present in water resources contribute to blockages of water distribution pipes and canals (Griffin et al., 2014).

Acid mine drainage (AMD) is caused by the oxidation of pyrites by oxygen and water in a process catalysed by acidophilic bacteria. The AMD process causes low pH, increased levels of sulphate salts, and metal ions in water resources (Griffin et al., 2014). The AMD process in South Africa originates from groundwater is mostly found in abandoned gold and coal mines which decant into surface water resources. The AMD process has become a major environmental threat to water resources in South Africa and the costs of addressing the issue are expensive (Griffin et al., 2014).

Effluent flowing into water resources from poorly managed wastewater treatment works causes high nutrient and salt concentrations, lower oxygen levels, and an increased number of pathogens. The impacts of wastewater treatment work effluents contribute to the alteration of ecological properties of the water resources and affect the intended use of the water resource downstream of the wastewater treatment works (Griffin et al., 2014).

The Crocodile-West River catchment is a developed catchment in South Africa and is influenced by land-use activities such urban development, sewerage works effluent, agricultural, mining and industrial activities (van Eeden, 2017). These land-use activities cause degradation of the water quality of Crocodile-West River catchment and it is important to determine the water quality status of the Crocodile-West River for protection purposes. The Crocodile-West River is monitored by the DWS and a complex set of water quality data has been collected from the River and stored in the water quality database known as the Water Management System (WMS) (DEAP, 2011).

1.2. Problem Statement

Protecting the water quality is a top environmental priority in the twenty-first century. Both developed and developing countries experience water quality problems (Abbaspour, 2011). The key to sustainable water resources is to ensure the quality of water resources is suitable for their intended uses .Therefore, sustainable management of water quality must incorporate policy, technical expertise, institutions and finance (Abbaspour, 2011). There is a challenge in determining whether the water resources were getting better or worse because interpretating water quality data is complex (Abbaspour, 2011). Traditional approaches of assessing the water quality of water resources is based on comparing the experimentally determined water quality variables to existing water quality guidelines. However, the evaluation of water quality of water resources from complex water quality data remains a challenge (Murugesan & Morphin-Kani, 2011).

The water quality of the Crocodile-West River is continuously deteriorating and has affected the functioning of the aquatic environment. Land use activities such as discharges from wastewater treatment works, excessive nutrient loads from agricultural run-off have negatively impacted the water quality of the Crocodile-West River catchment and have presented water quality issues in the catchment (Van Ginkel, 2011). There are methods to determine the quality of a water resource for its intended use. One such a method is to categorise the water quality of the water resource by its failure to meet a target water quality guideline (DEAP, 2011). The Crocodile-West River is monitored by the DWS and complex set of water quality data collected from the river is stored in the WMS database (Griffin et al., 2014).

Water Quality Indices (WQIs) are useful and efficient methods for assessing the suitability of water quality and to communicate the information on overall water quality of rivers and dams to policy makers and citizens. The WQI model involves developing WQIs to integrate water quality variables such physico-chemical and biological variables to summarise the data into useful information that can be reported in a consistent manner for management decisions (Abbaspour, 2011). The Canadian Council of Ministers of the Environment Water Quality index (CCME WQI) method is developed to evaluate surface water quality to protect aquatic ecosystems (Tyagi et al., 2013). The CCME WQI detects seasonal changes and historical water quality status of the water resource in question. The CCME WQI selects water quality variables and sets objectives for each water quality variable based on the purpose of the study (Lumb et al., 2006).

1.3. Research Aim

The aim of this study is to determine the applicability of a WQI (CCME WQI) as an assessment tool for managers in evaluating, monitoring, and interpreting the water quality and subsequently the aquatic ecosystem health of the Crocodile-West River.

1.4. Objectives

i. Obtain historical water quality data sets of selected sites on the Crocodile-West River from the Water Management System database.
ii. To select the appropriate water quality variables that reflect land use and historical and current impacts.
iii. Apply the CCME WQI to selected water quality variables of the chosen sites.
iv. Evaluate the selected WQI’s success as an appropriate tool to evaluate water quality data.
v. Use appropriate multivariate statistics to corroborate findings from the CCME WQI

Outline of the mini-dissertation

Chapter 1 of the mini-dissertation introduces the WQI as a useful tool as well as the relevant aim and the objectives of the research. **Chapter 2** is a literature review which introduces the strengths and weaknesses of water quality indices applied to water resources globally and the statistical analysis tools that validate the use of water quality indices**. Chapter 3** indicates the study area, the water quality variables and methodology of the water quality indices and statistical analytsis tools. **Chapter 4** details the analysis of the water quality data. **Chapter 5** discusses the results of the CCME WQI and PCA and the strengths and weaknesses of implementing the chosen water quality indices based on the objectives of the study **Chapter 6** concludes the study and provides relevant recommendations for future studies.

Chapter 2: Literature Review

2.1. Global Legislative Framework for monitoring water quality

The Monitoring of water quality in the European Union is mainly regulated by the Water Framework Directive (WFD) (Samborska et al., 2012). The WFD is strategic framework to provide a holistic integrated water management approach. The objectives of the WFD are to protect the pristine water resources, prevent degradation of water resources and restore the degradation of surface and groundwater to good status by year 2015 (Samborska et al., 2012).

The United States (US) government under the Clean Water Act Amendment Act of 1972 has established the Water and Watersheds Program to monitor the water resources. The Program was established to form interdisciplinary research to manage the water resources in the US to understand the natural and human-induced processes that influence the quantity, quality, and availability of water resources (Copeland, 2016).

A Water Quality Monitoring Program in Canada was established by the Canada-wide Framework for Water Quality Monitoring to enhance water quality management. A series of water quality monitoring programs were developed and implemented in Canada to strengthen the linkages and capacities in the existing water quality monitoring networks (Lumb et al., 2006). The framework envisioned that the collaboration and coordination of the water quality monitoring programs in all the jurisdictions in Canada will increase the efficiency, affordability, and credibility of water quality monitoring, database management, data interpretation, and reporting (Lumb et al., 2006).

2.2. South African Legislative Framework for monitoring water quality

2.2.1. National Chemical Monitoring Programme (NCMP)

The programme monitors the chemical parameters of the water resources at gauging weirs. The programme monitors 700 sites with an estimated 300 sites monitored at a frequency of two weeks (Griffin et al., 2014). The chemical data is deposited into the WMS database where it is synthesised in long-term data sets in excel spread sheets (Griffin et al., 2014). The WMS has a record of forty years' worth of water quality monitoring data of major ions, nutrients, and total dissolved salts but there is a gap in the data representing organic pollutants, turbidity, and oxygen (Griffin et al., 2014).

2.2.2. National Eutrophication Monitoring Programme (NEMP)

The programme monitors levels of chlorophyll, dissolved oxygen, total nitrogen, and total phosphorus in water resources and eighty dams in South Africa (Griffin et al., 2014). The objective of the monitoring programme is to monitor and quantify nutrient pollution. A guideline manual on the management of urban dams was drafted by the Water Research Commission (WRC) using the data from the WMS database (Griffin et al., 2014). The guideline manual included a framework that indicated how local authorities should manage water resources from planning and design of impoundments to management techniques that should be implemented to address water quality problems (Griffin et al., 2014).

2.2.3. National Microbial Monitoring Programme (NMMP)

The programme monitors the levels of faecal contamination in water resources. The data was stored in the WMS database (Griffin et al., 2014). The objectives of the National Microbial Monitoring Programme are as follows:

- To do an assessment and prioritisation of areas where the potential health risks related to faecal pollution of water resources are the highest
- To disseminate information on the trends and status of microbial quality of water resources in potential high-risk areas
- To disseminate information on potential health risks of the microbial quality of water resources used by humans
- To assess the effectiveness of microbial quality monitoring to protect water resources

The information of the microbial quality monitoring results is reported bi-monthly (Griffin et al., 2014).

2.2.4. National Toxicity Monitoring Programme (NTMP)

The monitoring programme measures, assesses, and regularly reports on the status and trends of toxic chemical pollutants to support the strategic management of water resources (Griffin et al., 2014). The National Toxicity Monitoring Programme (NTMP) was established to respond to local and international initiatives to limit the effects of toxic pollutants in water resources. The project was initiated in 2002 when South Africa signed the Stockholm Convention on persistent organic pollutants (POPs). The implementation of the pilot project was in 2008-2009 and the design of the NTMP includes monitoring and reporting on the impact of dioxins, furans, and hormones in water resources (Griffin et al., 2014).

2.2.5. National Aquatic Ecosystem Health Monitoring Programme (NAEMP)

The National Aquatic Ecosystem Health Monitoring Programme (NAEMP) was established to determine the Ecological Water Requirements (EWRs) and Ecological Reserve (ER) (Griffin et al., 2014). The programme investigated studies that considered both the biotic and abiotic aspects of the water resource including the water quality. The programme implemented the Rapid Habitat Assessment Model (RHAM) as an efficient and cost-effective method to assess instream habitat conditions of water resources (Griffin et al., 2014). The RHAM used fish and macro-invertebrate data to determine the suitability of the water resource to maintain its biota. The fish and macro-invertebrates are considered the responders in the water resources. The NAEMP also included the water quality monitoring of the physico-chemical properties of water resources to determine the drivers that cause a change in the population of fish species and macro-invertebrates (Griffin et al., 2014). The integration of monitoring both responders and drivers of water resources has been useful to transforming the NAEMP into a decision support system for determining the EWRs and ERs of water resources (Griffin et al., 2014).

2.3. Selecting the water quality variables

The water quality variables chosen in this study were: ammonia (NH_3), nitrate/nitrite (NO_3^-/ NO_2^-), phosphate (PO_4^{3-}), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), chloride (Cl^-), electrical conductivity (EC), sulphate (SO_4^{2-}) and pH. The water quality variables in the study were chosen based on land-use impacts by industry, mining, agriculture, urbanisation, informal settlements, and geological features present within the Crocodile-West River and its catchment and availability of data.

2.3.1. Calcium (Ca^{2+})

Calcium (Ca^{2+}) is a natural metal that occurs in the Earth’s crust and fresh waters as calcium carbonate. Natural Ca^{2+} concentration in rivers is 15 mg/l (Chapman, 1996). The magnitude of Ca^{2+} concentration in freshwaters indicates the “hardness’’ of the water. High concentrations of Ca^{2+} in freshwaters cause damage to infrastructure by clogging pipes and scaling of hot water appliances (Lowies, 2014). Sources of Ca^{2+} in freshwaters are from leeching of calcium carbonates from geology such as dolomites (Lowies, 2014).

2.3.2. Magnesium (Mg^{2+})

Magnesium (Mg^{2+}) is an important metal that is common in freshwater systems. Magnesium and calcium are the major ions in freshwater systems and contribute to the “hardness” of the rivers (Lowies, 2014). Sources of Mg^{2+} are ferromagnesian rocks and carbonate rocks which weather in the rivers. Natural Mg^{2+} concentrations are less than 100mg/l according to Chapman (1996). The Mg^{2+} used in industrial processes does not contribute significantly towards the pollution of freshwaters (Lowies, 2014). Magnesium is essential for the growth of chlorophyll and high concentrations of Mg^{2+} cause bitterness in domestic water (Lowies, 2014).

2.3.3. Potassium (K^+)

Potassium (K^+) is found in freshwater associated with sulphate, chloride, carbonate, and nitrate/nitrite. Natural sources of K^+ are from weathering rocks such as feldspars and micas. Natural K^+ concentrations are below 10 mg/l (Chapman, 1996). Sources of K^+ pollution in rivers is from potassium salts used in the industry and fertilisers applied in agricultural activities (Mosoa, 2013; Lowies, 2014). High concentrations of K^+ cause bitterness of portable water (Chapman, 1996).

2.3.4. Chloride (Cl^-)

Chloride (Cl^-) is a common element in water resources and exists with K^+, Na^+, Mg^{2+} and Ca^{2+}. The concentration of Cl^- in unpolluted water is less than 10 mg/l and higher concentrations of Cl^- in water resources are due to pollution from discharged effluents (Merolla, 2011). Other sources of Cl^- in water resources are irrigation return-flows and industrial processes (Lowies, 2014).

2.3.5. Electrical Conductivity (EC)

Electrical Conductivity (EC) is used to determine the total dissolved solids (TDS) of the Crocodile-West River system. The EC represents the concentration of major ions such as Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-} and HCO_3^- which indicate the salinity of river (Chapman, 1996). Sediments influence the concentration of total dissolved solids in water resources (Lowies, 2014).

2.3.6. Ammonia (NH_3)

Ammonia (NH_3) can exist in an ionised (NH_4^+) and unionised (NH_3) form and occurs naturally in low concentrations of below 0.2 mg/l (Mathebula, 2015). Higher concentrations of NH_3 in water resources indicate organic pollution, fertilizer run-off, domestic sewage, and livestock farming (Lowies, 2014). A high concentration of NH_3 in water resources can cause nutrient enrichment which causes high growth of blue-green algae and hyacinth (Frost & Sullivan, 2010).

2.3.7. Nitrate/Nitrite (NO_3^-/NO_2^-)

Nitrate/nitrite (NO_3^-/NO_2^-) is from the oxidation of ammonia by *Nitrobacter spp* and *Nitrosomas sp*p in the water resources. The NO_3^-/NO_2^- is the stable form of NH_3 (Mathebula, 2015). Natural sources of NO_3^-/NO_2^- are igneous rocks, land drainage, plant debris, and animal waste (Lowies, 2014). Natural concentrations of NO_3^-/NO_2^- are below 5 mg/l and higher concentrations of NO_3^-/NO_2^- are from agricultural run-off, leaches from landfill sites, and treated and untreated effluents from wastewater treatment works (Lowies, 2014). High concentrations of NO_3^-/NO_2^- in water resources can cause nutrient enrichment which causes the high growth of blue-green algae and hyacinth (Frost & Sullivan, 2010).

2.3.8. Phosphate (PO_4^{3-})

Phosphate (PO_4^{3-}) is the natural occurring form of phosphorus in water resources, and it originates from weathering rocks and soil containing PO_4^{3-} (Chapman, 1996). Phosphate is the limiting agent of algal growth in water resources (Frost & Sullivan, 2010). The concentration of PO_4^{3-} is lowest in mountain ranges due to crystalline geology and increases in lowland rivers that have excess sediments (Chapman, 1996). Natural PO_4^{3-} is present in low concentrations in rivers because it is taken up by aquatic plants and biota and high concentrations of PO_4^{3-} in water resources is due to point and non-point sources from urban run-off and drainage from agricultural fields where fertilisers have been applied (Lowies, 2014; Mosoa, 2013). The concentration of PO_4^{3-} is the driving force of eutrophic conditions in freshwaters (Oberholster & Ashton, 2008).

2.3.9. Sulphate (SO_4^{2-})

Sulphate (SO_4^{2-}) represents the total sulphur concentration in water resources. The source of high concentrations in the water resources is due to mining activities. The oxidation of sulphide-rich pyrite ores enriches the water resources with SO_4^{2-} (Lowies, 2014; Mutanga & Mujuru, 2016). Another source of SO_4^{2-} pollution in water resources is the run-off that has fertilisers and pesticides that have sulphate-based chemicals from agricultural activities (Chapman, 2006). High SO_4^{2-} in drinking water results in diarrhoea (Lowies, 2014).

2.3.10. pH

pH measures the acid-base equilibrium of dissolved elements in the water resources. Thus, pH indicates the acidity and basic properties of water resources (Mosoa, 2013). Suitable pH ranges for biological life in water resources is between 6 to 9 pH units (Chapman, 1996). The most important pH buffering system in water resources is the concentration of carbonate-bicarbonate system which buffers between pH values of 6.4 to 10.3 pH units (Mathebula, 2015). Dolomitic geology is a source of carbonates in the river that are responsible for increasing the pH of the water resources (WHO, 2011). Ammonia and phosphate-based fertilisers that are applied in irrigation farming of crops are sources of nutrients from irrigation return flows (Du Preez, 2018).

2.4. Water Quality Indices

Water quality indices (WQIs) transform selected water quality variables into a single qualitative value (Kachroud et al., 2019). The WQI is a mathematical instrument that summarises large amounts of water quality data into a simplified numerical value to report to management and the public in a consistent manner (Kannel et al., 2007). It is, therefore, the most useful and efficient method for assessing the suitability of water quality of a water resource by indicating if the overall water quality of the water resource is suitable to support aquatic organisms or use for irrigation, recreation, and drinking water purposes (Akoteyon et al., 2011; Kankal et al., 2013).

Four common steps are followed to calculate the WQI (Figure 2.1). Step 1 is the selection of appropriate physico-chemical variables, step 2 is the transformation of the variables with different dimensions into a common scale, step 3 involves assigning a weight to each transformed variable and step 4 is the aggregation of transformed variables into a final index score (Kachroud et al., 2019).

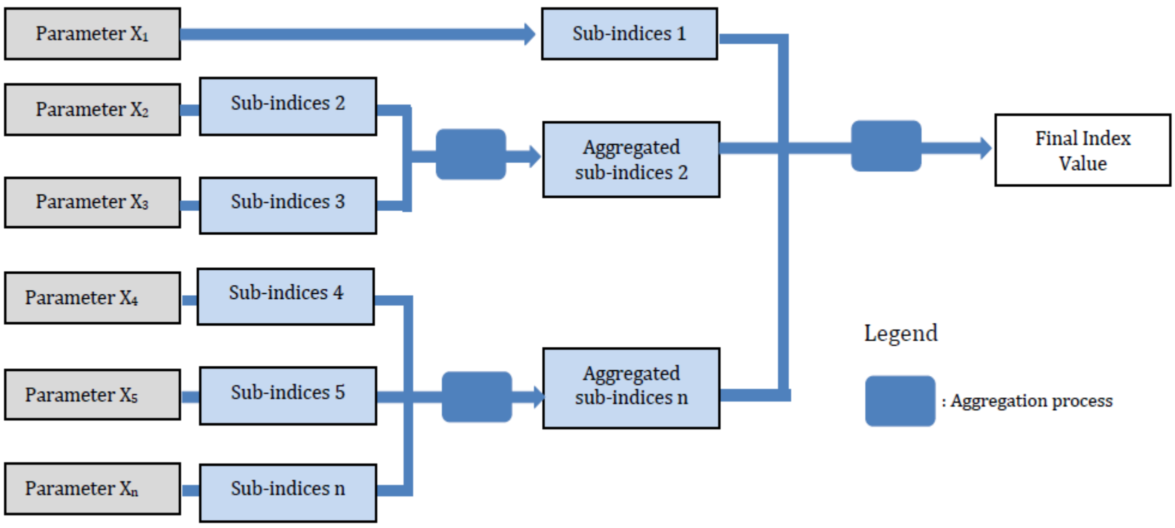


Figure 2-1: Process of calculating the overall Water Quality Index value (Taken from Sutadian et al., 2016)

The selection of variables is essential in developing the WQI because they are the core of the index. Each water quality index has a minimum number of variables that can be inputted into the index (Sutadian et al., 2016). The water quality variables are transformed into a common scale because the water quality variables have their own unique units of measurement, and the target water quality guidelines of each water quality variable differ. Therefore, it is important to standardise variables into sub-indices (Sutadian et al., 2016). A few WQIs don't consider the standardisation of sub-indices but include the actual values of the variables in a final aggregation step (Sutadian et al., 2016). An example of such an index is the CCME WQI. The CCME WQI uses a multivariate statistical procedure to aggregate the actual values without transforming them into sub-indices (Sutadian et al., 2016). Weights are allocated to each water quality variable according to their importance and influence on the water resource and the final index score is calculated (Sutadian et al., 2016). The weights of the water quality variables can be ranked equal or unequal where equal weights are assigned to water quality variables that have equal importance to the index with respect to the water resource (Sutadian et al., 2016). The assignment of equal and unequal weights is based on expert judgement and literature research. The index aggregation is done to arrive at a final index value. The common aggregation methods for sub-indices are the arithmetic and geometric methods (Sutadian et al., 2016).

There are several water quality indices that have been established globally. The US National Sanitation Foundation Water Quality Index (NSFWQI), British Columbia Water Quality Index (BCWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), Oregon Water Quality Index (OWQI) and Weighted Arithmetic Water Quality Index (WAWQI) are commonly used indices (Pooman &Tanushree, 2013).

2.4.1. Water Quality Indices Implemented globally

2.4.1.1. The Weighted Arithmetic Water Quality Index (WAWQI)

The weighted Arithmetic Water Quality index (WAWQI) is used to determine the degree of purity of water resources using physico-chemical water quality variables. The WAWQI was applied in water resources in various countries such as Godavari River system in India, Qalaysan River in Uzbekistan, Tigris River in Iraq, Owo and Siluko Rivers of Nigeria to classify the water quality of the river systems (Akoteyon et al., 2011; Salih et al., 2012; Darapu et al., 2013; Al-Sabah et al., 2016; Oboh & Agbala, 2017). These River systems were impacted by urban and agricultural run-off and industrial and wastewater effluent. The WAWQI was used to determine the temporal and spatial trends of the water quality of the rivers for drinking, irrigation, and domestic purposes for the different River systems (Akoteyon et al., 2011; Salih et al., 2012; Darapu et al., 2013; Al-Sabah et al., 2016; Oboh & Agbala, 2017). The WAWQI was efficient in measuring spatial and seasonal water quality changes of the Qalaysan River of Uzbekistan and Godavari River of India. These Rivers were influenced by flows and therefore the WAWQI can be applied as a water quality assessment tool to tropical Rivers that have rainfall influencing the water quality of the rivers (Salih et al., 2012; Darapu et al., 2013). The WAWQI was useful in assessing the suitability of the water quality of the Qalaysan River for drinking and irrigation purposes and other human uses based on World Health Organisation guidelines (Salih et al., 2012). The WAWQI detected the deteriorating water quality of the Qalaysan River of Uzbekistan, Godavari River of India, Tigris River of Iraq, Siluko River, and Owo River of Nigeria and that the water quality of the rivers was not suitable for human consumption when compared to the World Health Organisation guidelines and drinking guidelines (Akoteyon et al., 2011; Salih et al., 2012; Darapu et al., 2013; Al-Sabah et al., 2016; Oboh & Agbala, 2017). In all cases, the WAWQI was reliable in identifying water quality variables that cause deterioration of water quality of the rivers and highlighted water quality variables that may negatively impact the water quality of the rivers in the future, and proposed water quality monitoring of River systems to manage water quality impacts (Akoteyon et al., 2011; Salih et al., 2012; Darapu et al., 2013; Al-Sabah et al., 2016; Oboh & Agbala, 2017).

Neswiswi, B (2014) implemented the WAWQI to conduct a water quality assessment of the Jukskei River in South Africa. The WAWQI was used in the study to determine the water quality trends and pollution hotspots along the Jukskei River (Neswiswi, 2014). The WAWQI proved to be useful in transforming complex water quality data in determining the pollution hotspots and generating water quality trends over the summer and winter seasons. The information could be communicated easily to policymakers, managers, and the public (Neswiswi, 2014). The study also revealed that it would be beneficial to incorporate the WAWQI into the laboratory information system to improve data analysis, interpretation, and methodologies of the information system (Neswiswi, 2014). In noting the advantages of the WAWQI, Neswiswi (2014) did note in the study that the WAWQI should be complemented by other statistical data analysis processes to ensure that the root causes of pollution hotspots are adequately identified, monitored, and managed. However, the WAWQI has the disadvantage of eclipsing or over-emphasising water quality variables and that omission of certain water quality variables may not give the full picture of the water quality status of the river. A single WQI number was not sufficient to explain the water quality status of the river (Tyagi et al., 2013).

2.4.1.2. US National Sanitation Foundation Water Quality Index (NSFWQI)

The NSFWQI was developed to determine the water quality status of highly polluted water resources using pH, temperature, turbidity, faecal coliform, dissolved oxygen (DO), biological oxygen demand (BOD), total phosphates (PO_4^{3-}), nitrates (NO_3^-), and total dissolved solids (TDS) (Tyagi et al., 2013). The NSFWQI has been applied in countries like India, Iran, Indonesia, and Tanzania. The NSFWQI was implemented in the Yamuna River of India, Gongol River of Iran, Kreung Tamiang and Ciambulawung Rivers of Indonesia (Mohseni-bandpey et al., 2014; Abba et al., 2015; Effendi et al., 2015; Ichwana et al., 2016). The NSFWQI was used to determine the level of pollution of the Yamuna River in India and Gongol River of Iran.

The NSFWQI was accurate in determining the decline in water quality of the Yamuna River and Gongol River using historical water quality data from monitoring stations of the river (Mohseni-bandpey et al., 2014; Abba et al., 2015). Abba et al. (2015) and Mohseni-bandpey et al. (2014) were able to demonstrate that the NSFWQI can be used to determine the water quality status of the rivers and give directives into water management strategies that can assist in improving the water quality of the Gongol and Yamuna Rivers. Thus, the studies demonstrated that the NSFWQI had the advantage of detecting spatial and temporal water quality changes of rivers over a period (Mohseni-bandpey et al., 2014; Abba et al., 2015). However, in the study conducted by Mohseni-bandpey et al. (2014), water quality from six monitoring stations was used and showed that the NSFWQI was not sensitive to the number of monitoring sites that can be used to determine the water quality of a river. The reliability of the NFSWQI was solely based on using similar water quality variables.

Ichwana et al. (2016) used the NSFWQI to determine the water quality of the Kreung Tamiang River in Indonesia for drinking water purposes. The study found that the NSFWQI was efficient in determining the water quality status of the river for drinking purposes and in communicating the water quality status to the public. The information derived from the NSFWQI can be used to educate the public using the river about disinfecting the river water before using it for drinking and other domestic purposes (Ichwana et al., 2016). The NSFWQI was applied in the Ciambulawung River in Indonesia in the study by Effendi et al. (2015) to determine the impact of a small hydro-power plant and domestic purposes. A modification of weighting was used in the study to account for the omission of faecal coliform as the water quality variable that should have been included in the study (Effendi et al., 2015). The studies by Ichwana et al. (2016) and Effendi et al. (2015) demonstrated the flexibility of the NSFWQI in determining the water quality of the rivers in different regions of Indonesia impacted by different water uses.

The NSFWQI was applied to water resources in Africa. The NSFWQI was applied in the Nigerian Delta. Ebuete et al. (2019) applied NSFWQI in the Epic Creek to determine the health risk of the river to domestic users. The NSFWQI indicated seasonal changes of the Epic Creek. The NSFWQI could communicate the pollution levels of the water quality variables in the river to water managers so that stringent water quality guidelines and strategies can be implemented to preserve the water quality of the river (Ebuete et al., 2019). Alphayo & Sharma (2018) applied the NSFWQI to determine the water quality status of the polluted Ruvu River in Tanzania. The river is used for domestic and recreational purposes and threatened by other anthropogenic activities (Alphayo & Sharma, 2018). The study by Alphayo & Sharma (2018) demonstrated the reliability of the NSFWQI in determining the water quality trends in the fourteen sites and determining the water quality variables that posed the pollution risk in the Ruvu River.

The disadvantage of NSFWQI was that it was developed using stringent criteria of water quality variables prescribed for WQI. NSFWQI was more effective if DO, FC, pH, BOD, temperature, total PO_4^{3-} and NO_3^- concentrations, turbidity, and total dissolved solids are in included in the WQI. Modification of weighting is required to account for the omission of prescribed water quality variables (Tyagi et al., 2013; Kachroud et al., 2019). The calculation of NSFWQI seems to lose data during the data handling process because it uses the arithmetic mean method to calculate the overall water quality index of the water resource. Generally, the NSFWQI was effective when implemented in polluted water resources (Tyagi et al., 2013).

2.4.1.3. Oregon Water Quality Index (OWQI)

The Oregon Water Quality Index (OWQI) was developed for the Oregon River, and it created a score to measure the general water quality of the Oregon River. Cude, 2001 indicated that the OWQI was developed to be a simple and concise approach of expressing the significance of the water quality data of monitored in the Oregon River network. The OWQI was limited to assessing the water quality of a river for recreational purposes such as fishing and swimming (Cude, 2001). The disadvantages of the OWQI are that it cannot determine the water quality of River for other water uses and health hazards and that it is sensitive because one needs to consider all relevant chemical, physical and biological data to provide definite information (Cude, 2001). The OWQI was developed for application in rivers in the Oregon region and its application to rivers in other geographical regions or water body types is limited and should be approached with caution (Cude, 2001).

2.4.1.4. British Columbia Water Quality Index (BCWQI)

The British Columbia Water Quality Index (BCWQI) was established in 1995 by the Canadian Council of Ministers of Environmental to increase indices to classify water resources. The BCWQI is like the CCME WQI, where water quality variables are measured against target water quality guidelines (Pooman &Tanushree, 2013).

The accuracy of the BCWQI is dependent on the repeated sampling and monitoring stations. The disadvantage of the BCWQI is that it is limited to detecting water quality variables that are above target water quality guidelines (Pooman &Tanushree, 2013). Zandbergen & Hall (1998) initiated the study to evaluate the performance of the BCWQI and to assess its usefulness as a water quality management tool in two urban rivers. The study was implemented to protect aquatic life and to meet water quality objectives (Zandbergen & Hall, 1998). The limitation of the BCWQI is that it is not a good indicator of spatial and temporal trends of the water quality status on rivers. This is because the BCWQI relies on the accuracy and consistency of the monitoring design and data that is collected. The BCWQI was unreliable in comparing the water quality status of rivers that have different water quality objectives (Zandbergen & Hall, 1998).

2.4.1.5. Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)

The CCME WQI is useful in simplifying complex and technical water quality. The CCME WQI is a science-based communication tool that compares the multiple water quality variables of a water resource against target water quality limits for specific use (Pooman &Tanushree, 2013). The CCME WQI is a mathematically based tool used to aggregate the multi-variable water quality data into a single dimensionless index and compares the index to chosen target water quality limits (Davies, 2006).

The scope (F_1) assesses the extent of non-compliance to the water quality guidelines which is the water quality variables do not meet the objectives of the water quality guideline over a period (Lumb et al., 2006). The frequency (F_2) indicates the number of times the measured water quality variable is non-compliant with the water quality guideline. The magnitude (F_3) represents the extent to which the measured water quality variable is non-compliant with the water quality guideline (Lumb et al., 2006). The CCME WQI detects seasonal changes and the historical water quality status of the water resource.

To ensure that the CCME WQI is efficient and accurate, it is important that the data used is reviewed to ensure they align with the objectives of the water quality monitoring program (CCME, 2011). This means that the minimum data sets used in the CCME WQI must meet the objectives of the monitoring program or should be discarded. In the application of the CCME WQI, it is noted that old data should be used with caution. This is because analytical data and detection limits have improved over time and some water quality variables may appear to violate the detection limit of the water quality guidelines when it is essentially not the case (CCME, 2011). Therefore, care should be taken not to report “false positives” of the CCME WQI results because they may be misleading. The CCME WQI is sensitive to water quality variables used to calculate the water quality index (CCME, 2011). A minimum of eight water variables and a maximum of twenty variables should be used in the calculation of the CCME WQI. The CCME WQI for a specific river should only include data that represent the activities impacting the river (CCME, 2011). Inclusion of other irrelevant variables in the calculation process of the CCME WQI may cause an error in comparison of water quality index results over a time or sites of the river. The CCME WQI should therefore include water quality variables that are specific to water use and human health. Biological variables must be included for drinking and recreational purposes and not necessarily for aquatic life protection (CCME, 2011). To improve the efficiency and accuracy of the CCME

WQI, it must therefore include water quality data sets that are specific to water use and health risks and represent the seasonal changes. This can make the CCME WQI a powerful tool to determine seasonal changes of the river for management purposes (CCME, 2011). Therefore, it is suggested that a data set of a minimum of three years can be used to effectively give a true reflection of seasonal changes in the water quality. The validation process is important to determine the validity of the results generated by the CCME WQI (CCME, 2011).

The CCME WQI is one of the most widely used water quality indices to determine the quality of rivers. There are studies in Europe, Asia, North America, South America, and Africa which demonstrate the versatility of the CCME WQI. Paun et al. (2017) applied the CCME WQI in the Danube River of Romania to determine the suitability of the river for drinking. In the study, the CCME WQI was calculated for each monitoring site from a reference period (Paun et al., 2017). The study found that the CCCME WQI was effective in calculating the overall water quality and in determining the water quality variables for each site of the river that violated the limits of the water quality guidelines. A gap in the study was the omission of faecal coliform as the water quality variables that should have been included to determine the suitability of river water for domestic purposes (Paun et al., 2017). Hassan & Abbas (2018) implemented CCME WQI in the Diwanyiah River in Iraq. The study aimed to determine the water quality of the river to protect the aquatic ecosystem (Hassan & Abbas, 2018) which contrasted with the study that was conducted by Paun et al. (2017). The CCME WQI was reliable in determining the water quality trend of the Diwanyiah River from the reference time and determining water quality variables that exceeded the water quality guidelines limits (Hassan & Abbas, 2018). Ewaid (2016) showed the flexibility of the CCME WQI in calculating the water quality status of one river for more than one water use. The study by Ewaid (2017) determined the water quality of the Al-Gharraf River of Iraq for the protection of aquatic ecosystems, drinking, and irrigation use. The CCME WQI was able to give different water quality statuses of the Al-Gharraf River for the protection of the aquatic ecosystem, drinking, and irrigation based on the different water quality objectives of the river that were monitored (Ewaid, 2017). The evidence of the flexibility of the CCME WQI in determining the water quality status of the river for different water uses was established by the study that was done by Mahagamage & Manage (2014) on the Kelani River in Sri-Lanka. In the study, the CCME WQI was used to determine the water quality of the river for drinking, recreational, irrigation purposes, and use for livestock. Although seventeen water quality variables were used in the study, only appropriate water quality variables were considered for each water use (Mahagamage & Manage, 2014). The CCME WQI study was efficient and reliable in classifying the water quality of the river according to the different uses and water quality variables that violated the water quality guidelines were detected for each water use (Mahagamage & Manage, 2014).

The CCME WQI was applied in the North American river of Qu’Appelle in Canada. The goal of the study was to assess the spatial and temporal changes in water quality in the river and to assess the impact of the installation of a eutrophic clarifier on wastewater treatment works that discharge into the river (Davies, 2006). The study by Davies (2006) demonstrated the strength of the CCME WQI in determining the spatial and temporal changes of the water quality variables and the ability of the CCME WQI to detect improvements in the water quality of Rivers. The weakness of CCME WQI in the Davies (2006) study was its sensitivity to the sample size of water quality variables. Similar studies were conducted by Lumb et al. (2006).

Finotti et al. (2015) applied the CCME WQI in the urban rivers of Brazil as a communication tool of pollution sources in the rivers and to provide data to support the environmental licensing processes. The study by Finotti et al. (2015) indicated that the CCME WQI is an appropriate method of evaluating the water quality of urban rivers. Gyamfi et al. (2013) applied the CCME WQI to assess the pollution level of the Aboabo stream in Ghana. The CCME WQI was successful in predicting the decline in water quality of the river and to prompt policy reforms for water resources in Ghana (Gyamfi et al., 2013). The application of the CCME WQI in the river Asa in determining its suitability for drinking purposes and protection of aquatic life showed the flexibility of the CCME WQI in calculating the water quality status of one river for more than one water use, its reliability in determining the water quality trend of the river Asa from the reference period and determining water quality variables that exceeded the water quality guidelines (Edwin & Murtala, 2013; Ewaid, 2016; Hassan & Abbas, 2018). Keraga et al. (2017) applied the CCME WQI of the Awash River in Ethiopia to determine the suitability of the river for drinking and irrigation purposes. The CCME WQI was efficient and reliable in classifying the water quality of the river according to the different uses and water quality variables that violated the water quality guidelines were detected for each water use (Keraga et al., 2017).

The study by Namugize & Jewitt (2018) implemented the CCME WQI to assess the effect water quality monitoring frequency has on reporting on the level of pollution of uMgeni River of South Africa. The study used a twenty-eight-year water quality dataset to determine the deterioration of uMgeni water using the CCME WQI (Namugize & Jewitt, 2018). The CCME WQI in the study was effective in determining the water quality variables that were drivers and influenced the eutrophic condition of the river and the suitability of the uMgeni River for recreational use. This indicated the sensitivity of the CCME WQI to the water quality variables applied in the index (Namugize & Jewitt, 2018). The usefulness of the CCME WQI was dependent on the frequency and quality of water quality variables of the monitoring programme. The study showed that the information provided by the CCME WQI was compromised by the ability of the water quality variables to meet or fail the thresholds set in the CCME WQI (Namugize & Jewitt, 2018). The study indicated that the lack of available data for dissolved oxygen and biological oxygen demand prevented the use of FSWQI and OWQI. The study suggested that the reporting of the CCME WQI should be supplemented by scientific and local knowledge of the river (Namugize & Jewitt, 2018).

2.4.2. Water quality indices implemented in South Africa

Kleynhans et al. (2005) developed Eco-classification methodologies to calculate indices to determine the overall status of water ecosystems that included the Physico-chemical Driver Assessment Index (PAI), Hydrological Driver Assessment Index (HAI), Fish Response Assessment Index (FRAI), Geomorphological Driver Assessment Index (GAI), Macroinvertebrate Response Assessment Index (MIRAI) and the riparian Vegetation Response Assessment Index (VEGRAI) are the indices developed in South Africa to determine the overall health status of the River (Rangeti et al., 2015). The indices were developed on the assumption that a good ecological indicator should be able to quantify the magnitude of stress and the degree of exposure to the stress of the water resource (Rangeti et al., 2015). Therefore, these indices are integrated to determine the overall health status of water resources in South Africa (Rangeti et al., 2015).

2.4.2.1. Physico-chemical Driver Assessment Index (PAI)

The PAI is a tool used to determine the present water quality status of water resources or sites using its physical and chemical variables (Kleynhans et al., 2005). The PAI considers the extent to which the present water quality variables have changed from the reference conditions (rating) and the importance of the water quality variables to the biotic responses (rank and weight) (Kleynhans et al., 2005). The process to determine the present water quality status for each water quality variable is represented in Figure 2-2.

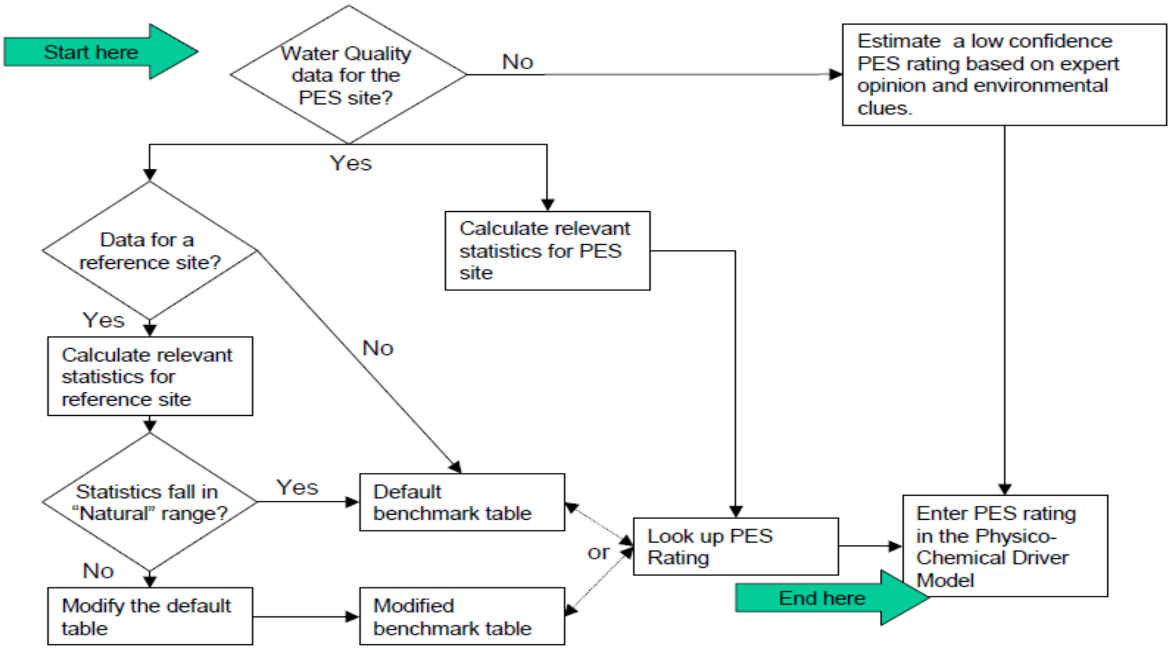


Figure 2-2: Process to used determine the present ecological status of a water resource (Taken from Kleynhans et al., 2005)

The PAI can be used to determine the water quality of surface water in reserve determination processes of the water resource (Kleynhans et al., 2005). The PAI was used as a water quality index to determine the water quality status of water resources for reserve determination studies. There is limited literature where PAI was implemented to determine the reserve of a series of catchments in South Africa. The PAI was used to determine the water quality status of the Phongolo River in KwaZulu-Natal province of South Africa (de Necker et al., 2020). The aim of the study by de Necker et al. (2020) was to determine the historic and present water quality state of the middle and lower Phongolo River and assess the possible impacts of the 2015-2018 drought and whether the flow releases of the Pongolapoort Dam has an impact on the water quality in the lower Phongolo Dam (de Necker et al., 2020). The PAI was able to link the deteriorating water quality status of the Pongola River to climate extremes like drought and environmental flows and sedimentation. The PAI was able to distinguish between water quality status upstream and downstream of the dam (de Necker et al., 2020). The study was limited by the inconsistency of the availability of historical data, as monthly records obtained from the DWS monitoring stations consisted of incomplete recordings, making direct comparisons between data sets was difficult (de Necker et al., 2020).

2.4.2.2. Geomorphological Driver Assessment Index (GAI)

The GAI is a model that is used to determine the ecological health of the stretch of the river where the site is situated. The GAI uses logical reasoning because there is no reference condition to measure the judgements against (Kleynhans et al., 2005). The GAI uses on-site hydraulic data of the river such as depth and velocity and integrates it with sediment data such as clay, silt, gravel, sand, cobbles, or boulders to determine the ecological status of the river on that site and to contribute to the understanding of observed changes to the biological species at biomonitoring sites (Kleynhans et al., 2005).The GAI has been implemented in the determination of the ecological water requirements for the Komati , Kromme , and the Kat river and to assess the impact of the Kabouga dam on the water resource (Kleynhans et al., 2005).

2.4.2.3. Hydrological Driver Assessment Index (HAI)

The HAI model is used to provide information on the changes in the hydrological characteristics such as volume, timing, and duration of flows of a river from its reference condition. The HAI uses monthly natural and present-day hydrology and the daily neutralised and observed hydrology to determine intermediate and comprehensive reserve study (Kleynhans et al., 2005). The HAI was implemented in the Elands River in Mpumalanga and Mvoti River in Kwazulu-Natal in the study by conducted by von Bratt (2007). In the study, von Bratt (2008) used the HAI as one of the tools to determine the present ecological status of the Elands and Mvoti Rivers.

2.4.2.4. Fish Response Assessment Index (FRAI)

The FRAI model is based on determining the response of fish species to environmental conditions impacting a particular water resource. A particular fish species that are present in the water resource at a particular time is compared to the fish species that existed historically in that water resource (Kleynhans et al., 2007a). The deviation of the current fish species data to the historical fish species data is linked to environmental conditions. The FRAI is normally based on the combination of sampled fish data and habitat data (Kleynhans et al., 2007a). The FRAI has been implemented in a series of studies in South Africa to determine the ecological status of the rivers. The FRAI was implemented in the uMngeni River in KwaZulu-Natal (Dlamini, 2019). The aim of the study was to determine the response of fish communities to changes in environmental drivers and influence of alien fish species using field data (Dlamini, 2019). The FRAI was able to determine spatial changes in fish species upstream and downstream reaches of the uMngeni River and linked the changes in fish species was due to flow modification and impacts by land use activities (Dlamini, 2019). The FRAI was implemented in the lower Amatikulu, Thukela and Umvoti Rivers in KwaZulu-Natal to determine the ecological status of the rivers (Venter, 2013).

The FRAI and the multivariate statistical analysis was successful in determining the different ecological statuses of the lower Amatikulu, Thukela and Umvoti Rivers using field surveys (Venter, 2013). The ecological status of the different regions of the Vaal Barrage was determined using the FRAI and analysis of variance (ANOVA) statistics based on desktop and field data (Wepener et al., 2011). The aim of the study was to establish the risk of exposure of fish in the different regions of Vaal Barrage. The FRAI was efficient in determining the ecological status of the different regions of the Vaal Barrage using fish data (Wepener et al., 2011). The FRAI was implemented in the non-perennial Seekoei River in the Orange-Vaal River system to determine the response of fish species to habitat changes in geomorphology, hydrology, and water quality (Avenant, 2010). The FRAI was able to determine the spatial differences in the fish communities between the upper reaches and downstream reaches of the Seekoei River. However, the study indicated challenges in implementing the FRAI (Avenant, 2010). The FRAI was influenced by scientific judgement and that some assumptions may lead to incorrect FRAI scores and interpretation of ecological status of the reaches. The FRAI scores improves with increasing sample sites but in some cases, it is not possible because of the conditions of the river (Avenant, 2010). The use of accumulated data of FRAI to determine the ecological status is incorrect under ephemeral conditions. The FRAI is not appropriate to rivers which have low species diversity (Avenant, 2010). The study by Avenant (2010) suggested that samples should be taken under similar hydrological conditions to ensure scientifically justifiable results.

2.4.2.5. Macroinvertebrate Response Assessment Index (MIRAI)

Aquatic macroinvertebrates are used to assess the biological integrity of the rivers because the macroinvertebrates give an indication of prevailing flow regime and water quality of the river (Thirion, 2007). The macroinvertebrate taxa are determined by implementing a semi-quantitative tool call SASS 5 and the comprehensive MIRAI model which includes flow and habitat information. The MIRAI measures the deviation of macroinvertebrate species from the reference conditions (Thirion, 2007). The MIRAI model requires site visit and extensive sampling of the macroinvertebrates to ensure that all data is collected. Implementation of MIRAI requires literature survey as well as data mining from the Rivers Database to setting reference conditions for the study. The MIRAI model is flexible and can be used to determine the ecological status of macroinvertebrate communities under various scenarios where there is change in flow, habitat, and water quality conditions (Thirion, 2007).

2.4.2.6. Vegetation Response Assessment Index (VEGRAI)

The VEGRAI model includes data from the different lateral riparian zones and the response of vegetation to the different inundation levels. The VEGRAI was used in the Reserve determination process (Kleynhans et al., 2007a). The VEGRAI model is composed of a series of metrices that use field data and provides a quantitative assessment of the response of vegetation to environmental impacts. The VEGRAI model describes the ecological status of the river in its current and reference states (Kleynhans et al., 2007b). The VEGRAI model is based on sampling on woody and non-woody zones based on different vegetation characteristics. The interpretation of VEGRAI is based on defining the reference conditions as those absent from land-use activities but some reference conditions are determined from reference sites (Kleynhans et al., 2007b) The VEGRAI can be used to make qualitative predictions on the behaviour of vegetation to future changes in environmental conditions. However, these scenarios will have low confidence to how close they will be to the real situation (Kleynhans et al., 2007b).

2.4.3. Studies conducted in the Crocodile-West River catchment

There have been several studies on rivers and tributaries of the Crocodile West/Marico catchment to determine their water quality status using physico-chemical variables and other biological indices. The study by Enoch (2018) used spatial analysis to determine the potential threats to the water quality status of Freshwater Ecosystem Priority Areas (FEPAs) in the upper Crocodile-West River catchment. The study incorporated the use of physico-chemical variables and macroinvertebrates to determine the water quality status of the Skeerpoort River, Sterkstroom River, Buffelsfontein stream, Magalies River, and Brandvlei River (Enoch, 2018). A 12-month physico-chemical water quality sampling was conducted, and a single set of macroinvertebrate sampling was collected during the 12-month period. The macroinvertebrate data were analysed using the South African Scoring System (SASS 5) which is an adapted biotic index (BI) developed by Chutter in 1972 (Enoch, 2018). The advantages of SASS 5 as a bio-assessment tool was that it was an inexpensive tool to implement to show the deterioration of water quality of rivers over time, macroinvertebrates are sensitive to pollution and habitat changes and makes SASS 5 a good indicator of pollution and to identify pollution sources of rivers (Enoch, 2018). The SASS 5 tool in the study was able to determine the ecological condition of the rivers in the upper Crocodile-West River catchment. The principal component analysis (PCA) was used in the study to confirm the land-use activities as potential sources of water pollution to the Skeerpoort River, Sterkstroom River, Buffelsfontein stream, Magalies River, and Brandvlei River (Enoch, 2018).

Taylor et.al (2007) applied several biotic indices to calculate the changes in water quality of the Crocodile West/Marico catchment using diatom species. The data was run using the OMNIDIA version 3.1 to determine the index scores for the Crocodile-West/Marico catchment (Taylor et al., 2007). In addition, chemical data were collected from the National Chemical Monitoring Programme from the DWS. Correlation analysis was implemented to determine the relationship between the chemical data and diatom data (Taylor et al., 2007). The study by Taylor et al. (2007) indicated that there was a significant correlation between the diatom data and the chemical water data. The diatom indices can be utilised to reflect changes in water quality status of water resources. The diatom index approach used to indicate water quality status was useful in South African streams and rivers. However, there is the disadvantage of implementing diatom indices adapted from Europe to calculate the water quality status of water resources. The occurrence of endemic species will necessitate the creation of a unique diatom index specific for South African conditions (Taylor et al., 2007). The study by Taylor et al. (2007) indicated that diatom index has the potential to improve the recognition of diatom-based approaches to conduct water quality studies, allow the dissemination of simple and useful information to water resource managers, and collect data to formulate a unique diatom index calculator. de La Rey et al. (2007) implemented a similar study to Taylor et al. (2007) but the study focused on the correlation between SASS 5 and biotic indices to the water quality variables. The SASS 5 scores for macroinvertebrates responded more to changes in water quality variables than habitat changes (de La Rey et al., 2007). The study by de La Rey et al. (2007) noted that the diatom-based indices responded adequately to the study but there was a need to adapt the method to include endemic species. The PCA was implemented in the study to determine which water quality variables were drivers in the Crocodile-West/Marico catchment. The PCA was efficient in identifying the problematic water quality variables both geographically in the study (de La Rey et al., 2007).

Walsh and Wepener (2009) implemented the Generic Diatom Index (GDI), Specific Pollution Sensitivity Index (SPI), Biological Diatom Index (BDI), Eutrophication/Pollution Index (EPI) and Percentage Pollution Tolerant Valves incorporated in the OMNIDIA software to assess the integrity of diatoms per land-use activities impacting the Crocodile West and Magalies Rivers. Similarly, to the study conducted by Taylor et al. (2007), Walsh and Wepener (2009) implemented a principal component analysis (PCA) to show similarity or dissimilarity of water quality variables during low and high flow conditions in the Crocodile-West and Magalies Rivers. The study by Walsh and Wepener (2009) indicated that diatom species were impacted by changes in water quality due to land use activities. The study by Walsh and Wepener (2009) acknowledged that the health of rivers must incorporate both water quality variables and biological indicators since diatoms remain in one place and can show a cumulative effect of the water quality impact of a specific site. Tshivhase (2019) implemented a mini-SASS tool to determine the current ecosystem conditions of the Crocodile and Marico Rivers in correlation with selected water quality variables. The water quality variables in the study were effective in differentiating the seasonal temporal conditions in both Crocodile and Marico Rivers. Mini-SASS was derived from the SASS 5 system to eliminate the complexity of macroinvertebrates taxa to small groupings of macroinvertebrates. According to Tshivhase (2019), the mini-SASS 5 biomonitoring tool was limited by its accuracy to identify specific types of macroinvertebrate taxa and the water pollution impacts. The mini-SASS 5 biomonitoring tool is intended to be an early warning tool to be used by the public (Tshivhase, 2019).

Levin et al. (2019) implemented the Fish Response Assessment Index (FRAI) as a bio-indicator of urban impacts on the Braamfontein spruit, Jukskei, Muldersdriftsloop, Swartspruit, Magalies and Skeerpoort Rivers in the Crocodile-West River catchment. Fish assemblages in rivers are indicators of land and environmental conditions impacting the Crocodile-West River catchment. The principal component analysis was used to determine which fish species are possible bio-indicators based on their response to land and environmental impacts (Levin et al., 2019). The FRAI was effective in linking the impacts of urbanisation on rivers in that the ecological integrity of rivers that were close to urban areas decreased in fish diversity. The FRAI was able to show that fish species responded negatively to urbanisation (Levin et al., 2019). The FRAI was efficient in detecting land use impacts from urban to rural rivers. Levin et al. (2019) indicated in the study that implementing FRAI is highly specialised, and the approach requires resources and practitioners to be trained to identify the reason for the disappearance of certain fish species in the area. Implementation of FRAI required more research to be implemented to identify the fish species and their response to key land-use activities (Levin et al., 2019).

2.5. <u>Selection of Water Quality Index</u>

Lumb et al. (2011) indicated that the accuracy and efficiency of the water quality index (WQI) is dependent on the monitoring programme, methodology of analysis of physico-chemical variables, and the water quality guidelines and objectives. This statement indicates that each water quality index has strengths and weaknesses that prevent its use in a particular river and that there is no universally acceptable water quality index (Tyagi et al., 2013) (refer to Table 2.1). Tyagi et al. (2013) indicated the advantages and disadvantages of the water quality indices used in the literature review.

Table 2-1: The summary of the advantages and disadvantage WQIs that were discussed in the literature review (Kleynhans et al., 2005; Kleynhans et al., 2007a; Kleynhans et al., 2007b; Thirion, 2007; Avenant, 2010; Wepener et al., 2011; Venter, 2013; Tyagi et al., 2013; de Necker et al., 2020)

Weighted Arithmetic Water Quality Index (WAWQI)	
Advantage	**Disadvantage**
1. Data from multiple water quality variables incorporated into a mathematical equation to classify the health of the water resource 2. WQI not strict of the type and number of water quality variables 3. Useful in communicating overall water quality to public and policy makers 4. Reliable tool in identifying water quality variables which may cause deterioration of water quality 5. Assess the suitability of the water quality for different purposes	1. Eclipsing or over-emphasising water quality variable 2. Omission of certain water quality variable may not give full picture of water quality status 3. A single WQI number not sufficient to explain the water quality status of river 4. WQI should be complemented by other statistical data analysis processes to ensure root causes of pollution hotspots are adequately identified, monitored and managed.
National Sanitation Framework Water Quality Index (NSFWQI)	
Advantage	**Disadvantage**
1. WQI credible because more than hundred experts were considered in the development of the WQI 2. Summarises water quality data into single number in an objective, rapid and reproducible manner 3. WQI not sensitive to number of monitoring sites used to determine the water quality status 4. WQI detects spatial and temporal water quality changes of rivers over a time	1. Stringent criteria of water quality variables prescribed for WQI 2. Loss of data during data handling 3. Modification of weighting required to account for the omission of prescribed water quality variable 5. WQI applied to polluted water resources

Oregon Water Quality Index (OWQI)	
Advantage	**Disadvantage**
1. Unweighted harmonic square formula to calculate WQI 2. Formula sensitive to changing conditions and significant impacts of water quality 3. Method acknowledges different water quality variables pose different significance in different sites and locations	1. Limited to assessing water for recreational purposes such as fishing and swimming 2. Sensitive to chemical, physical and biological data 3. Cannot determine the water quality for other water uses and health hazards 4. Limited application of the WQI

British Columbia Water Quality Index (BCWQI)	
Advantage	**Disadvantage**
1. Water quality variables are measured against target water quality limits and objectives 2. Flexible and applied to rivers with different objectives	1. Accuracy of WQI is dependent on sampling frequency and monitoring stations 2. WQI is not a good indicator of spatial and temporal trends of the water quality status 3. WQI unreliable in comparing the water quality status of rivers that have different water quality objectives

Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)	
Advantage	**Disadvantage**
1. Useful in simplifying complex and technical water quality 2. Compares multiple water quality variables of a water resource against target water quality limits for specific use 3. WQI detects seasonal changes and historical water quality status of the water resource 4. Biological variables included for drinking and recreational purposes and not necessarily for aquatic life protection 5. WQI used for different water uses	1. Minimum data sets used in the WQI must meet the objectives of the monitoring program 2. Old data should be used with caution 3. WQI sensitive to water quality variables used to calculate the WQI 4.Reporting of the WQI should be supplemented by scientific and local knowledge

6. WQI adapted to different legal requirements 7. WQI flexible to be applied in different regions	
Physico-chemical Driver Assessment Index (PAI)	
Advantage	**Disadvantage**
1. Data from multiple water quality variables incorporated into a mathematical equation to classify the health of the water resources 2. Useful in communicating overall water quality to public and policy makers 3. Reliable tool in identifying water quality variables which may cause deterioration of water quality 4. Assess the suitability of the water quality for different purposes 5. WQI adapted to different legal requirements	1. WQI developed to determine health of water resources in South Africa 2. Strict to the type and number of water quality variables 3. WQI not extensively applied globally to test its potential as a WQI 4. Only applied in a reserve determination study of a few water resources in South Africa and limited in research literature
Geomorphological Driver Assessment Index (GAI)	
Advantage	**Disadvantage**
1. Implemented to determine the ecological health of river 2. WQI uses hydraulic and sedimentation data 3. Used to determine the ecological water requirements for the river for protection 4. WQI adapted to different ecological water requirements	1. On-site data collection required 2. Strict to the type of data that is inputted into the WQI 3. WQI not extensively applied globally to test its potential as a WQI 4. Applied in a reserve determination studies in SA water resources
Hydrological Driver Assessment Index (HAI)	
Advantage	**Disadvantage**
1. Implemented to determine the ecological health of river 2. WQI uses volume, timing, and duration of flow data	1. On-site data collection is required 2. Strict to the type of data that is inputted into the WQI 3. WQI not extensively applied globally to test its potential as a WQI

3. Flexible in intermediate and comprehensive reserve determination studies 4. Used to determine the ecological water requirements for the river for protection	4. Applied in a reserve determination study of water resources in South Africa
Fish Response Assessment Index (FRAI)	
Advantage	**Disadvantage**
1. Implemented to determine the ecological health of river 2. WQI uses fish and habitat data 3. Compare current fish species data to the historical fish species data is linked to environmental conditions 4. WQI tool can determine spatial changes in fish species upstream and downstream reaches 5. Efficient in detecting land use impacts from urban to rural rivers 6. Flexible in using desktop and field data	1. On-site data collection is required 2. Strict to the type of data that is inputted into the WQI 3. Implementing WQI is highly specialised 4. Results of WQI is influenced by scientific judgement and some assumptions may lead to incorrect FRAI scores and interpretation of ecological status 5. Applied in a reserve determination study of water resources in South Africa
Macroinvertebrate Response Assessment Index (MIRAI)	
Advantage	**Disadvantage**
1. Implemented to determine the ecological health of river 2. WQI uses macroinvertebrate, flow, habitat, and water quality data 3. Used to determine the ecological water requirements for the river for protection 4. WQI is flexible and can be used to determine the ecological status of macroinvertebrate communities under various scenarios	1. Extensive on-site data collection is required 2. Strict to the type of data that is inputted into the WQI 3. WQI requires literature survey as well as data mining from rivers Database to setting reference conditions for the study 4. Applied in a reserve determination study and quantifying impact of environmental conditions of water resources in South Africa
Vegetation Response Assessment Index (VEGRAI)	
Advantage	**Disadvantage**

1. Implemented to determine the ecological health of river 2. WQI uses vegetation data 3. Used to determine the ecological water requirements for the river for protection 4. WQI adapted to different scenarios	1. On-site data collection is required 2. Strict to the type of data that is inputted into the WQI 3. Applied in a reserve determination study and quantifying impact of environmental conditions of water resources in South Africa

The CCME WQI will be used in this study. The CCME WQI is flexible because it allows the selection of water quality variables to suite the local conditions (Lumb et al., 2006). This means that the CCME WQI can be used to classify the fitness of use of water resources for different water use objectives (Rangeti et al., 2015). The CCME WQI has been extensively applied globally to test its potential as a WQI and is reliable WQI that can be applied in the Crocodile-West River using water quality metadata. Similarly, the WAWQI, NSFWQI, OWQI, BCWQI and PAI could be used to assess the physico-chemical variables in the Crocodile-West River but these WQIs are limited in their applications. The WAWQI has a disadvantage of eclipsing or over-estimating the water quality index results and that a single water quality index number is not sufficient to explain the water quality status of the river (Tyagi et al., 2013). The NSFWQI is stringent in criteria of the water quality variables that inputted into the WQI. Loss of data is prevalent during the data handling process in preparation to use the NSFWQI and NSFWQI can only be applied to polluted water resources (Tyagi et al., 2013). The OWQI is applied to assessing the water resource for recreational purposes such as fishing and swimming and is not fit to determine water quality for other uses and health hazards (Tyagi et al., 2013). The disadvantage of BCWQI is that the accuracy of the WQI is dependent on the sampling frequency and monitoring stations. The WQI is unreliable in comparing the water quality status of rivers that have different water quality objectives (Tyagi et al., 2013). The PAI was alternative to assess the water quality of Crocodile-West River because it was developed for local conditions however, the WQI is not extensively applied globally to test its potential as WQI because there is limited research literature to compare its credibility as a WQI (de Necker et al., 2020). The GAI, MIRAI, FRAI and VEGRAI were developed to determine the ecological health of water resources in South Africa but the WQIs have stringent data requirements, requires extensive on-site data collection, and requires extensive literature surveys and data mining to setting reference conditions (Kleynhans et al., 2005; Kleynhans et al., 2007a; Kleynhans et al., 2007b; Thirion, 2007).

CHAPTER 3: METHODOLOGY

3.1. Description of the Study Area

The Crocodile-West River originates from the Witwatersrand Mountain range in Gauteng province. The Crocodile-West River joins the Marico River before it joins the Limpopo River. The Limpopo River flows through the Limpopo province and drains into the Indian Ocean through the country of Mozambique (Mosoa, 2013). The Crocodile-West River is influenced by flows from its tributaries such as the Elands, Hex, Sands, Hennops, Pienaars, Jukskei, Magalies, and Bierspruit Rivers (Mosoa, 2013). The Crocodile-West River catchment can be divided into the upper and lower Crocodile-West River sub-catchments and Elands and Apies/Pienaars sub-areas (Mosoa, 2013).

3.1.1. Upper Crocodile-West River sub-catchment

The upper Crocodile-West River sub-catchment is upstream of the confluence of the Crocodile-West River and Elands River with major tributaries being the Jukskei, Hennops and Bloubankspruit Rivers (Figure 3-1). The major cities in the upper Crocodile sub-catchment are the northern suburbs of Johannesburg, Kempton Park, Krugersdorp with major water resources being the Roodekopjes dam and Hartebeespoort Dam (Mosoa, 2013; Du Preez, 2018). Figure 3-1 shows that site 90194 is situated upstream of Hartebeespoort Dam and site 90167 is situated downstream of the Hartebeespoort Dam and Roodekopjes dam (Mosoa, 2013).

3.1.2. Apies/Pienaars sub-areas and Elands sub-areas

The Apies and Pienaars Rivers are the major tributaries of the Crocodile-West River. The Apies/ Pienaars Rivers drains towns such as Pretoria, Bela-Bela, and other industrial industries. Klipvoor and Roodeplaat dam are located along the Pienaars River as well (Mosoa, 2013). The Elands River is the mainstream in this sub-area with its major tributaries being Koster, Selons and Hex Rivers (Figure 3-1). The sub-catchment drains the town of Rustenberg and the surrounding mining operations. The Bospoort and Vaalkop dams in the Elands River are major water storage in the Eland sub-area (Du Preez, 2018). Site 90203 is downstream to sites 90194 and 90167. Site 90204 is situated downstream of site 90203 and the confluence of Crocodile-West River and Pienaars River (Mosoa, 2013).

3.1.3. Lower Crocodile-West sub-catchment

The part of the Crocodile-West River in figure 3-1 shows that the sub-catchment consists of two tributaries, namely, the Sand and Bierspruit Rivers. The main town in this sub-catchment is Thabazimbi and other small villages. The main activities in the sub-catchment are mining and irrigation. Site 90233 of the study is situated in this region downstream of sites 90203 and 90204 (Mosoa, 2013; Du Preez, 2018).

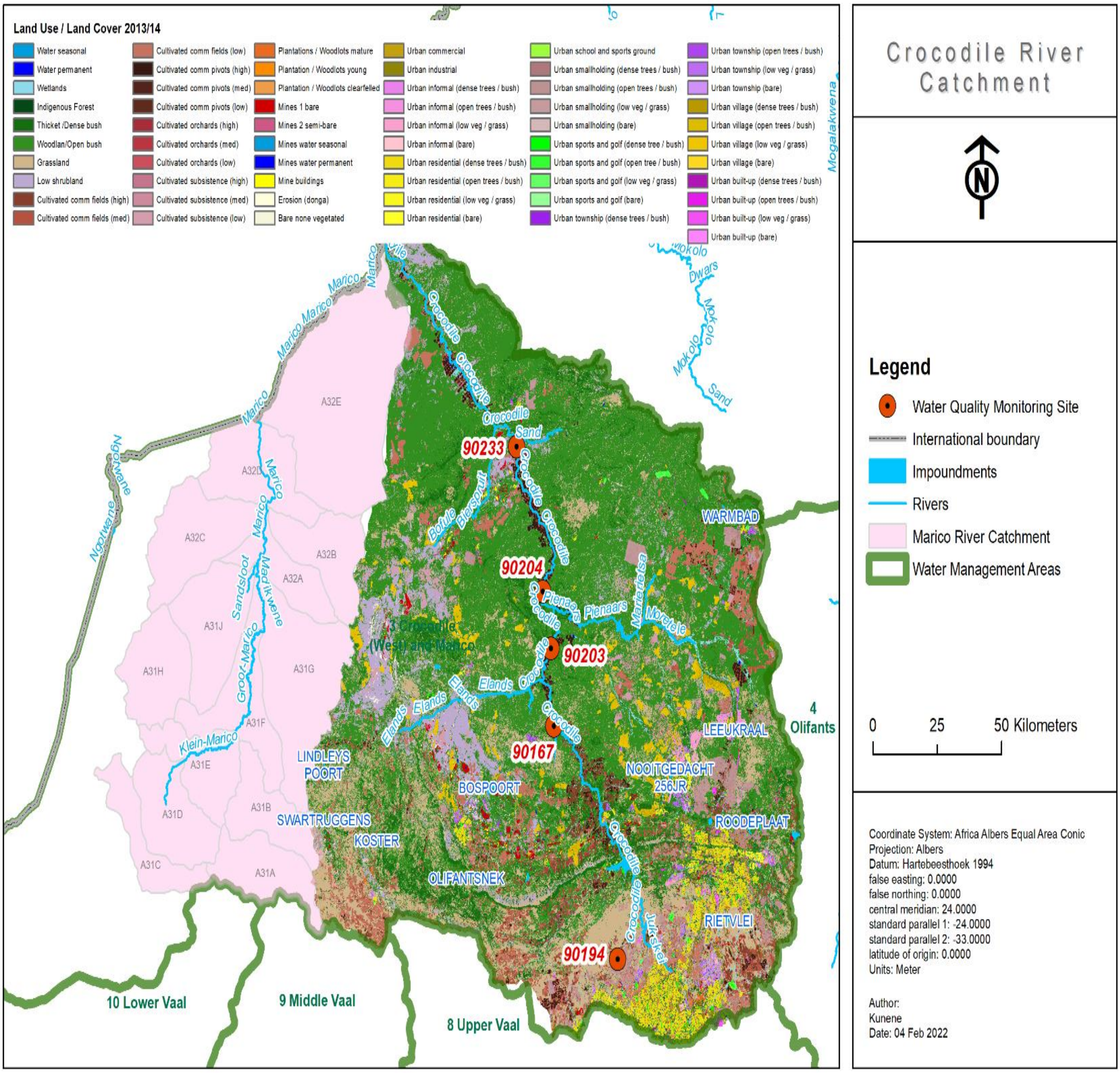


Figure 3-1: Land-use map Crocodile-West including the monitoring sites which are in the study

3.2. Geology of the Crocodile-West/Marico catchment

The geology of the Crocodile-West River is shown in figure 3-2. The geology consists of the Bushveld Complex supergroup which consists of mafic-ultramafic Rustenberg supergroup, Rashoop Granophyre supergroup and Lebowa Granite supergroup (Kent, 1980). The upper Crocodile-West River is underlain with the acid and intermediate extrusive, dolomite and limestone geology sources of carbonates in the river (Chapman, 1996). The Pienaars and Elands River sub-areas of the Crocodile-West River are underlain with The Transvaal, Rooiberg, Griqualand West supergroup in combination with the Suurberg, Drakensberg, and Lebombo supergroup and Beaufort supergroup which consists of dolomite and porous sedimentary strata, intercalated arenaceous and argillaceous strata, limestone, and porous unconsolidated and consolidated sedimentary geology. The Lower Crocodile-West River sub-catchment is underlain with Rustenberg, Lebowa, and Rashoop supergroup that is the core of the platinum ore that consists of basic mafic and ultramafic intrusive, dolomite limestone, porous unconsolidated and consolidated sedimentary strata, and intercalated assemblage of compact sedimentary and extrusive rocks (Figure 3-2).

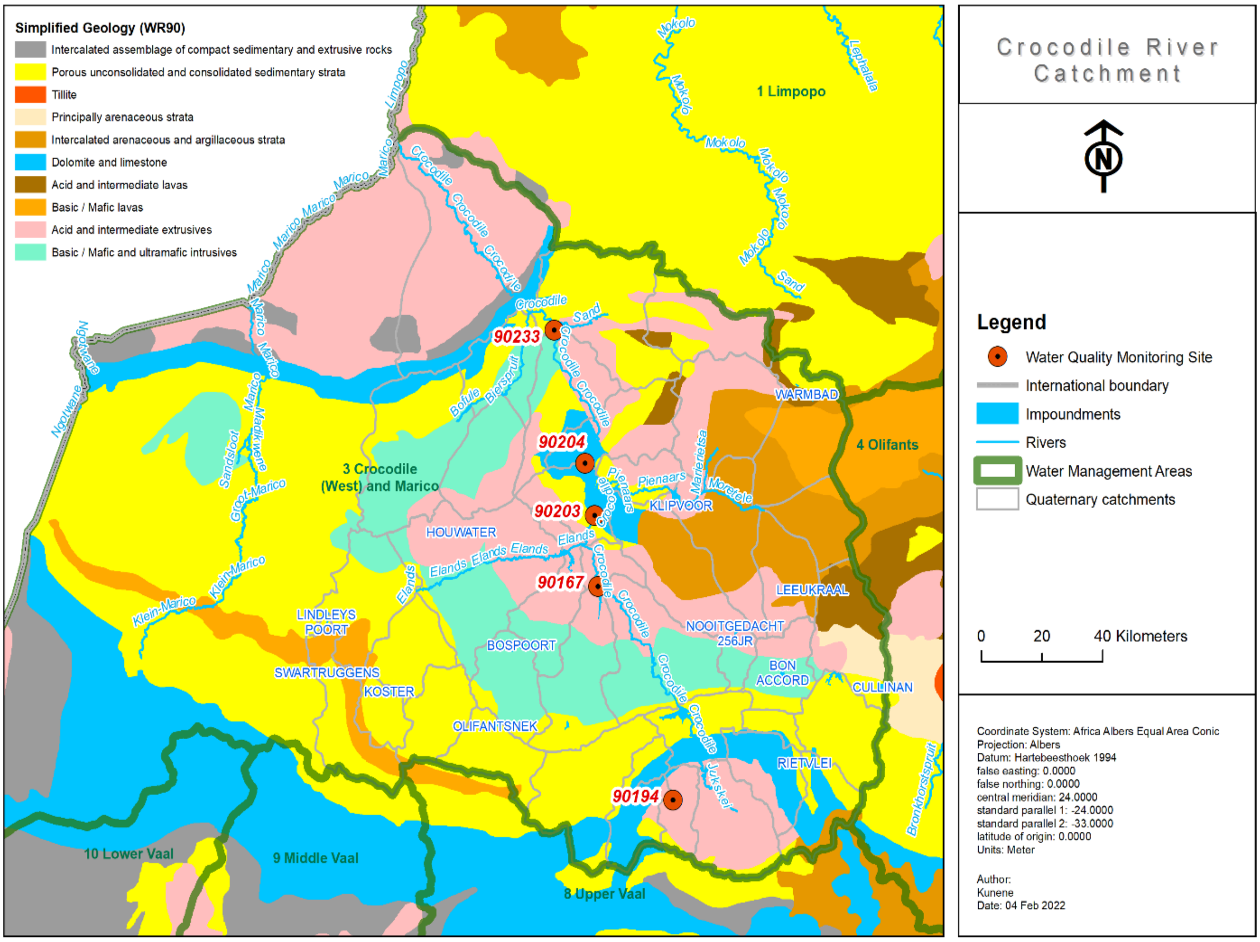


Figure 3-2: The geology of the Crocodile West/Marico catchment

3.3. Topography of Crocodile-West/ Marico catchment

The topography of the Crocodile-West and Marico catchment is uniform with gently undulating plains of the Highveld plateau located in the southern parts of the catchment. The altitude of the WMA ranges from 1700 masl on the Witwatersrand area to approximately 900 masl in the region where the Crocodile River joins the Limpopo River. The Witwatersrand, Magaliesberg, Waterberg and Pilanesberg form part of the topography of the Crocodile-West and Marico catchment (Smith-Adao et al., 2006).

3.4. Vegetation type of Crocodile-West/ Marico catchment

The Crocodile-West and Marico catchment is dominated by Mixed Bushveld vegetation type which comprises of Waterberg Mountain Bushveld, Carletonville Dolomite Grassland, Central Sandy Bushveld, Marikana Thornveld and eastern Temperate Freshwater Wetlands (Figure 3-3). The northern parts of the Crocodile West and Marico WMA are dominated by Mixed Bushveld, Sweet Bushveld, and Mopane Bushveld (Smith-Adao et al., 2006). The central and western part of the catchment comprises Mixed Bushveld with the eastern part dominated by North-Eastern Mountain Grassland and Mixed Bushveld vegetation. The Dry Sandy Highveld Grassland and Moist Cool Highveld Grassland vegetation dominate the southernmost sections of the catchment (Smith-Adao et al., 2006).

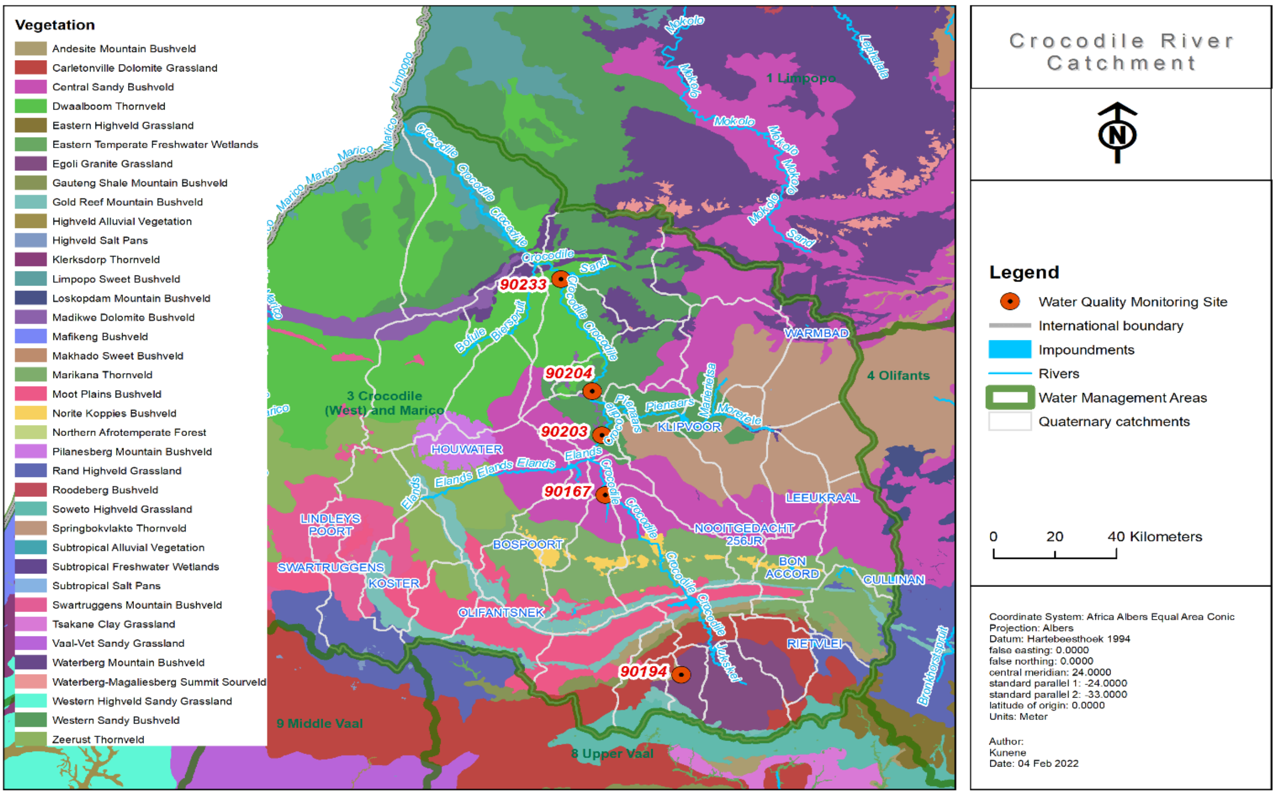


Figure 3-3: Vegetation of the Crocodile West/Marico catchment

3.5. Land Use of the Crocodile West/ Marico Catchment

The south-eastern part of the Crocodile-West and Marico catchment consists of the urban areas of northern Johannesburg, Midrand, and Tshwane. The Marico and upper Molopo sub-catchment areas are dominated by rural economic activities such as Dryland agriculture, cattle grazing, and game farming (Smith-Adao et al., 2006). There is commercial irrigation in the upper catchment and along the Marico River downstream of the Marico Bosveld Dam and Molatedi Dam. Maize crops are found in the south and south-eastern parts of the Crocodile-West and Marico catchments and citrus farming is found north of the Magaliesberg while irrigation occurs downstream of the Hartebeespoort Dam and along the Crocodile-West River (Smith-Adao et al., 2006). Mining activities occur in the towns of Thabazimbi, Brits, Cullinan, and Rustenberg, with small open-cast stone, gravel, and sand quarries found in the upper Crocodile-West River sub-catchment (Smith-Adao et al., 2006).

3.6. Site Selection

Table 3-1 showed the sites selected for the study based on the criteria of data availability and their importance as monitoring sites for water resource management by the Department of Water and Sanitation. The sites were situated along the Crocodile-West River in areas impacted by impoundments, wastewater treatment works, industry, mining, agriculture, urbanisation, and informal settlements. The sites were along the Crocodile-West River upstream and downstream of the Hartebeespoort Dam (van Eeden, 2017). The water quality monitoring data was outsourced from the WMS database of the DWS (Table 3-1). The sites were chosen because

Table 3-1: Position of the five sites selected for this study on the Crocodile-West River with the period of data availability and the water quality variables sampled

Monitoring Point	Regions	River	Land-use activities	Latitude	Longitude	Date	Variables
90194	A21E	Crocodile-West	Cultivated lands; Plantations; Mines; Urban areas;	-25.9913	27.8420	1979-2018	NH_3, NO_3/ NO_2, ,PO_4, Ca, Mg, K, Cl, EC, SO_4, pH
90167	A21E	Crocodile-West	Cultivated lands; Urban residential and villages,	-25.403	27.574	1976-2018	
90203	A21E	Crocodile-West	Cultivated lands; Urban residential and townships	-25.2063	27.558	1985-2018	
90204	A21E	Crocodile-West	Cultivated lands; Urban areas; mines	-25.0622	27.521111	1984-2018	
90233	A21E	Crocodile-West	Cultivated lands; mines; Urban villages	-24.6951	27.40906	1990-2018	

3.7. Calculating the CCME Water Quality Index

The CCME WQI was used to determine the overall water quality status of the Crocodile-West River. The CCME WQI uses water quality variables and sets objectives for each water quality variable based on the purpose of the study. The CCME WQI was flexible because it allowed the selection of water quality parameters to suit local conditions (Lumb et al., 2006). This meant that the CCME WQI could be used to classify the fitness of use of water resources for different water use objectives (Rangeti et al., 2015). Four common steps were followed to calculate the WQI (Kachroud et al., 2019).

(a) Selection of appropriate physico-chemical parameters

The selection of appropriate physico-chemical parameters was determined by a literature review of water quality related articles of the Crocodile-West Catchment and the data outsourced from the WMS of the DWS. (Sutadian et al., 2016). Relevant water quality variables and targeted water quality guidelines were provided in Table 3-2.

(b) Transformation of the parameters into a common scale

The equation to calculate the CCME WQI was:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right)$$

where F_1 = number of variables whose objectives are not met

F_2 = number of times which objectives are not met

F_3 = magnitude which the objectives are not met

The scope (F_1) assessed the extent of non-compliance to the water quality guidelines and those water quality variables that do not meet the objectives of the water quality guidelines over time (Lumb et al., 2006).

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) \text{ x } 100$$

The frequency (F_2) indicated the number of times the measured water quality parameter was non-compliant with the water quality guideline.

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of variables}}\right) \text{ x } 100$$

The magnitude (F_3) represented the extent to which the measured water quality variable is non-compliant with the water quality guideline (Lumb et al., 2006). The magnitude was determined in three steps. The first step calculated the number of times the concentrations of specific water quality were greater than or lower than the target water quality limit. The target water quality limit was called an excursion. For a condition when the observed value must not exceed the target water quality limit, the excursion was calculated as follows (CCME, 2001):

$$\text{excursion}_i = \left(\frac{\text{Failed Test Value}}{\text{TargetWaterQualityLimit}}\right) - 1$$

For a condition where the observed value must not fall below the target water quality guideline, the excursion was calculated as follows (CCME, 2001):

$$\text{excursion}_i = \left(\frac{\text{TargetWaterQualityLimit}}{\text{Failed Test Value}}\right) - 1$$

The magnitudes through which the observed data were non-compliant to target water quality guidelines were calculated by summing the excursions of non-compliant data and divided by the total number of compliant and not compliant tests (CCME, 2001):

$$\text{nse} = \left(\frac{\sum_{i=0}^{n} \text{excursion}}{\text{total number of tests}}\right)$$

$$F_3 = \left(\frac{\text{nse}}{0.01\text{nse} + 0.01}\right)$$

The physico-chemical water quality variables were compared to the South African Water Quality Guidelines Volume 7 of 1996 which has target water quality limits for water quality parameters required to protect aquatic ecosystems and South African Water Quality Guidelines Volume 7 of 1996 which has compilation of the target water quality limits for all water uses (DWAF, 1996). Target water quality limits for physico-chemical variables that are not present in the South African water quality guideline will be substituted with those present in the literature from Chapman, 1996. There is a set of target water quality guideline thresholds for NO_3^-/NO_2^- for aquatic ecosystems in relation to water resources. The target water quality guideline of 10 mg/l NO_3^-/NO_2^- represents a hypertrophic status which is the highest polluted state of water resource in terms NO_3^-/NO_2^- (DWAF, 1996). The target water quality guidelines of Ca^{2+}, K^+, EC and SO_4^{2-} were taken from literature from Chapman (1996) which are global average concentrations found in natural river systems.

Table 3-2: Water quality variables and the water quality guidelines used in the CCME WQI calculations

Water Quality Variable	Lower Target Water Quality Guideline	Upper Target Water Quality Guideline	Water Quality Guideline Source	Unit of measurement
Ammonia (NH_3)	-	0.007	DWAF 1996	mg/l as N
Phosphate (PO_4^{3-})	-	0.15	DWAF 1996	mg/l as P
Calcium (Ca^{2+})	-	100	Chapman 1996	mg/l
Magnesium (Mg^{2+})	-	125	DWAF 1996a	mg/l
Potassium (K^{+})	-	100	Chapman 1996	mg/l
Chloride (Cl^{-})	-	250	DWAF 1996b	mg/l
Electrical Conductivity (EC)	-	300	Chapman 1996	µS/cm
Nitrate/Nitrite (NO_3^{-}/NO_2^{-})	-	10	DWAF 1996	mg/l
pH	6	8	DWAF 1996a	units
Sulphate (SO_4^{2-})	-	400	Chapman 1996	mg/l

The overall water quality classification of water resources calculated from CCME WQI will be classified using classification system adopted from Tyagi et al (2013) and as is indicated in Table 3-3:

Table 3-3: CCME Water Quality Index Classification Scale (Tyagi et al., 2013; CCME WQI, 2006)

CCME Water Quality Index Scale	
Water Quality Rating	**Classification**
0-44	Water resource with poor water quality
45-59	Water resource with marginal water quality
60-79	Water resource with good to fair water quality
80-94	Water resource with good water quality
95-100	Water resource with excellent water quality

3.8. Statistical analysis and representation of CCME WQI

Water quality variables in water resources often change over a time due to seasonal changes and either abrupt or steady increases of land-use impacts (Mozejko, 2012). Detection of temporal or spatial changes in water quality of water resources is the main objective of environmental monitoring (Mozejko, 2012). Trend analysis indicates increasing or decreasing concentrations of water quality variables in the water resources and statistical methods are crucial in detecting whether the trend is significant or not (Mozejko, 2012). There are different statistical methods that are used to detect and estimate trends in selected water quality variables. The methods may use correlation and regression analysis, box-and whisker plot, time-series analysis, or non-parametric statistics (Mozejko, 2012). The time series data is designed to illustrate trends with respect to time. The graphs of a time series data should be individual points connected by a line. A trendline is used to follow a general trend in water quality data which is represented by the linear equation (y= x+1) where the slope is determined a positive (+x) and negative (-x) trend. Box-plots are used to represent comparisons of data from different groups such as water quality data from different sites. The box-plots are used to calculate different interquartile ranges and determine the median of each box (Mozejko, 2012).

The water quality data was sourced from the DWS database called WMS. The selected water quality variables were NH_3, NO_3^-/NO_2^-, PO_4^{3-}, Ca^{2+}, Mg^{2+}, K^+, Cl^-, EC, SO_4^{2-}, and pH. Each data set was organised into seasons: Summer, Autumn, Winter, and Spring. December, January, February represented the summer season; March, April, May represented the autumn season; June, July, August represented winter, and September, October, and November months represented spring. This was done for each water quality variable per year for each site.

The Microsoft Excel spreadsheet was used to calculate average seasonal data of water quality variables per year for each site. The water quality data of average seasonal data of DWS monitoring sites 90194 (n=159), 90167 (n=141), 90203 (n=128), 90204 (n=129) and 90233 (n=108) was used to plot the water quality trend, PCA and calculation of the annual CCME WQI of each site per year from 1976 to 2018.

The average seasonal data for each water quality variable for each site were organised into a series data [NH_3 (n=651), NO_3^-/NO_2^- (n=660), PO_4^{3-} (n=664), Ca^{2+} (n=666), Mg^{2+} (n=651), K^+ (n=656), Cl^- (n=665), EC (n=662), SO_4^{2-} (n=664), and pH (n=664)]. The missing water quality data for each water quality variable was simply discarded. The series of the average seasonal data for each water quality variable was plotted into graphs using Microsoft Excel spreadsheet to represent the water quality trend of each site from 1976 to 2018.

The average seasonal series data was used to calculate the annual CCME WQI for sites 90194, 90167, 90203, 90204, and 90233 from 1976 to 2018 using the Microsoft Excel spreadsheet. The calculated annual CCME WQI for each site was plotted onto Microsoft Excel spreadsheet to determine the trend in the calculated annual CCME WQI per site from 1976 to 2018. A trendline was plotted onto the CCME WQI trend analysis graph for each site and the trendline equation was used to determine the positive or negative trend of the CCME WQI for each site over time. A box-and whisker plot using the CCME WQI of each site was plotted using Microsoft Excel spreadsheet. The box-and-whisker plot was used to determine the spatial differences in the annual CCME WQIs of each site between 1976 to 2018.

A principal component analysis (PCA) was used to valid the success or failure of the implemented CCME WQI as an appropriate tool to evaluate water quality data of the Crocodile-West River. The principal component analysis (PCA) method was implemented to compare the temporal and spatial differences in the composition of the water quality variables for each site from 1976 to 2018. Canoco version 5 was used to calculate the PCA biplots for each site and the overall PCA biplot (de Necker et al., 2020). All water quality variables, except for pH, were standardised using a log transformation [y = log (x + 1)] to reduce the distribution of skewness in the data (de Necker et al., 2020).

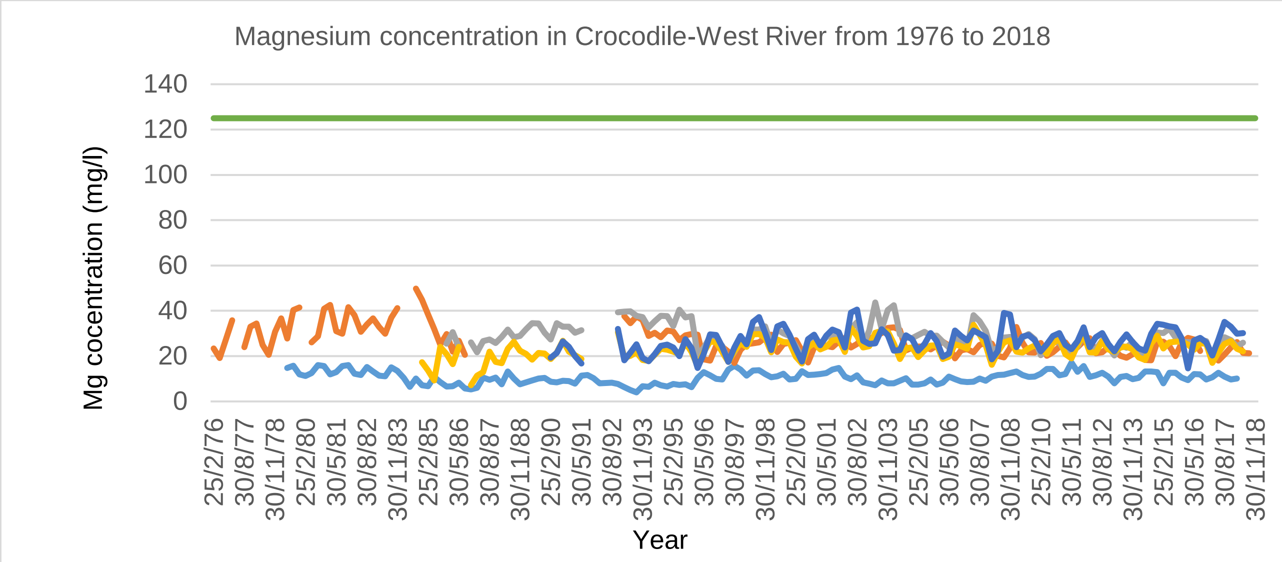
CHAPTER 4: RESULTS

4.1. Water Quality Trends

Analysis of figure 4-1, showed that the concentration of Mg^{2+} in site 90194 ranged from 15 mg/l Mg^{2+} to 10 mg/l Mg^{2+} from 1979 to 2018 but there was a steady increase in Mg^{2+} concentration from 1976 (23 mg/l Mg^{2+}) to 1984 (38 mg/l Mg^{2+}) per year. Figure 4-1 indicated a temporal change in Mg^{2+} concentration in site 90194 where it decreased over time from concentration of 15.7 mg/l Mg^{2+} in 1976 to 9.7 mg/l Mg^{2+} in 2018. Figure 4-1 showed a temporal change in Mg^{2+} concentration in site 90167 from 1976 to 2018. There was a steady decrease in Mg^{2+} concentration from 45 mg/l Mg^{2+} to 25 mg/l Mg^{2+} from 1984 to 2018 (Figure 4-1). The Mg^{2+} concentration in site 90203 showed temporal changes over time. Magnesium concentration is high in mid-1980s and mid-1990s (40 mg/l of Mg^{2+}). The concentration of Mg^{2+} on site 90203 was low between 2008 and 2018 where the concentration of Mg^{2+} was 25 mg/l (Figure 4-1). Similarly, the average Mg^{2+} concentration on site 90204 from 1984 to 2018 was 20 mg/l. Site 90233 also recorded low Mg^{2+} concentration of 25 mg/l Mg^{2+} from 1990 to 2018 (Figure 4-1).

The figure 4-1 represents the water quality trend of Ca^{2+} of the Crocodile-West River from 1976 to 2018. There was no temporal change in Ca^{2+} concentration in site 90194 from 1976 to 2018. The Ca^{2+} concentration for forty-two years ranged between 20 mg/l Ca^{2+} and 40 mg/l Ca^{2+} (Figure 4-1). The concentration of Ca^{2+} on site 90167 showed a temporal change in from 1976 to 2018. There was a gradual increase in Ca^{2+} concentration from 29 mg/l Ca^{2+} in 1976 to 65 mg/l in 1984 (Figure 4-1). The Ca^{2+} concentration decreased to 30 mg/l Ca^{2+} from 1985 to 2000. The concentration of Ca^{2+} increased from 2001(33mg/l Ca^{2+}) to 2018 (51 mg/l Ca^{2+}).

The water quality trend in figure 4-1 showed a temporal change in the concentration of Ca^{2+} in site 90203 from 1976 to 2018. The Ca^{2+} concentration on site 90203 was high in 1980s and 1990s (60 mg/l Ca^{2+}). The concentration of Ca^{2+} decreased to 45 mg/l Ca^{2+} from 1997 and remained constant in the mid-2000s until 2018 (Figure 4-1). The concentration of Ca^{2+} in site 90204 changed slightly from 1976 to 2018.The average Ca^{2+} concentration in site 90204 was 40 mg/l Ca^{2+} from 1984 to 2018 (Figure 4-1). The Ca^{2+} concentration in site 90233 showed temporal changes from 1990 to 2018. The Ca^{2+} concentration on site 90233 increased gradually from 46 mg/l Ca^{2+} in 1990 to 55 mg/l Ca^{2+} in 2018 (Figure 4-1).



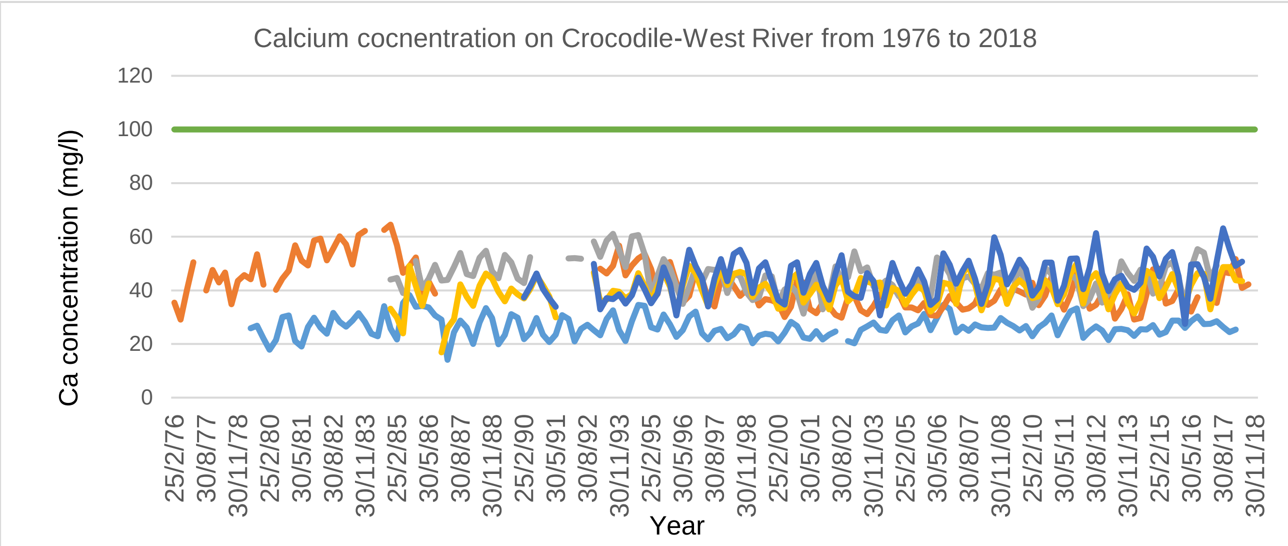
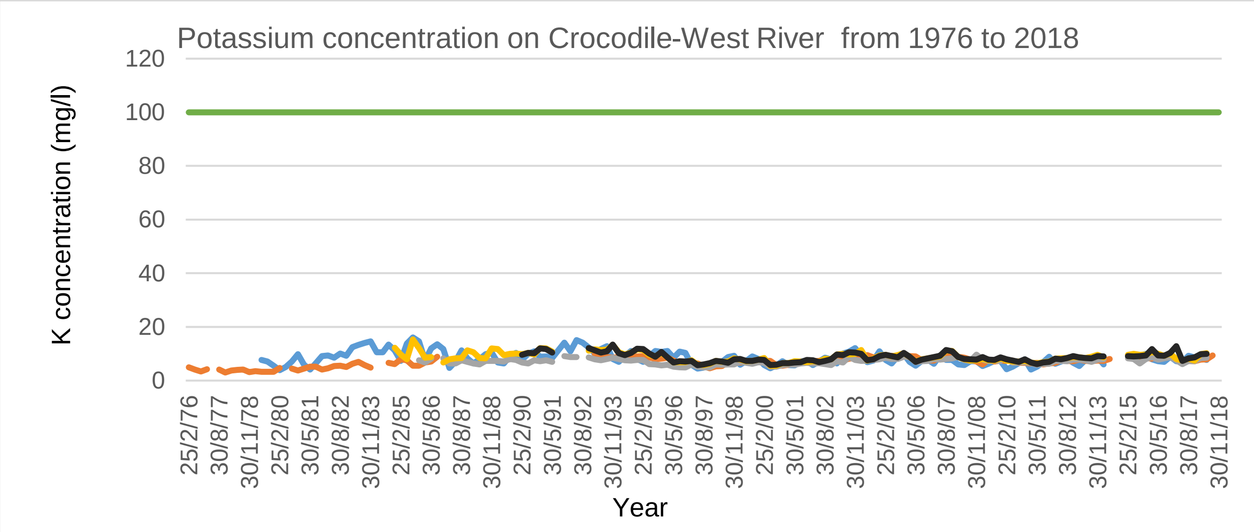
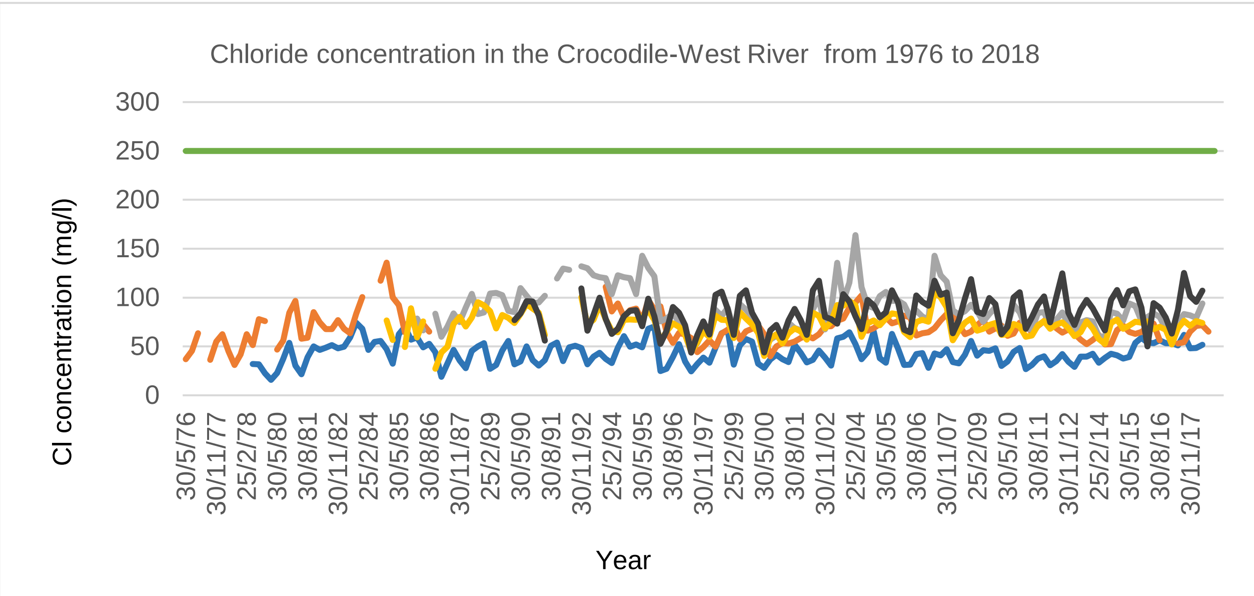


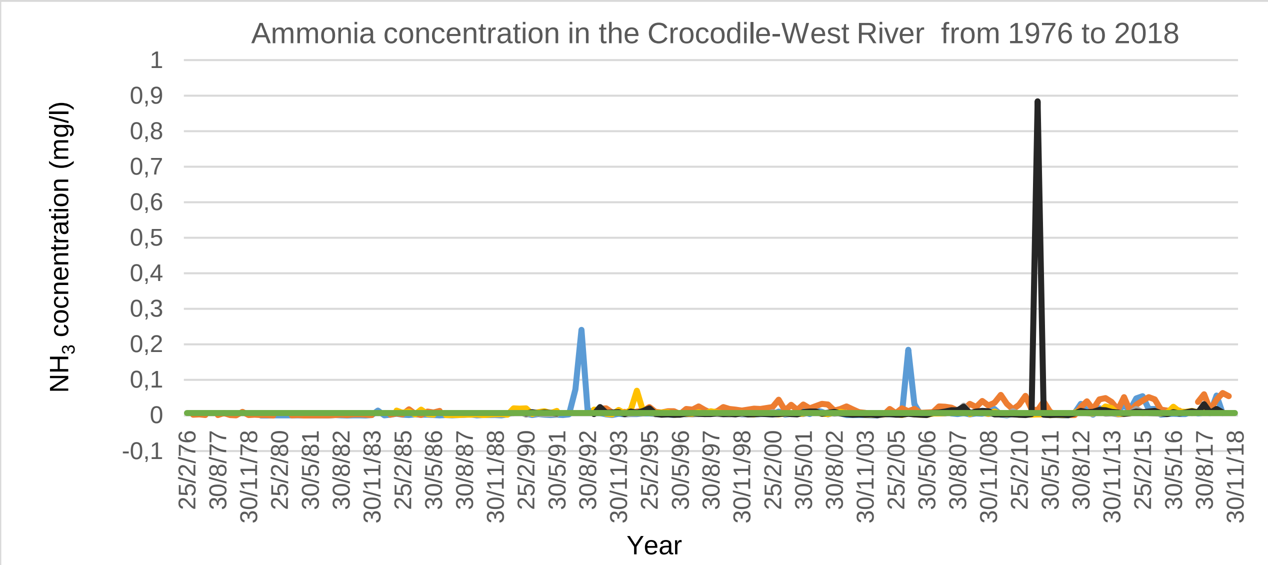
Figure 4-1: Water quality trend of magnesium (Mg^{2+}) and calcium (Ca^{2+}) for Crocodile-West River from 1976 to 2018. The green line represents the target water quality ranges as presented in Table 3-2. The following colours represent the sites surveyed: Light Blue=Site 90194, Red=90167, Grey=90203, Orange=90204 and dark Blue=Site 90233

The figure 4-2 of the water quality trend represents the seasonal concentration of K^+ and Cl^- from 1976 to 2018 in site 90194 of the Crocodile-West River. There were temporal changes in Cl^- concentration on site 90194 from 1979 to 1985. The concentration of Cl^- on site 90194 increased from 32 mg/l Cl^- in 1979 to 89 mg/l Cl^- 1985 (Figure 4-1). The concentration of Cl^- on site 90194 decreased to 50 mg/l Cl^- from 1985 to 1988 and remained constant at 50 mg/l Cl^- from 1988 to 2018 (Figure 4-2). Site 90167 had the highest concentration of Cl^- in 1970 and mid-1980s. The Cl^- concentration on site 90167 increased from 37 mg/l Cl^- (1976) to 136 mg/l Cl^- (1985). There was a significant temporal change in Cl^- concentration on site 90167 during that period (Figure 4-1). Site 90203 recorded high Cl^- concentration of 130 mg/l Cl^- in the mid-1980s and mid-1990s and in the mid-2000s (140 mg/l Cl^-). The concentration of chloride on site 90204 was 60 mg/l Cl^- from 1976 to 2018 while site 90233 recorded a concentration of 100mg/l Cl^- from 1976 to 2018 (Figure 4-2). There was a temporal change in K^+ concentration in site 90194 between the 1970s and 1990s. The K^+ concentration on site 90194 increased from 46 mg/ K^+ to 62.5 mg/l K^+ between 1979 and 1992 and declined to an approximately 45 mg/l K^+ from 1992 to 2018 (Figure 4-2). The K^+ concentration in site 90167 was low at 4 mg/l of K^+ in the 1970s and mid-1980s but increased to approximately 9 mg/l K^+ in the late 1980s and 1990s and the concentration of K^+ in site 90167 remained constant until 2018 (Figure 4-2). Similarly, the time series of K^+ concentration of site 90203, 90204 and 90233 followed the same temporal changes as site 90167 and 90194 from 1980 to 2018. The K^+ concentration in site 90204,90203 and 90233 was approximately 10 mg/l K^+ between 1980 to 2018 (Figure 4-2).





<u>Figure 4-2: Water quality trend of potassium (K^+) and chloride (Cl^-) for Crocodile-West River from 1976 to 2018. The green line represents the target water quality ranges as presented in Table 3-2. The following colours represent the sites surveyed: Blue=Site 90194, Red=90167, Grey=90203, Orange=90204 and Black=Site 9023</u>



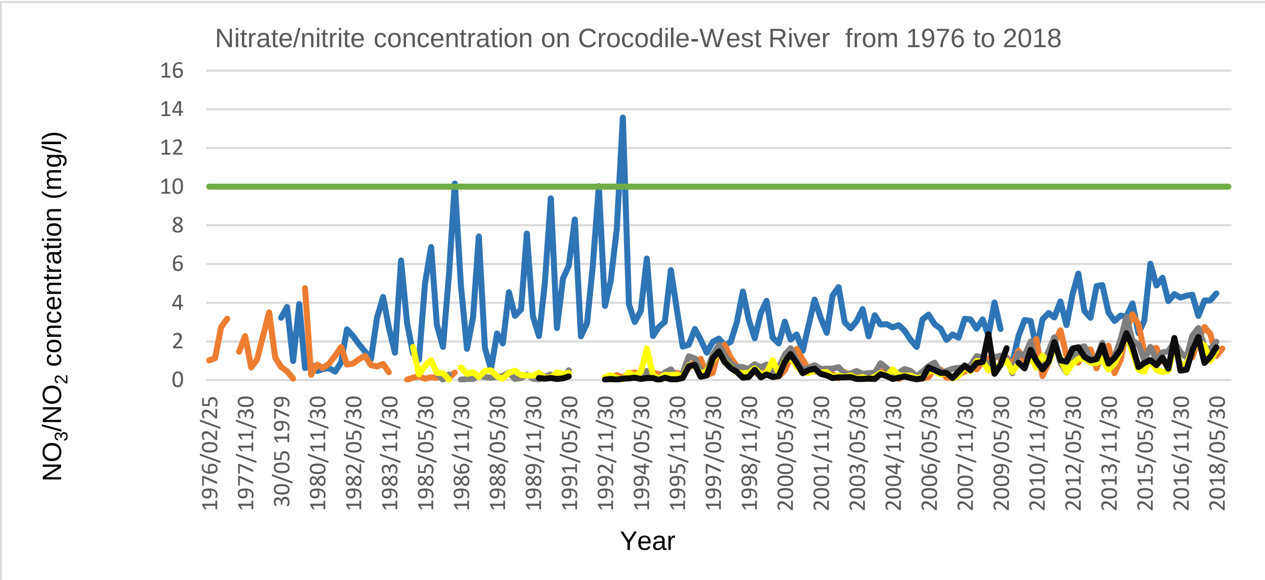


Figure 4-3: Water quality trend of ammonia (NH_3) and nitrate/nitrite (NO_3^-/NO_2^-) for Crocodile-West River from 1976 to 2018. The green line represents the target water quality ranges as presented in Table 3-2. The following colours represent the sites surveyed: Blue=Site 90194, Red=90167, Grey=90203, Orange=90204 and Black=Site 90233

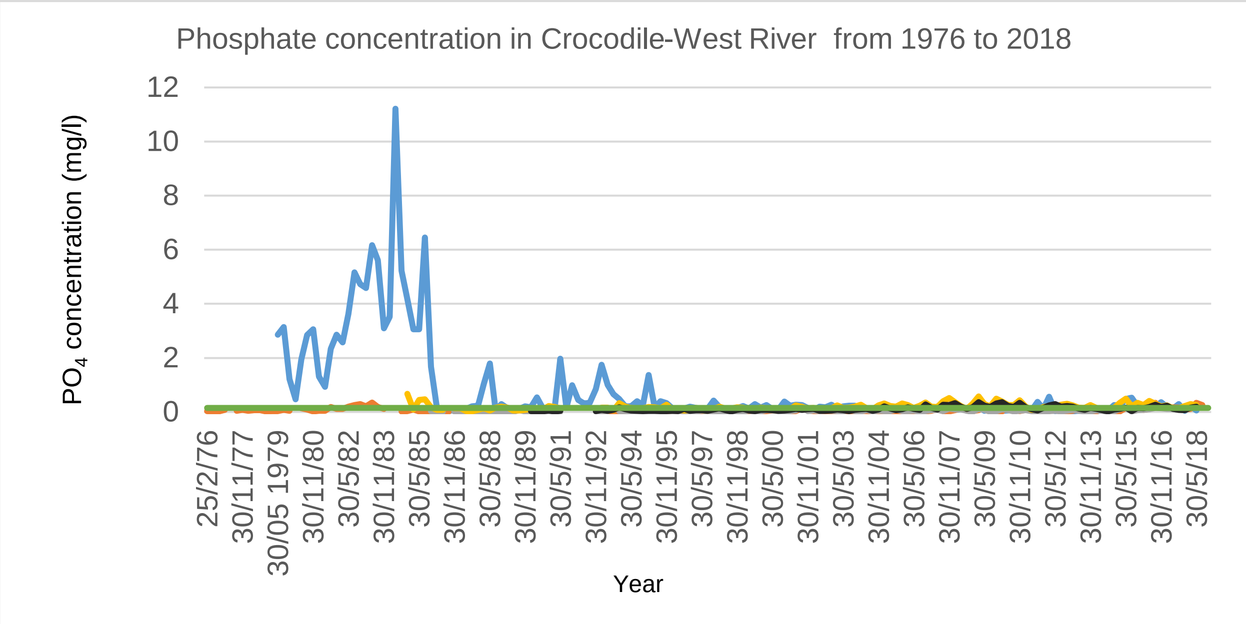
The figure 4-3 represents the water quality trend of NH_3 and NO_3^-/NO_2^- for Crocodile-West River from 1976 to 2018. The NH_3 concentration in site 90194 was constant from 1976 to 2018 with a few spikes NH_3 concentration visible in 1992 and 2005 (Figure 4-3). There were peaks of NH_3 concentrations in 1992 (0.24 mg/l NH_3), 2005 (0.18 mg/l NH_3) and an increasing trend of ammonia from 2011 to 2018 (0.001mg/l NH_3 to 0.0564 mg/l NH_3) on site 90194 (Figure 4-3). The NH_3 concentration on site 90167 showed an increasing temporal change from 0.0010 mg/l NH_3 to 0.063 mg/l NH_3 from 1976 to 2018. There were spikes in concentration of site 90167 that exceeded the target water quality guideline of 0,007 mg/l NH_3.There were spikes of NH_3 concentrations in 1997 (0.025mg/l NH_3), 2000 (0.044 mg/l NH_3), between 2004 to 2005 (0.018 mg/l NH_3 and between 2009 to 2018 (0.063mg/l NH_3).

The concentration of NH_3 on site 90203 increased gradually from 0.008 mg/l NH_3 in 1985 to 0.0118 mg/l NH_3 in 2018 (Figure 4-3). High concentrations of NH_3 in 1990 to 1993 (0.015 mg/l NH_3), 1994 (0.07 mg/l NH_3), 2006 (0.023 mg/l NH_3) and 2012 to 2016 (0.025 mg/l NH_3) were visible on site 90204. The NH_3 concentrations in site 90233 increased from 1990 to 2018 (0.007 mg/l NH_3) with spikes in NH_3 concentration observed in 1993 (0.023 mg/l NH_3,1995 (0.020 mg/l NH_3), 2001 (0.007 mg/l NH_3), 2007 (0.025 mg/l NH_3),2010 (0.884 mg/l of NH_3). The concentration of NH_3 also exceeded the target water quality guideline in 2012-2017 where the concentration of NH_3 was between 0.007 mg/l NH_3 and 0.032 mg/l NH_3.

The water quality trend in figure 4-3 showed that the range of NO_3^-/NO_2^- concentration in site 90194 increased from 3.0 mg/l NO_3^-/NO_2^- to 14 mg/l NO_3^-/NO_2^- from 1979 to 1993 and decreased to 3.0 mg/l NO_3^-/NO_2^- from 1994 to 1995 and remained constant from 1995 to 2018. The NO_3^-/NO_2^- in site 90194 exceeded the target water quality guideline of 10 mg/l NO_3^-/NO_2^- in 1992, 1993 and 1986. Site 90194 had the highest NO_3^-/NO_2^- concentration than the other sites from 1976 to 2018 (Figure 4-3). High concentrations of NO_3^-/NO_2^- on site 90167 was in the 1970s and 1980s (3.5 mg/l NO_3^-/NO_2^-) and from 2010 to 2018 (2.87 mg/l NO_3^-/NO_2^-) while the concentration of NO_3^-/NO_2^- on the Crocodile-West River on site 90203 increased gradually from 0.10 mg/l NO_3^-/NO_2^- to 1.9 mg/l NO_3^-/NO_2^- from 1990 to 2018 (Figure 4-3). The concentration of NO_3^-/NO_2^- on the Crocodile-West River on site 90204 increased gradually to 1.5 mg/l NO_3^-/NO_2^- from 1980s to 2018. The concentration of NO_3^-/NO_2^- on the Crocodile-West River on site 90233 increased gradually to 1.7 mg/l NO_3^-/NO_2^- (Figure 4-3).

The water quality trend figure 4-4 showed temporal changes in the concentration of PO_4^{3-} on site 90194 where it increased from 2.8 mg/l PO_4^{3-} in 1979 to 11 mg/l PO_4^{3-} between 1979 and 1984 and declined to 0.16 mg/l PO_4^{3-} from 1984 to 2018. The concentration of PO_4^{3-} during this period exceeded the target water quality guideline set at 0.15 mg/l PO_4^{3-}. There were two periods on site 90167 where the concentration of PO_4^{3-} on site 90167 exceeded the water quality guidelines (Figure 4-4). The first period was from 1976 to 1983 where the concentration of PO_4^{3-} was 0.35 mg/l PO_4^{3-} and the second period was from 2006 to 2018 where the concentration of PO_4^{3-} was high was in 2018 (0.34 mg/l PO_4^{3-}).

The water quality trend in figure 4-4 presented the water quality trend of SO_4^{2-} concentration in site 90194 from 1976 to 2018. The concentration of SO_4^{2-} showed temporal changes in all sites between 1976 to 2018. The SO_4^{2-} concentration increased from 50 mg/l SO_4^{2-} in 1979 to 137 mg/l SO_4^{2-} in 1985 and declined to 30 mg/l SO_4^{2-} and remained constant until 2018 (Figure 4-4). The SO_4^{2-} concentration on site 90167 increased from 59 mg/l SO_4^{2-} to 160 mg/l SO_4^{2-} between 1976 and 1984 and decreased gradually between 1985 and 1998 (71 mg/l SO_4^{2-}) and maintained a concentration of 70 mg/l of SO_4^{2-} between 1998 and 2018 (Figure 4-4). The SO_4^{2-} concentration on site 90203 increased from 44 mg/l SO_4^{2-} to 108 mg/l SO_4^{2-} between 1985 and 1993 and declined gradually between 1993 and 2001 (77 mg/l SO_4^{2-}) and concentration of 75 mg/l of SO_4^{2-} remained constant between 2001 and 2018 (Figure 4-4). The average concentration of SO_4^{2-} from 1984 to 2018 on site 90204 was 60 mg/l SO_4^{2-} and the average concentration of SO_4^{2-} from 1990 to 2018 was 66 mg/l SO_4^{2-} on site 90233 (Figure 4-4).



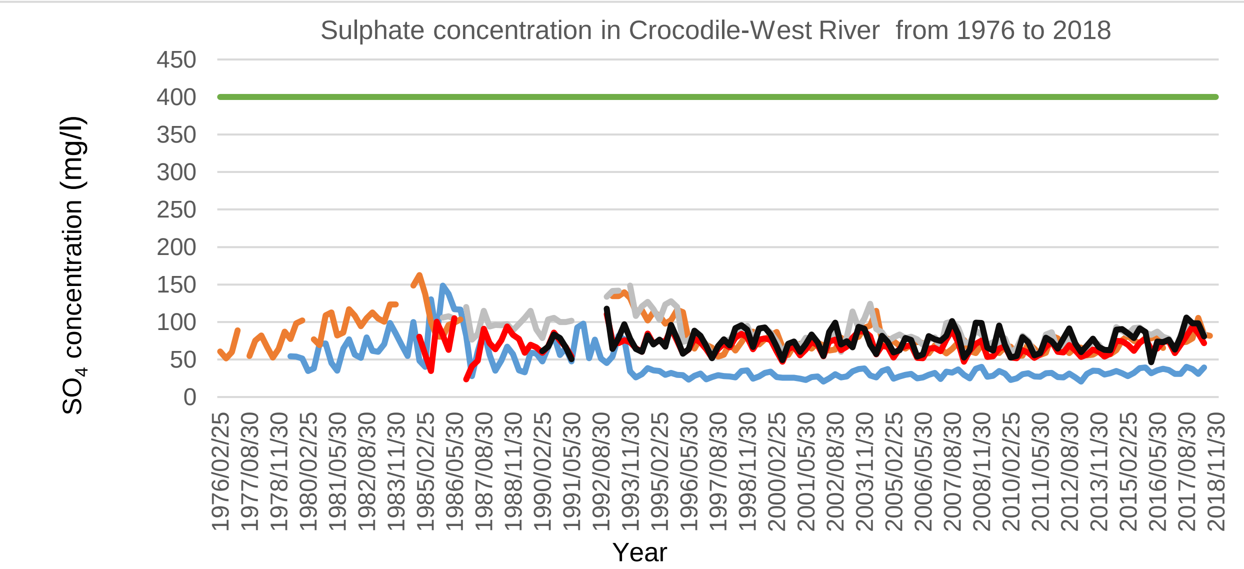
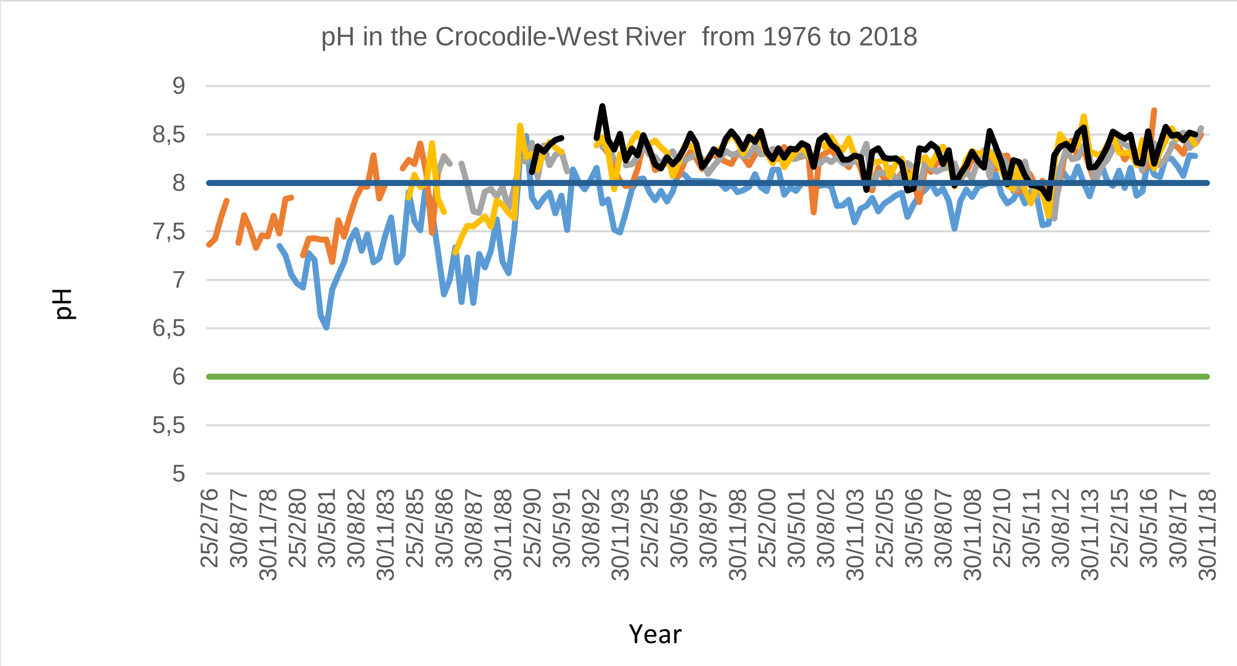


Figure 4-4: Water quality trend of phosphate (PO_4^{3-}) and sulphate (SO_4^{2-}) for Crocodile-West River from 1976 to 2018. The green line represents the target water quality ranges as presented in Table 3-2. The following colours represent the sites surveyed: Blue=Site 90194, Red=90167, Grey=90203, Orange=90204 and Black=Site 90233



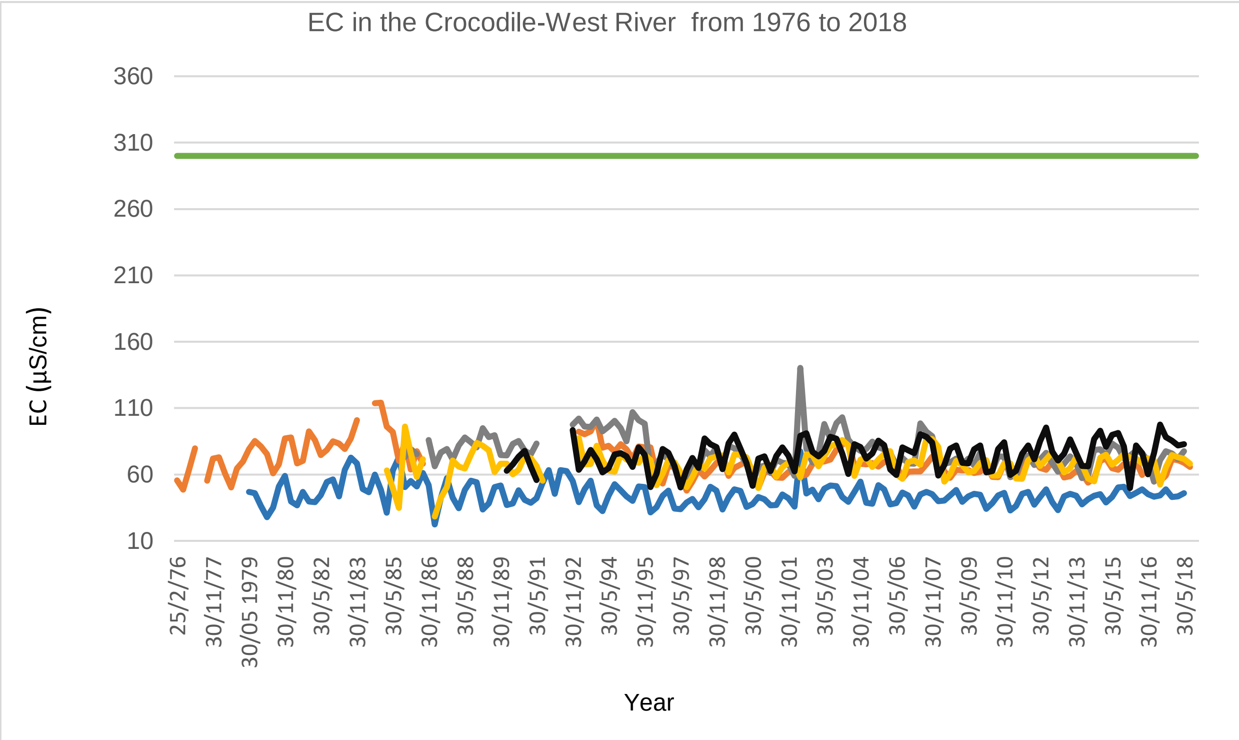


Figure 4-5: Water quality trend of pH for Crocodile-West River from 1976 to 2018. The green and dark blue line represents the target water quality ranges as presented in Table 3-2. The following colours represent the sites surveyed: Blue=Site 90194, Red=90167, Grey=90203, Orange=90204 and Black=Site 90233

The water quality trend in figure 4-5 represents the water quality trend of pH in all sites of the Crocodile-West River from 1976 to 2018. There was a temporal change of pH levels in site 90194 where the pH levels increased between 1976 to 2018. The pH levels on site 90194 increased from 7.3 units to 8.3 units between 1979 and 2018. The pH levels on site 90167 also increased from 7.3 units to 8.41 units between 1976 and 1985 and remained basic (8.1 units) between 1985 and 2018 (Figure 4-5). The pH levels on site 90203 have been basic (pH = 8.3 units) since 1984 and continued to be basic until 2018 (Figure 4-5). Site 90204 had an average pH value of 8.5 units from 1985 to 2018 and the pH levels on site 90233 remained basic (pH = 8.3 units) from 1990 to 2018 (Figure 4-5). Generally, the pH levels in all sites experienced a temporal change between 1976 and 1980s where there was an exponential increase of pH levels in all sites. The pH levels stabilised above 8 units in all sites between 1990s to 2018 (Figure 4-5).

The water quality trend in figure 4-5 represented the EC levels in all sites. The average EC on site 90194 remained constant at 10 µS/cm between 1979 to 2018. The EC on site 90167 experience temporal changes during 1976 and 2018 (Figure 4-5). The EC levels increased from 1976 (55.6 µS/cm) to 1984 (114 µS/cm). The concentration of electrical conductivity declined from 1984 to 2018 (71 µS/cm). Site 90203 exhibited high concentration of EC in the mid-1980s, mid-1990s and mid-2000s with EC values ranging between 80 µS/cm and 140 µS/cm (Figure 4-5). The EC value on site 90204 did not change significantly between 1076 to 2018 and remained constant (70 µS/cm) between 1984 and 2018. The EC levels on site 90233 did not change significantly between 1990 to 2018. The EC Levels remained constant at an average of 85 µS/cm (Figure 4-5).

4.2. Water Quality Index Calculations

4.2.1. Water Quality Index of site 90194

The calculated CCME WQI for site 90194 from 1979 to 2018 are shown in figure 4-8. The WQI of 90194 recorded WQI of 64 in 1979 and gradually increased to WQI values of 68 in 1981. Initially the water quality of Crocodile-West River was fair (Figure 4-6). The WQI on site 90194 decreased from WQI=68 in 1981 to WQI=51 in 1984. The water quality of Crocodile-West River deteriorated to marginal water resource between 1981 and 1984 (Figure 4-6). The WQI increased to 94 from 1982 to1987 and remained at an average WQI value of 85 from 1987 to 2016 and slowly deteriorated from 2016 to 2018 (WQI=64). The WQI value of site 90194 in 1996 was 38 which indicated that the water quality of Crocodile-West River was poor that year. Analysis of the calculated WQI trend of Crocodile-West River on site 90194 in figure 4-6 showed that the water quality status of the river can be classified as marginal to good and improved from 1979 (y=0.46x).

The data in table 4-1 represented the Individual CCME WQI scores, Scope (F_1), Amplitude (F_3) and water quality variables of Crocodile-West River using the water quality index data. The F_1 scores represented the number of variables whose guidelines have not been achieved and F_3 score represented the extent to which the water quality guidelines were not met. Table 4-2 indicated that high PO_4 concentrations on site 90194 were responsible for the marginal water quality status of the Crocodile-West River from 1979 to 1985. The WQI recorded The F_3 scores of between 60 and 70 were calculated by the WQI during1979 and 1985 (Table 4-2). The high F_3 scores showed that PO_4 concentrations far exceeded the set target water quality guideline during this period (Table 4-1). However, the water quality status of the Crocodile-West River increased to good water quality status (WQI=90) from 1986 to 1990 despite PO_4^{3-} concentrations failing to reach the target water quality guideline. The reason is that the F_3 score (F_3 score = 0.8 to 6) was low during this period and indicated that showed that PO_4^{3-} exceeded the target water quality guideline minimally (Table 4-1). The NO_3^-/NO_2^- only exceeded the target water quality guidelines in 1986, 1992 and 1993 and was one of the water quality variables flagged by the WQI in 1992 when the WQI was 57 indicating poor water quality of the Crocodile-West River. The WQI score deteriorated from 2011 to 2018 because the calculated F_1 and F_3 scores increased which was an indication of the number of water quality variables that exceeded the target water quality guidelines and the magnitude of which the water quality variables failed to meet the target water quality guidelines had increased (Table 4-1).

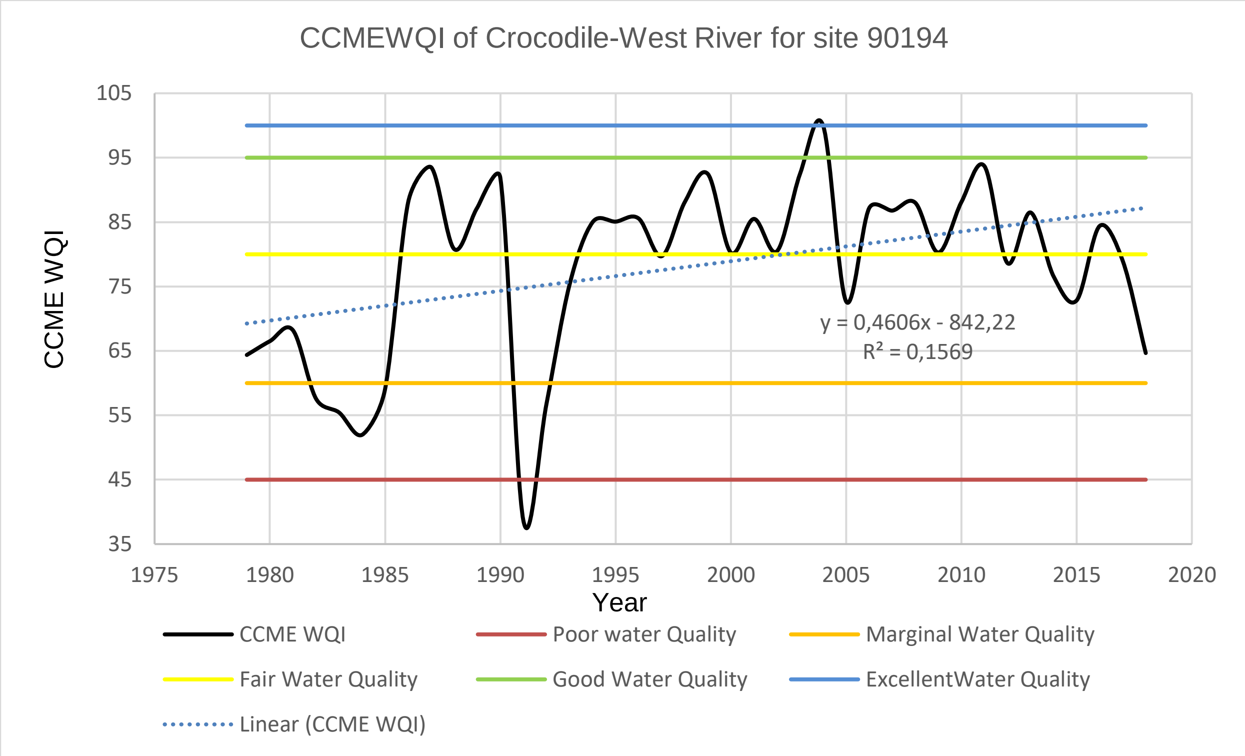


Figure 4-6: CCME WQI trend of Crocodile-West River for site 90194 from 1976 to 2018 Black=CCME WQI, Blue =Threshold CCME QWI of Excellent water quality, Green= Threshold CCME WQI of Good Water Quality, Yellow= Threshold CCME WQI of Fair water quality, Orange= Threshold CCME WQI of Marginal water quality and Red= Threshold CCME WQI of Poor water Quality

Table 4-1: CCME WQI scores, Scope (F_1), Amplitude (F_3) and failed variables of Crocodile-West River for site 90194 from 1979 to 2018

Year	CCME WQI	Scope (F_1)	Amplitude (F_3)	Variables	Variables Failed
1979	64	10	60	10 (1)	PO_4^{3-}
1980	66	10	56	10 (1)	PO_4^{3-}
1981	68	10	53	10 (1)	PO_4^{3-}
1982	57	10	72	10(1)	PO_4^{3-}
1983	55	10	75	10(1)	PO_4^{3-}
1984	52	30	79	10(2)	$PO_4^{3-}$and NH_3
1985	59	10	69	10 (1)	PO_4
1986	88	10	1.5	10 (2)	$PO_4^{3-}$and NO_3^- /NO_2^-
1987	93	10	1.3	10 (1)	PO_4^{3-}
1988	80	10	31	10 (1)	PO_4^{3-}
1989	87	20	5.6	10 (2)	PO_4^{3-} and NH_3
1990	91	10	6.6	10 (1)	PO_4^{3-}

Table 4-1 continued					
1991	60	10	57	10 (3)	PO_4^{3-}, NH_3 and pH
1992	57	10	68	10 (2)	$PO_4^{3-}$and NO_3^-/NO_2^-
1993	75	10	35	10 (3)	PO_4^{3-}, NH_3 NO_3^-/NO_2^-, and pH
1994	84	20	7.2	10 (3)	PO_4^{3-}, NH_3, and pH
1995	85	10	22	10 (1)	PO_4^{3-}
1996	85	20	0.86	10 (2)	$PO_4^{3-}$and pH
1997	79	30	5.4	10 (3)	PO_4^{3-}, NH_3, and pH
1998	88	20	0.50	10 (2)	PO_4^{3-} and pH
1999	92	10	3.7	10 (1)	PO_4^{3-}
2000	80	30	6.6	10 (3)	PO_4^{3-}, NH_3, and pH
2001	85	20	8.7	10 (2)	PO_4^{3-} and ammonia
2002	80	30	4.41	10 (3)	PO_4^{3-}, NH_3, and pH
2003	95	10	3.61	10 (3)	PO_4^{3-}
2004	100	0	0	10 (0)	none
2005	72	20	42	10 (2)	PO_4^{3-} and NH_3
2006	87	20	6.2	10 (2)	PO_4^{3-} and NH_3
2007	86	20	4.9	10 (2)	PO_4^{3-} and NH_3
2008	88	20	2.5	10 (2)	PO_4^{3-} and NH_3
2009	80	30	5.6	10 (3)	PO_4^{3-}, NH_3 and pH
2010	88	20	0.58	10 (3)	$PO_4^{3-}$and NH_3
2011	93	10	3.6	10 (1)	PO_4^{3-}
2012	78	30	15.7	10 (3)	PO_4^{3-}, NH_3 and pH
2013	86	20	6.88	10 (3)	PO_4^{3-} and pH
2014	76	30	20.1	10 (3)	PO_4^{3-}, NH_3 and pH

Table 4-1 continued					
2015	77	30	28	10 (3)	PO_4^{3-}, NH_3 and pH
2016	84	20	4.9	10 (2)	PO_4^{3-} and pH
2017	64	30	28	10 (3)	PO_4^{3-}, $NH_3$and pH
2018	64	30	30	10 (3)	PO_4^{3-}, NH_3 and pH

4.2.2. <u>Water Quality Index of site 90167</u>

The CCME WQI in figure 4-7 indicates the calculated water quality index (WQI) trend of site 90167 from 1976 to 2018. The calculated WQI of site 90167 deteriorated from excellent water quality status (WQI=100) in 1976, 1987 to 1989 and 1990 to marginal water quality status in 2018 (WQI=64). Generally, the calculated WQI of site 90167 was good to fair in 1990s and 2000s (WQI=80). There was temporal variation in the calculated WQIs between the years from 1976 to 2018. The y value of linear trendline slope was negative (y= -0.53x) to show that the water quality of site 90167 declined since 1976.

The analysis of table 4-2 indicated that the ammonia (NH_3) and pH were the major water quality variables that caused a deterioration of water quality at site 90167. Phosphate (PO_4^{3-}) was flagged 17% of the time, ammonia (NH_3) was flagged 81% of the time, NO_3^-/NO_2^- was flagged 2% of the time and pH was flagged 83% of the time as exceeding the target water quality guidelines (Table 4-2). Ammonia and pH failed the target water quality guidelines from 1990 to 2016 while PO_4^{3-} failed the target water quality guidelines in 1981 to 1983, 1988, 1990, 1991, and 2017 to 2018 and (Table 4-2). The calculated F_3 scores for the calculated WQI ranged between 8 and 30 during the years where NH_3 and pH exceeded the target water quality guidelines. This indicated that the NH_3 and pH exceeded the target water quality range minimally. The calculated WQI in 2017 and 2018 decreased exponentially from 80 to 64 because the calculated F_1 score (F_1=30) and F_3 scores (F_3 =46) for 2017 and 2018 had increased. This indicated that the number of water quality variables and magnitude which they exceeded the target water quality guidelines had increased (Table 4-2).

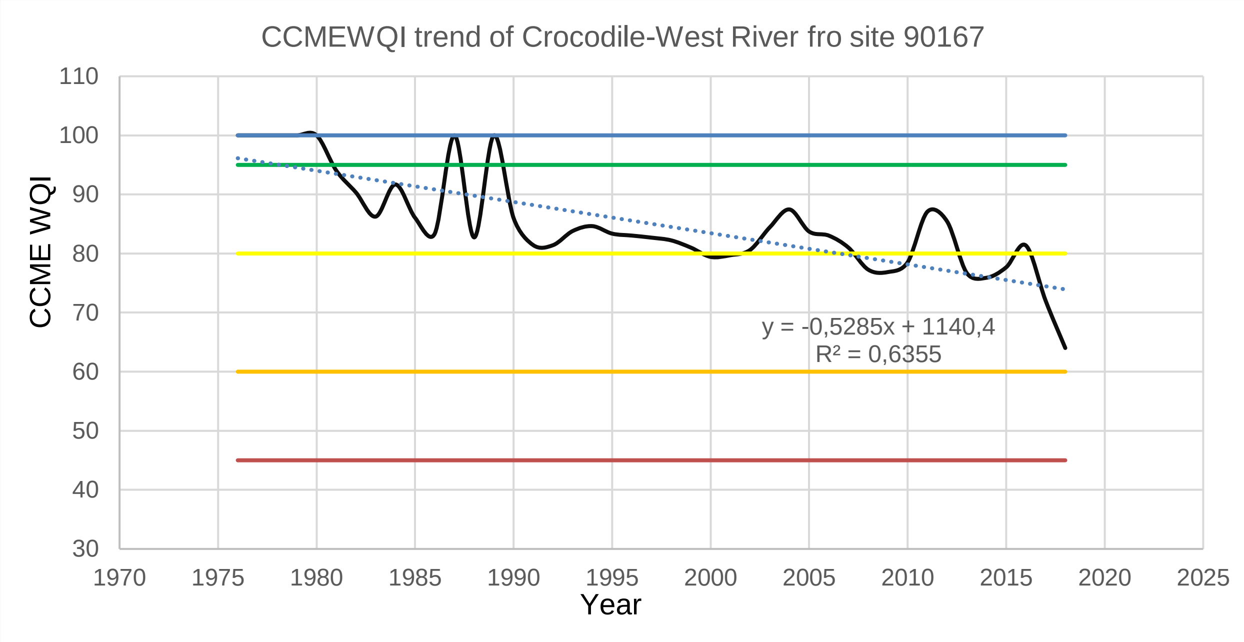


Figure 4-7: CCME WQI trend of Crocodile-West River for site 90167 from 1976 to 2018. Black=CCM WQI, Blue =Threshold CCME QWI for Excellent water quality, Green= Threshold CCME WQI for Good Water Quality, Yellow= Threshold CCME WQI for Fair water quality, Orange= Threshold CCME WQI for Marginal water quality and Red= Threshold CCME WQI for Poor water Quality

Table 4-2: CCME WQI scores, Scope (F_1), Amplitude (F_3) and failed variables of Crocodile-West River for site 90167 from 1976 to 2018

Year	CCME WQI	Scope (F_1)	Amplitude (F_3)	Variables	Variables Failed
1976	100	0	0	10 (0)	None
1977	100	0	0	10 (0)	None
1978	94.0	10	1.1	10 (1)	NH_3
1979	100	0	0	10 (0)	None
1980	100	0	0	10 (0)	None
1981	94.0	10	0.56	10 (1)	PO_4^{3-}
1982	90	10	6.5	10(1)	PO_4^{3-}
1983	86	20	5.8	10(2)	PO_4^{3-} and pH
1984	91	10	0.25	10(1)	pH
1985	86	20	5.3	10 (2)	$NH_3$and pH
1986	83	20	5.4	10(2)	NH_3 and pH
1987	100	0	0	10 (0)	None

Table 4-2 continued					
1988	80	30	13	10 (3)	PO_4^{3-}, NH_3 and pH
1989	80	30	5.9	10 (3)	NH_3 and pH
1990	82	20	9.8	10 (2)	PO_4^{3-}, NH_3 and pH
1991	80	30	8.7	10 (3)	PO_4^{3-}, NH_3 and pH
1992	81	20	15	10 (2)	NH_3 and pH
1993	83	20`	6.8	10 (2)	NH_3 and pH
1994	84	20	9.1	10 (2)	NH_3 and pH
1995	83	20	5.4	10 (2)	NH_3 and pH
1996	83	30	3.0	10 (2)	NH_3 and pH
1997	82	20	10	10 (2)	NH_3 and pH
1998	82	20	12	10 (2)	NH_3 and pH
1999	80	20	16.8	10 (2)	NH_3 and pH
2000	79	20	22	10 (2)	NH_3 and pH
2001	79	20	23	10 (2)	NH_3 and pH
2002	80	20	18	10 (2)	NH_3 and pH
2003	84	20	4.6	10 (2)	NH_3 and pH
2004	87	20	3.9	10 (2)	NH_3 and pH
2005	83	20	9.4	10 (2)	NH_3 and pH
2006	83	20	13	10 (2)	NH_3 and pH
2007	80	20	16	10 (2)	$NH_3$and pH
2008	77	20	27	10 (2)	NH_3 and pH
2009	76	20	28	10 (2)	NH_3 and pH
2010	78	20	26	10 (2)	NH_3 and pH
2011	87	20	1.3	10 (3)	NH_3 and pH
2012	85	20	8.9	10 (2)	NH_3 and pH
2013	76	20	30	10 (2)	NH_3 and pH
2014	75	20	30	10 (2)	$NH_3$and pH
2015	76	20	28	10 (2)	NH_3 and pH
2016	81	20	16	10 (2)	NH_3 and pH
2017	64	30	46	10 (3)	PO_4^{3-}, NH_3 and pH

Table 4-2 continued					
2018	64	30	46	10 (3)	PO_4^{3-}, NH_3 and pH

4.2.3. Water Quality Index of site 90203

The CCME WQI in figure 4-8 the CCME WQI of site 90203 from 1985 to 2018 calculated using CCME WQI method. The calculated WQI showed temporal variation between the years from 1985 to 2018. The WQI of 90203 deteriorated from water quality of excellent condition (WQI=100) from 1987 to good water quality condition in 2018 (WQI=83). This correlated by the negative y value (y= -0.11x) of the linear trendline plot. The Crocodile-West River was in excellent water quality condition (WQI=100) in 1987, 1988 and 2011 where all the water quality variables were within the target water quality guidelines (Figure 4-8).

The analysis of table 4-3 showed that NH_3 and pH were the major contributors to the deterioration of water quality at site 90203 because PO_4^{3-} was flagged 6.1% of the time, NH_3 was flagged 61% of the time, and pH was flagged 94% of the time as exceeding the target water quality guidelines (Table 4-3). Phosphate, ammonia, and pH failed the target water quality guidelines from 1985 to 2018 but there were exceptions. The calculated WQI flagged years where pH was the sole water quality variable that exceeded the target water quality guideline. pH failed the target water quality guideline in 1991 and 1992, 1996 to 1999, 2003 to 2005 and 2010 while PO_4 failed the target water quality guidelines in 2001 and 2002 (Table 4-3). The F_3 scores were between 0.80 and 4.00 from 1985 to 2018 which indicated that PO_4^{3-}, NH_3 and pH exceeded the target water quality guidelines minimally.

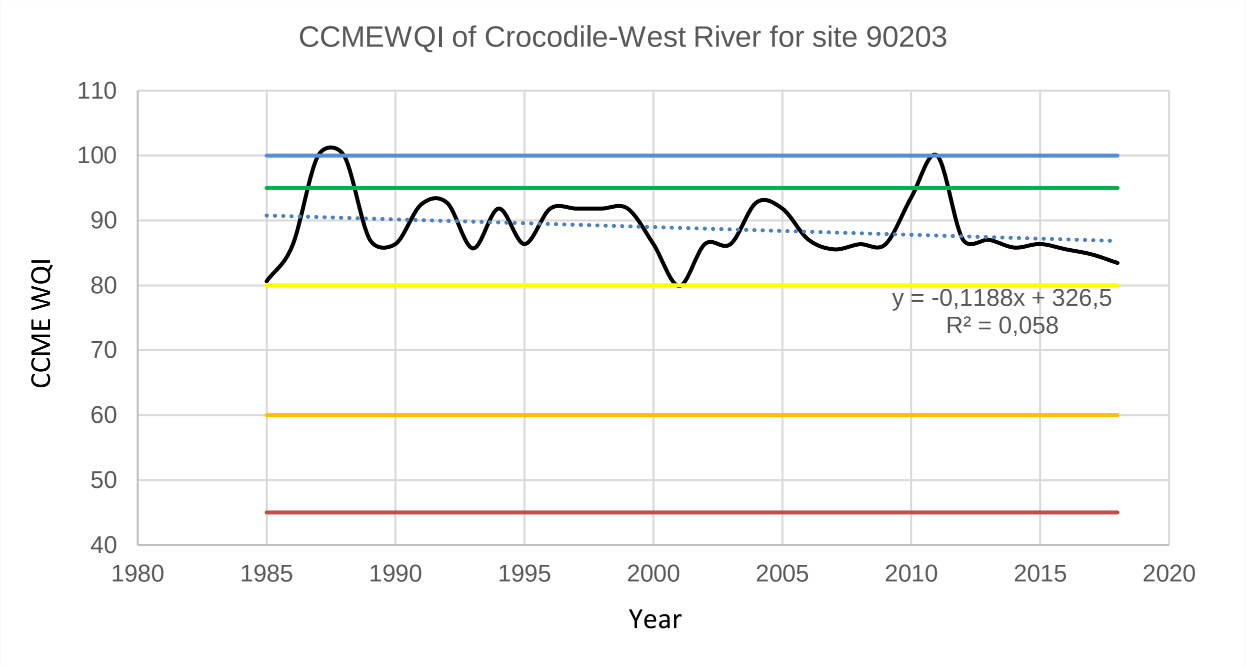


Figure 4-8: CCME WQI trend of Crocodile-West River for site 90203 from 1985 to 2018. Black=CCM WQI, Blue =Threshold CCME QWI of Excellent water quality, Green= Threshold CCME WQI of Good Water Quality, Yellow= Threshold CCME WQI of Fair water quality, Orange= Threshold CCME WQI of Marginal water quality and Red= Threshold CCME WQI of Poor water Quality

Table 4-3: CCME WQI scores, Scope (F_1), Amplitude (F_3) and failed variables of Crocodile-West River for site 90203 from 1976 to 2018

Year	CCME WQI	Scope (F_1)	Amplitude (F_3)	Variables	Variables Failed
1985	80	30	0.83	10 (2)	Ammonia and pH
1986	86	20	0.28	10 (3)	NH_3 and pH
1987	100	0	0	10 (0)	None
1988	100	0	0	10 (0)	None
1989	87	20	1.4	10 (2)	NH_3 and pH
1990	86	20	0.58	10 (2)	NH_3 and pH
1991	92	10	0.23	10 (1)	pH
1992	92	10	0.36	10 (1)	pH
1993	85	20	4.5	10 (2)	NH_3 and pH
1994	91	10	0.36	10 (1)	pH
1995	86	20	1.2	10 (2)	NH_3 and pH

Table 4-3 continued

1996	91	10	0.31	10 (1)	pH
1997	91	10	0.24	10 (1)	pH
1998	91	10	0.37	10 (1)	pH
1999	91	10	0.40	10 (1)	pH
2000	86	20	1.1	10 (2)	NH_3 and pH
2001	79	30	2.3	10 (3)	PO_4^{3-}, NH_3 and pH
2002	86	20	0.72	10 (3)	PO_4^{3-}, NH_3 and pH
2003	86	20	0.28	10 (1)	pH
2004	97	10	0.19	10 (1)	pH
2005	91	10	0.15	10 (1)	pH
2006	87	20	0.17	10 (2)	NH_3 and pH
2007	83	20	9.0	10 (3)	NH_3 and pH
2008	85	20	1.3	10 (3)	NH_3 and pH
2009	86	20	2.0	10 (2)	NH_3 and pH
2010	93	10	0.13	10 (1)	pH
2011	100	0	0	10 (0)	None
2012	87	20	0.79	10 (2)	NH_3 and pH
2013	87	20	2.3	10 (2)	NH_3 and pH
2014	85	20	4.5	10 (2)	NH_3 and pH
2015	86	20	1.1	10 (2)	NH_3 and pH
2016	85	20	1.1	10 (2)	NH_3 and pH
2017	84	20	4.3	10 (3)	NH_3 and pH
2018	83	20	4.7	10 (3)	NH_3 and pH

4.2.4. Water Quality Index of site 90204

The CCME WQI in figure 4-9 represents the temporal trend of CCME WQI of site 90204 from 1984 to 2018 calculated using CCME WQI method. The WQI of 90204 deteriorated from water quality of excellent condition (WQI=100) from 1984 to fair water quality condition in 2018 (WQI=74). This correlated by the negative y value (y= -0.26x) of the linear trendline plot. The calculated WQI showed temporal variation between the years from 1984 to 2018 (Figure 4-9).

The analysis of table 4-4 showed that the PO_4^{3-}, NH_3, and pH were the water quality variables responsible for the change in water quality status of site 90204. However, phosphate and pH contributed more to the water quality status on site 90204 than NH_3. Phosphate was flagged 85% of the time, ammonia was flagged 68% of the time, and pH was flagged 88% of the time for exceeding the target water quality guidelines (Table 4-4). The calculated F_1 score for the WQI ranged between F_1 score=10 and F_1 score=30 and the calculated F_3 scores of the WQI were between 5 and 15. The low F_3 scores indicated that PO_4^{3-}, $NH_{3,}$ and pH exceeded the target water quality guidelines minimally although the number of water quality variables that exceeded the target water quality guidelines was high (Table 4-4).

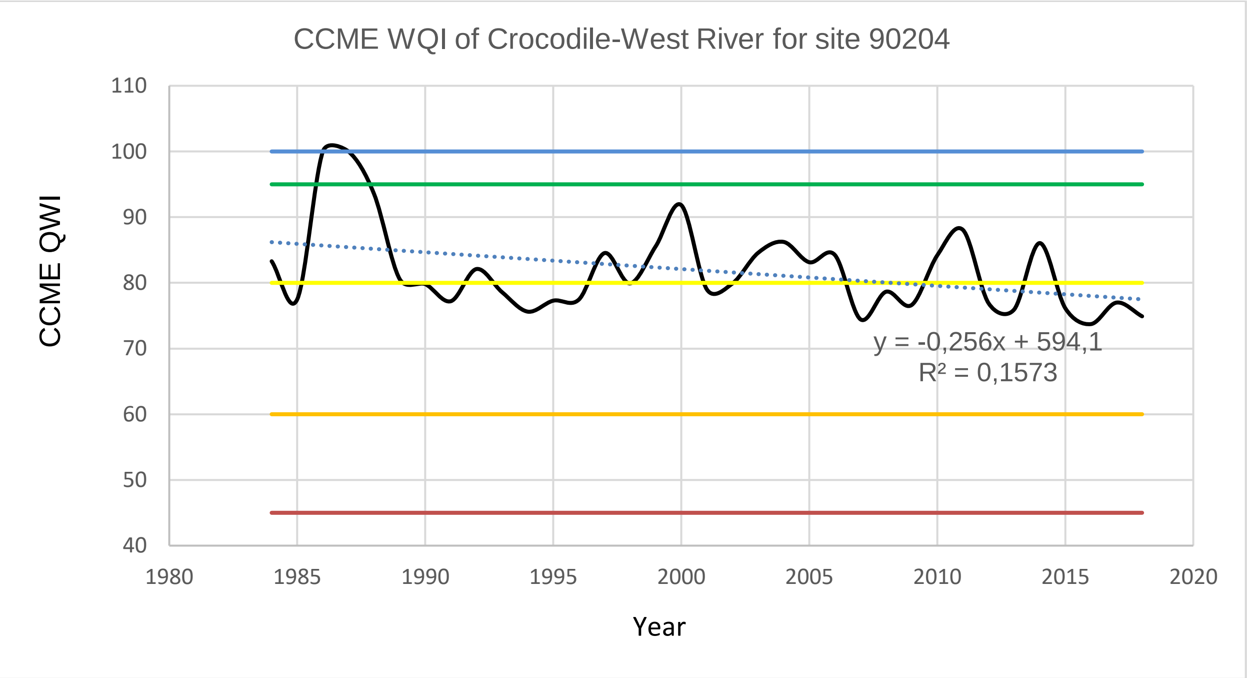


Figure 4-9: CCME WQI trend of Crocodile-West River for site 90204 from 1984 to 2018. Black=CCM WQI, Blue =Threshold CCME QWI of Excellent water quality, Green= Threshold CCME WQI of Good Water Quality, Yellow= Threshold CCME WQI of Fair water quality, Orange= Threshold CCME WQI of Marginal water quality and Red= Threshold CCME WQI of Poor water Quality

Table 4-4: CCME WQI scores, Scope (F_1), Amplitude (F_3) and failed variables of Crocodile-West River for site 90204 from 1984 to 2018

Year	CCME WQI	Scope (F_1)	Amplitude (F_3)	Variables	Variables Failed
1984	83	20	18	10(2)	PO_4^{3-} and NH_3
1985	77	30	14	10 (3)	PO_4^{3-}, NH_3 and pH
1986	100	0	0	10(0)	None
1987	100	0	0	10 (0)	None
1988	93	10	0.90	10 (1)	PO_4^{3-}
1989	80	30	8.7	10 (3)	PO_4^{3-}, NH_3 and pH
1990	79	30	4.1	10 (3)	PO_4^{3-}, NH_3 and pH
1991	77	30	5.7	10 (3)	PO_4^{3-}, NH_3 and pH
1992	82	20	13	10 (2)	NH_3 and pH
1993	78	30	8.7	10 (3)	PO_4^{3-}, NH_3 and pH
1994	75	30	23	10 (3)	PO_4^{3-}, NH_3 and pH
1995	77	30	4.7	10 (3)	PO_4^{3-}, NH_3 and pH
1996	77	30	0.33	10 (1)	pH
1997	84	20	3.4	10 (2)	NH_3 and pH
1998	79	30	1.8	10 (3)	PO_4^{3-}, NH_3 and pH
1999	85	20	0.86	10 (2)	PO_4^{3-} and pH
2000	91	10	0.31	10 (3)	pH
2001	78	30	4.8	10 (3)	PO_4^{3-}, NH_3 and pH
2002	79	30	2.1	10 (3)	PO_4^{3-}, NH_3 and pH

Table 4-4					
2003	84	20	2.9	10 (3)	PO_4^{3-} and pH
2004	86	20	3.5	10 (2)	PO_4^{3-} and pH
2005	83	20	7.3	10 (2)	PO_4^{3-} and pH
2006	84	20	6.2	10 (2)	PO_4^{3-} and pH
2007	74	30	17	10 (3)	PO_4^{3-}, NH_3 and pH
2008	78	30	8.2	10 (3)	PO_4^{3-}, NH_3 and pH
2009	76	30	15	10 (3)	PO_4^{3-}, NH_3 and pH
2010	84	20	11	10 (2)	PO_4^{3-} and pH
2011	88	20	1.4	10 (1)	PO_4^{3-}
2012	76	30	8.5	10 (3)	PO_4^{3-}, NH_3 and pH
2013	79	30	8.7	10 (3)	PO_4^{3-}, NH_3 and pH
2014	86	20	1.0	10 (3)	PO_4^{3-}, NH_3 and pH
2015	76	30	14	10 (3)	PO_4^{3-}, NH_3 and pH
2016	73	30	17	10 (3)	PO_4^{3-}, NH_3 and pH
2017	76	30	7.9	10 (3)	PO_4^{3-}, NH_3 and pH
2018	74	30	9.4	10 (3)	PO_4^{3-}, NH_3 and pH

4.2.5. Water Quality Index of site 90233

The CCME WQI in figure 4-10 represents the calculated CCME WQI for site 90233 from 1990 to 2018 using CCME WQI method. The calculated WQI showed temporal variation between the years from 1990 to 2018 (Figure 4-10). The calculated WQI of 90233 deteriorated from excellent water quality status (WQI=100) from 1990 to fair water quality status in 2018 (WQI=74). This correlated by the negative y value (y= -0.34x) of the linear trendline plot. The WQI for site 90233 maintained good water quality status (WQI=90) from 1990 to 2011 except for 1993 where the WQI was good to fair (WQI =77), and similarly in 2007 (WQI=75.9) and 2013 (WQI=75). This indicated that the water quality of the Crocodile-West River at site 90233 has the potential to deteriorate to poor water quality over time if the land-use activities are not managed (Figure 4-10).

The table 4-5 shows the calculated F_3 scores were generally low (F_3 score of 0.2 to 20) with an exception to 2010 where the WQI had an F_3 score of 76.3. This indicated phosphate (PO_4^{3-}), ammonia (NH_3) and pH concentrations had exceeded the target water quality guideline drastically and contributed to the deterioration of water quality status at site 90233 from good to fair. The analysis of table 4-5 showed that the PO_4^{3-}, NH_3, and pH were the water quality variables responsible for the change in the water quality status of site 90233. However, NH_3 and pH contributed more to the water quality status on site 90233 than PO_4^{3-}. Phosphate was flagged 46% of the time, ammonia was flagged 61% of the time, and pH was flagged 100% of the time for exceeding the target water quality guideline (Table 4-5).

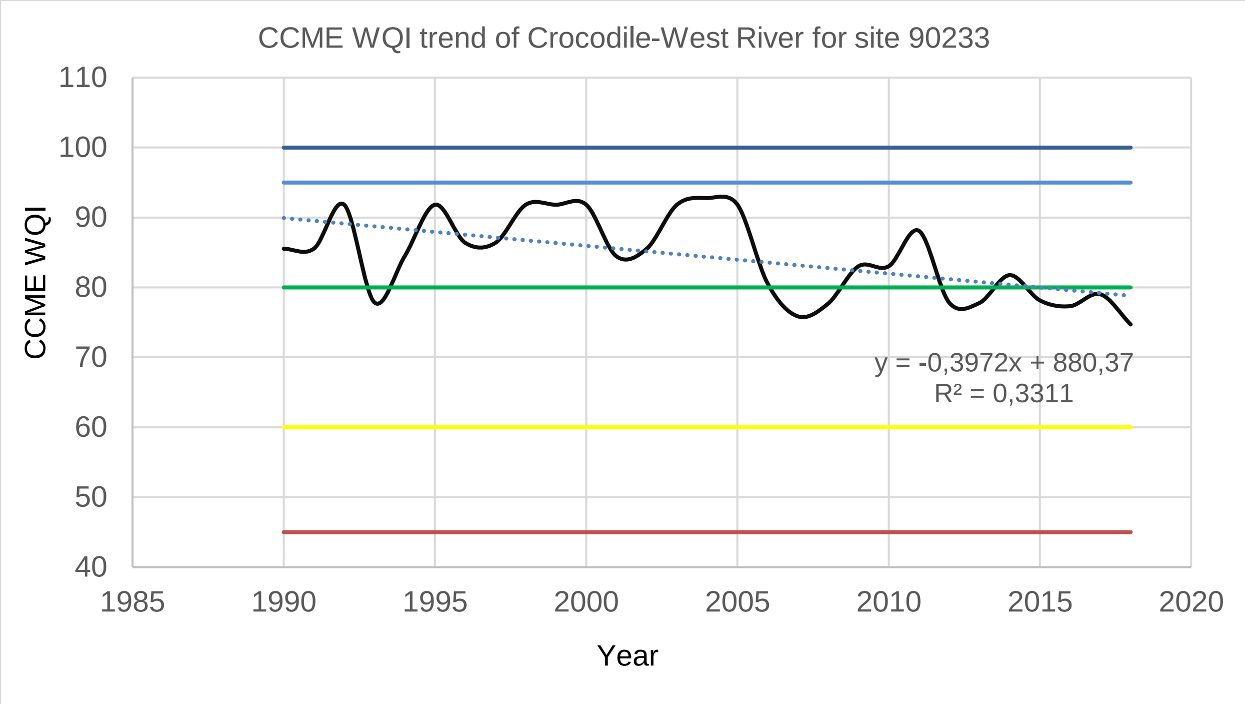


Figure 4-10: CCME WQI trend of Crocodile-West River for site 90233 from 1990 to 2018. Black=CCM WQI, Blue =Threshold CCME QWI of Excellent water quality, Green= Threshold CCME WQI of Good Water Quality, Yellow= Threshold CCME WQI of Fair water quality, Orange= Threshold CCME WQI of Marginal water quality and Red= Threshold CCME WQI of Poor water Quality

Table 4-5: CCME WQI scores, Scope (F_1), Amplitude (F_3) and failed variables of Crocodile-West River for site 90233 from 1990 to 2018

Year	CCME WQI	Scope (F_1)	Amplitude (F_3)	Variables	Variables Failed
1990	85	20	1.7	10 (2)	NH_3 and pH
1991	80	30	8.7	10 (1)	pH
1992	91	10	0.56	10 (1)	pH
1993	77	30	8.1	10 (3)	PO_4^{3-}, NH_3 and pH
1994	84	20	4.1	10 (2)	NH_3 and pH
1995	91	10	0.30	10 (1)	pH
1996	86	20	0.36	10 (2)	NH_3 and pH
1997	91	30	0.56	10 (3)	PO_4^{3-}, NH_3 and pH
1998	91	10	0.54	10 (1)	pH
1999	91	10	0.56	10 (1)	pH

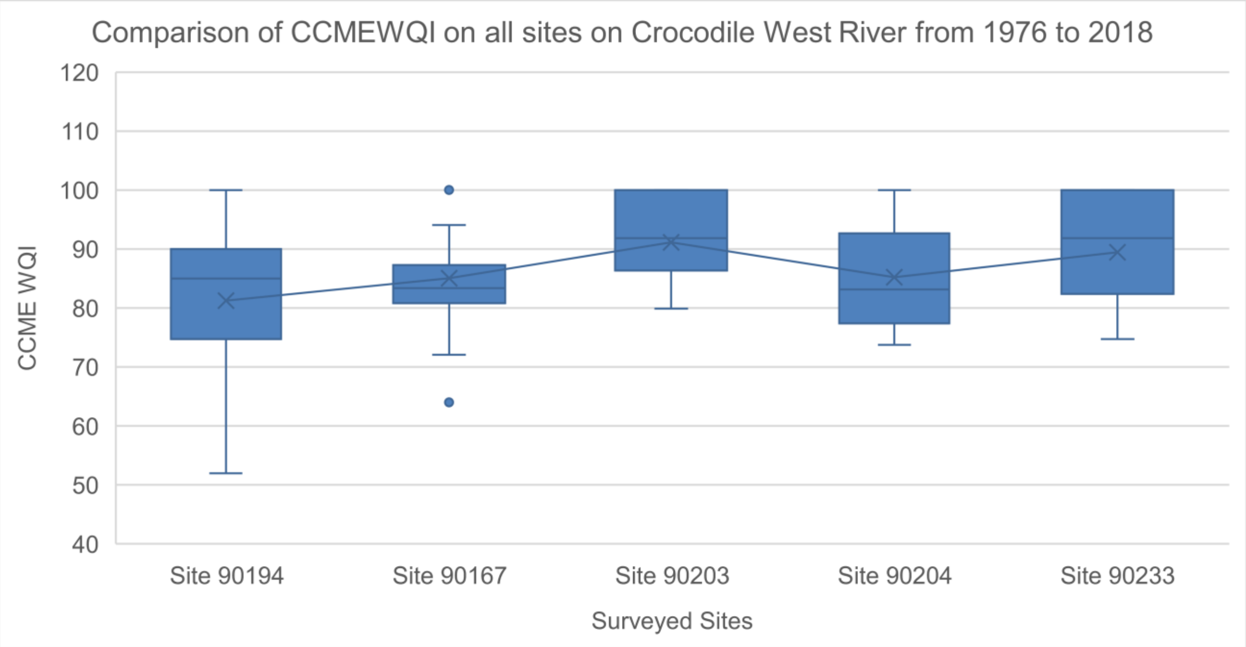
Table 4-5 continued					
2000	91	10	0.37	10 (1)	pH
2001	84	20	4.3	10 (2)	NH_3 and pH
2002	85	20	1.6	10 (2)	NH_3 and pH
2003	91	10	0.35	10 (1)	pH
2004	92	10	0.29	10 (1)	pH
2005	91	10	0.30	10 (3)	pH
2006	80	30	3.2	10 (3)	PO_4^{3-}, NH_3 and pH
2007	75	30	15	10 (3)	PO_4^{3-}, NH_3 and pH
2008	77	30	9.3	10 (3)	PO_4^{3-}, NH_3 and pH
2009	83	20	8.0	10 (3)	PO_4^{3-} and pH
2010	52	30	76	10 (3)	PO_4^{3-}, NH_3 and pH
2011	88	20	0.37	10 (2)	PO_4^{3-} and pH
2013	77	30	8.6	10 (3)	PO_4^{3-}, NH_3 and pH
2014	81	20	2.5	10 (2)	NH_3 and pH
2015	78	30	5.1	10 (3)	PO_4^{3-}, NH_3 and pH
2016	77	30	4.2	10 (3)	PO_4^{3-}, NH_3 and pH
2017	72	30	20	10 (3)	PO_4^{3-}, NH_3 and pH
2018	74	30	11	10 (3)	PO_4^{3-}, NH_3 and pH

3.8.1. <u>4.2.6. Spatial Distribution of Water Quality Index trend of all sites in the Crocodile-West River</u>

The box-and-whisker plot indicates a spatial variation in the calculated WQI between the sites using annual CCME WQI results, but the variation between the WQIs between sites is minimal (Figure 4-13). The median WQI values of all the sites range between 85 and 92. This indicated that the water quality status of the Crocodile-West River was generally good from 1976 to 2018. However, site 90194 (WQI=84), 90167(WQI=83) and 90204 (WQI=85) have slightly lower median WQI values than site 90203 (WQI=91) and site 90233 (WQI=91). This gives an indication that site 90194, site 90167, and site 90204 were impacted more by land-use activities than site 90203 and site 90233 (Figure 4-11).

<u>Table 4-6: The box-and-whisker plot that shows the 75 upper quartile and 25 percentile quartile, 50 percentiles median and upper and lower CCMEWQI value for each site.</u>

	Site 90194	Site 90167	Site 90203	Site 90204	Site 90233
Q1(25 percentile)	72	80	86	77	81
Median	84	83	91	85	91
Q2 (75 percentile)	89	87	100	93	100



<u>Figure 4-11: The box-and whisker plot explains the spatial distribution of CCME WQI trend between site 90194,90167,90203,90204 and 90233 of Crocodile-West River from 1976 to 2018. The box-and-whisker plot represents 75 upper quartile and 25 percentile quartile, 50 percentiles median and upper and lower CCMEWQI value for each site.</u>

4.3. Principal Component Analysis

4.3.1. Calculation of PCA plots for site 90194

The PCA biplot in figure 4-12 explains an 83% variation between the water quality variables and time and the first axis of the PCA indicated 66% variation in the differences in water quality variables and 17% variation of water quality variables in the second axis. The PCA indicated temporal variation of water quality variables and their contribution to the water quality status of the Crocodile-West River on site 90194 over time (Figure 4-12). The PCA showed that Ca^{2+}, EC, SO_4^{2-}, PO_4^{3-}, Cl, NO_3^-/NO_2^-, pH and K^+ are grouped together and characterised by positive high PC 1 and PC 2 values (Figure 4-12). The Ca^{2+}, EC, Cl^-, K^+, NO_3^-/NO_2^- are grouped together while SO_4^{2-} and PO_4^{3-} have same grouping on the positive PC plane. pH is grouped separately on the positive PC plane. Magnesium (Mg^{2+}) and ammonia (NH_3) reflected positive PC value but a negative loading to Ca^{2+}, EC, SO_4^{2-}, PO_4^{3-}, Cl^-, EC, NO_2^-/NO_3^-, pH and K^+ (Figure 4-12). The PCA indicated temporal differences in water quality variables that contribute to water quality each year. A high concentration of NO_3^-/NO_2^- and pH levels were present in 1989, 1990, 1992, 1994-1995 and from 2013-2018 (Figure 4-12). Site 90194 had high concentration of Ca^{2+}, EC, SO_4^{2-}, PO_4^{3-}, Cl^-, K^+ in 1985-1986, 1991, 1993. The Mg^{2+} and NH_3 has high concentration from 1996-1999, 2000-2009 and 2010-2014 (Figure 4-12). The PCA biplot indicated that site 90194 was minimally impacted from 1979-1988 and was highly impacted in the 1990s and 2010s (Figure 4-12).

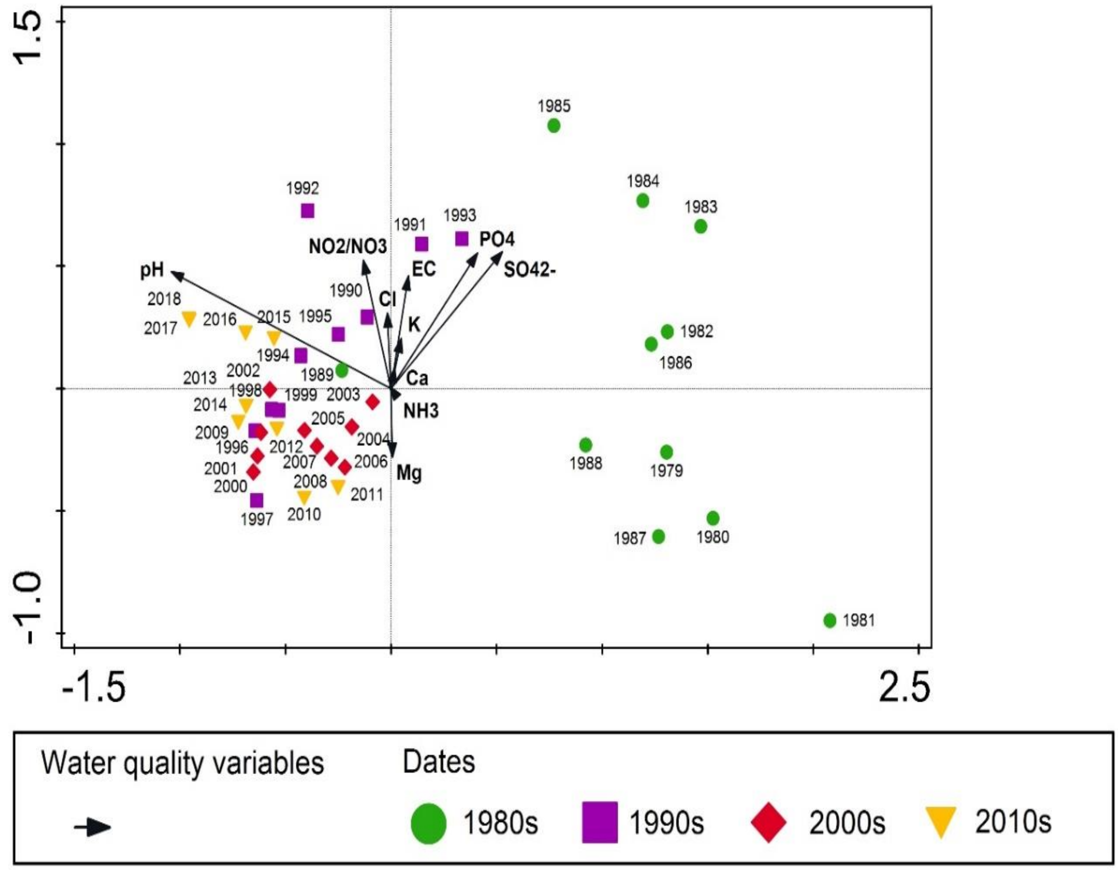


Figure 4-12: PCA showing the water quality data from 1979 to 2018 for site 90194. The biplot explains the 83% variance in water quality data with a total of 66% variance explained in the first axis and 17% in the second axis

4.3.2. Calculation of PCA plots for site 90167

The PCA biplot in figure 4-13 explains a 72% variation between the water quality variables and time in site 90194. The first axis of the PCA explains the 44% variation for the differences in water quality variables and the second axis explained the 28% temporal variation of water variables. We have observed that Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^- were grouped and characterised by positive high PC values in 1983, 1985, 1986, 1990-1994, and 2003-2007 (Figure 4-13). There was a presence of a high concentration of Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^- at site 90167 in the mid-1980s, mid-1990s, and mid-2000s (Figure 4-13). Potassium has positive PC values but is independent of Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^- in its contribution to the water quality status of site 90167. High K^+ concentration was present between 2005 to 2007 at site 90167. Nitrate/nitrite reflected a positive PC value but a negative PC loading to Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^-, and K^+ (Figure 4-13). Nitrate/nitrite has a high concentration in 2006 and 2010-2018 and could be problematic to the water quality status if it is not monitored. pH reflected a negative PC loading to Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^-, K^+, and NO_2^-/NO_3^-. pH levels on site 90167 were high in 1996-1997, 2000-2002, 2008, 2009 and 2010-2018. The PCA indicated that the Crocodile-West River at site 90167 was impacted less by land-use activities in 1976 -1979 and 1980-1987 (Figure 4-13).

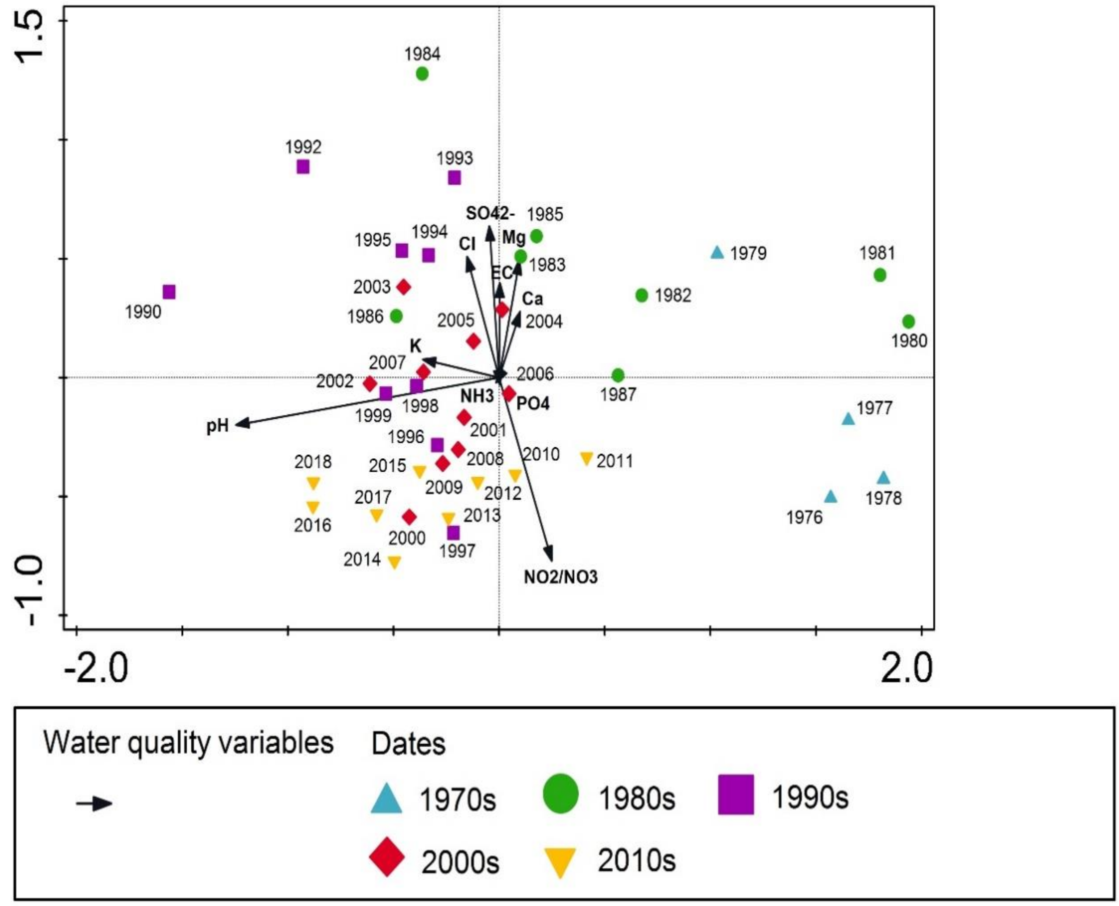


Figure 4-13: PCA showing the water quality data from 1976 to 2018 for site 90167. The PCA explains the 72% variance in water quality data with a total of 44% variance explained in the first axis and 28% in the second axis

4.3.3. Calculation of PCA plots for site 90203

The PCA biplot in figure 4-14 explains an 86% variation between the water quality variables and time in site 90203. The first axis of the PCA explains the 47% variation for the differences in water quality variables and the second axis explained the 38% temporal variation of water variables (Figure 4-14). The Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^-, and K^+ are grouped and characterised by positive high PC 1 values and pH has a strong loading in the positive PC 1 plane (Figure 4-14). Nitrate/nitrite and phosphate reflected negative loading to pH, Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^-, and K^+ (Figure 4-14). The PCA analysis indicated that the concentration of Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^-, and K^+ were highest in 1991-1995 and 2003 while the concentration of pH and NO_3^-/NO_2^- and

PO_4^{3-} were highest in 1996, 1999, 2002, 2009, and 2013- 2018. Site 90203 was impacted minimally by natural and land-use activities in 1985-1989, 1990, 2004-2008, and 2010-2012 (Figure 4-14).

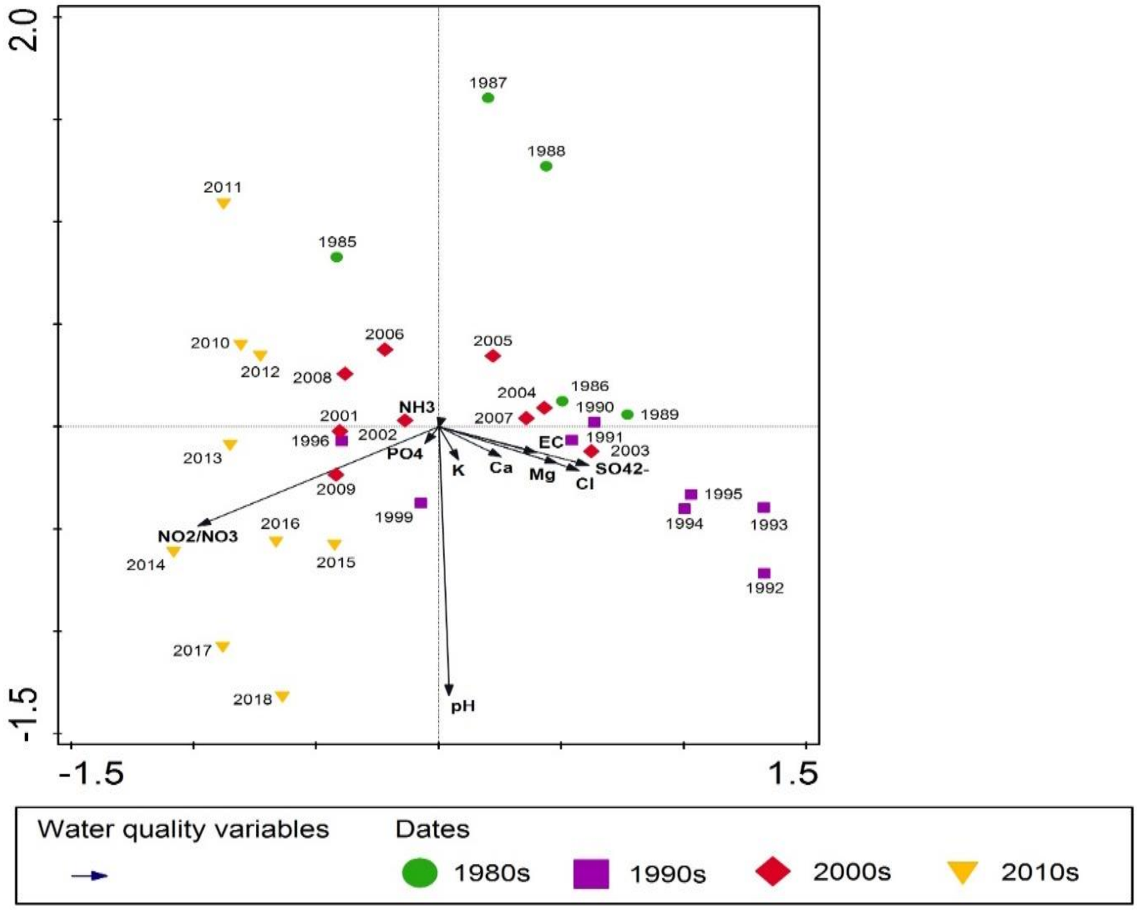


Figure 4-14: PCA biplot showing the water quality data from 1985 to 2018 for site 90203. The PCA biplot explains the 86% variance in water quality data with a total of 47% variance explained in the first axis and 38% in the second axis

4.3.4. Calculation of PCA plots for site 90204

The PCA biplot in figure 4-15 shows an 87% variation between the water quality variables and time in site 90203. The first axis of the PCA biplot explains the 71% variation for the differences in water quality variables and the second axis explained the 16% temporal variation of water variables in site 90204 (Figure 4-15). The water variables Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^-, and K^+ are grouped and characterised by positive high PC 1 values. Nitrate/nitrite, ammonia, and phosphate reflected negative loading to Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^-, and K^+ (Figure 4-15). The PCA biplot explains a high concentration of Ca^{2+}, Mg^{2+}, EC, SO_4^{2-}, Cl^- and K^+ in 1991-1995, 2002, 2003, 2007 and 2015 and high concentration of pH, NO_3^-/NO_2^- and PO_4^{3-} in 1994, 1996, 1997, 1999, 2000, 2001, 2009 and 2012-2018. Site 90204 was impacted the least by natural and land-use activities in 1984, 1986-1988, 2004, 2006, 2008 and 2010-2011 (Figure 4-15).

The negative PC loading of pH and NO_3^-/NO_2^- is greater than the PC loading of PO_4^{3-} and NH_3 which was indicative that the pollution from irrigation return flow from fertilisers from agricultural activities contributed more than the pollution from untreated effluent from informal settlements and treated wastewater treatment works (Figure 4-15).

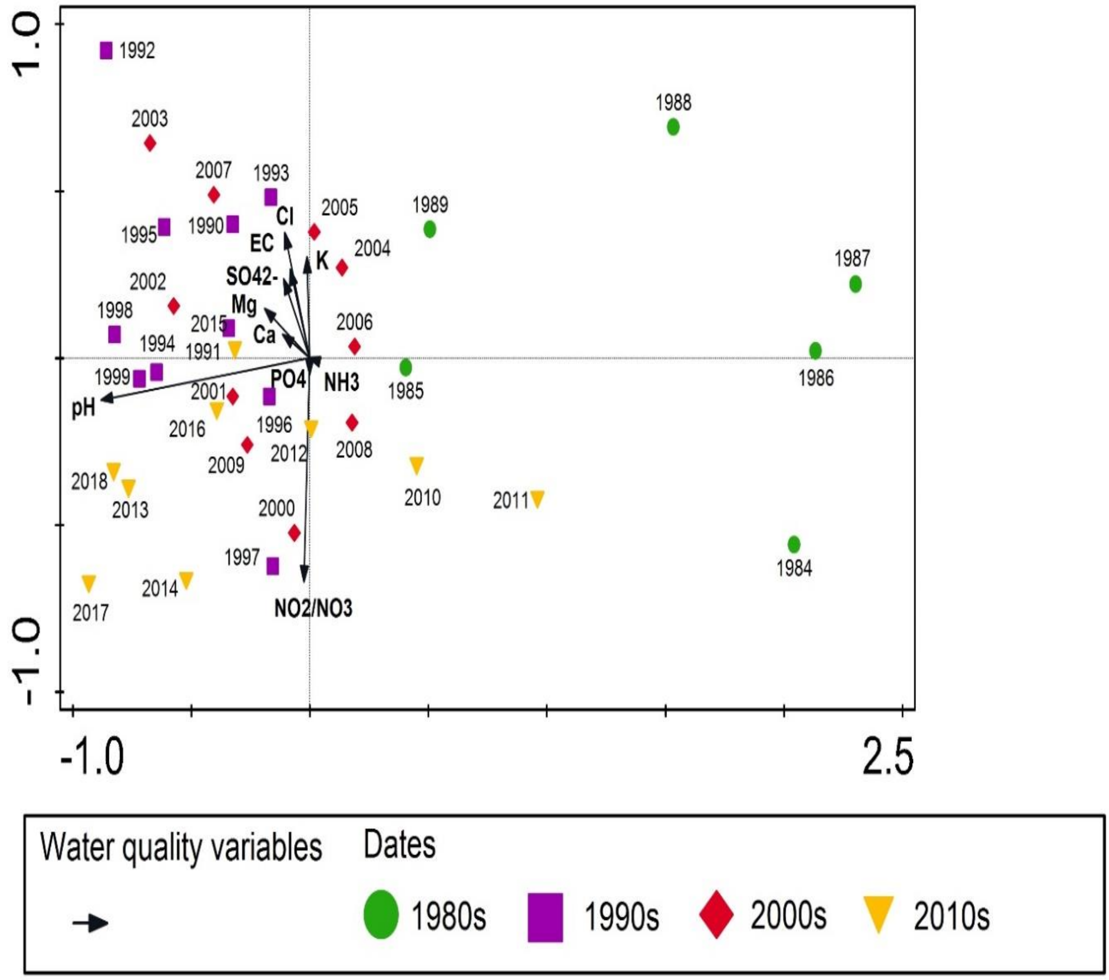


Figure 4-15: PCA biplot showing the water quality data from 1980 to 2018 for site 90204. The PCA biplot explains the 87% variance in water quality data with a total of 71% variance explained in the first axis and 16% in the second axis

4.3.5. Calculation of PCA plots for site 90233

The PCA biplot in figure 4-16 explains an 87% variation between the water quality variables and time. The first axis of the PCA biplot explains the 71% variation for the differences in water quality variables and the second axis explained the 16% temporal variation of water variables of Crocodile-West River at site 90233 over time. Calcium (Ca^{2+}), electrical conductivity (EC), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), chloride (Cl^-), nitrate/nitrite (NO_3^-/NO_2^-), magnesium (Mg^{2+}), pH, and potassium (K^+) are grouped and characterised by positive high PC 1 and PC 2 values. However, the PC loading of pH and NO_3^-/NO_2^- contributed more to the water quality deterioration on site 90233 of the Crocodile-West River but are not influenced by each other. The water quality at site 90233 was equally influenced by a combination of natural and anthropogenic activities. The PCA analysis showed that NO_3^-/NO_2^-, PO_4^{3-}, Mg^{2+}, and Ca^{2+} were dominant pollutant in 2009 and 2012-2018. EC, Cl^-, SO_4^{2-}, pH, and K^+ were dominant elements in 1992, 1993, 1998, 1999, and 2007 while NH_3 was the dominant element in 1997, 2000, 2006, 2008, and 2010-2011. Site 90233 was impacted the least by the natural and anthropogenic activities in 1991, 1994-1996, and 2002-2005.

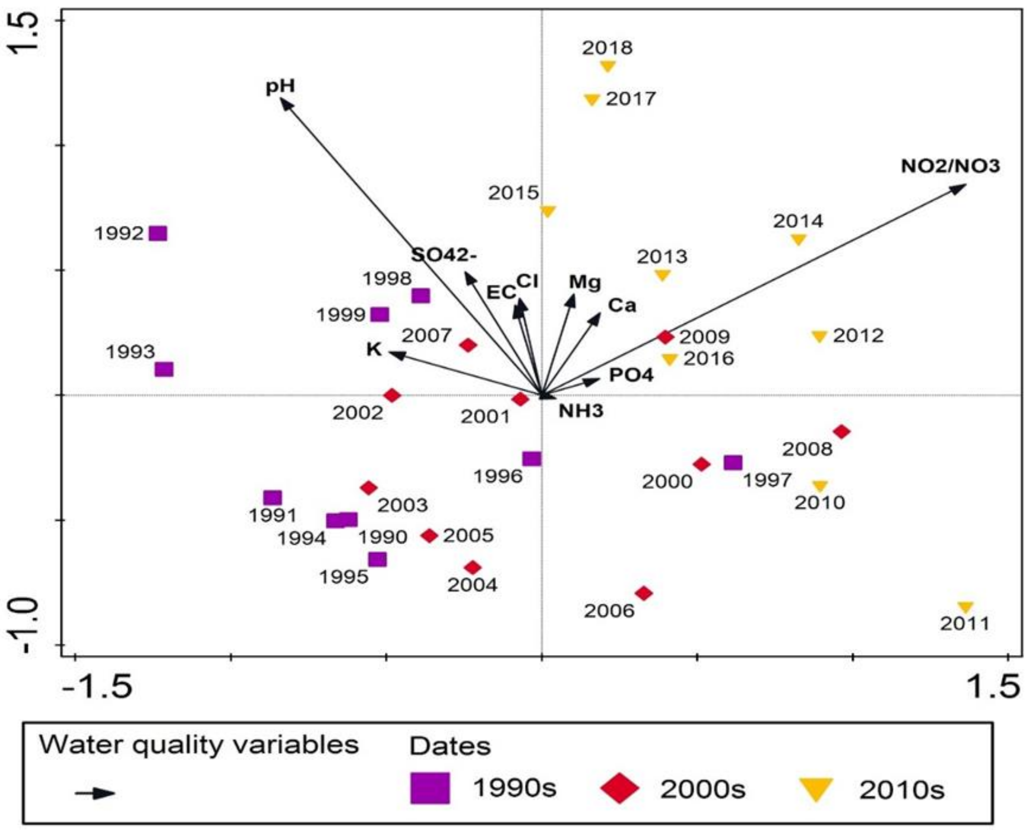


Figure 4-16: PCA biplot showing the water quality data from 1990 to 2018 for site 90233. The biplot explains the 74% variance in water quality data with a total of 43% variance explained in the first axis and 31% in the second axis

4.3.6. Calculation of spatial and temporal trends in PCA biplot for all sites

The PCA biplot figure 4-17 explains the variation between the water quality variables and different sites. The first axis of the PCA indicated 75% variation and second axis indicated 14% variation of water quality variables in all the different sites during the years surveyed. The analysis of PCA biplot figure 4-17 explains a high concentration of NO_3^-/NO_2^- and K^+ in site 90194 in the 1980s, 1990s, 2000s and 2010s and only high concentrations of PO_4^{3-} and NH_3 in the 1980s. Site 90167 had high concentration of Cl^- and pH in the 1970s, 1980s, 2000s and 2010s which was like site 90204 and 90233.The PCA biplot showed that site 90204 had high concentration of PO_4^{3-} and NH_3 in the 1980s and high concentration of EC, Ca^{2+}, Mg^{2+} and SO_4^{2-} in the 1980s and 2010s (Figure 4-17). Site 90203 and site 90233 also had high concentration of EC, Ca^{2+}, Mg^{2+} and SO_4^{2-} in the 1980s similarly to site 90204 but also had high concentration of EC, Ca^{2+}, Mg^{2+} and SO_4^{2-} in the 1990s, 2000s and 2010s (Figure 4-17).

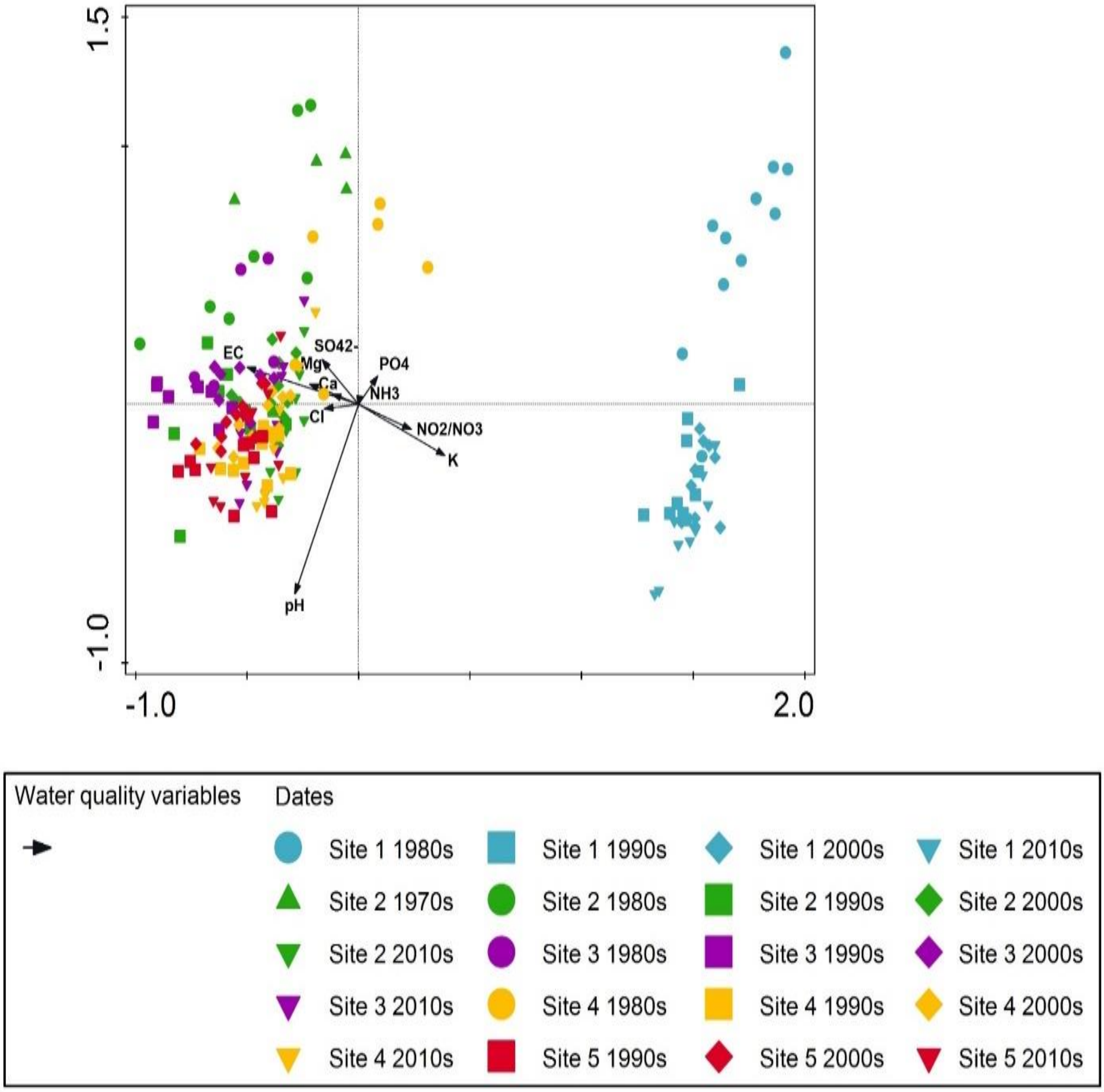


Figure 4-17: PCA biplot showing the water quality data from 1976 to 2018 for all sites. The PCA biplot explains the 89% variance in water quality data with a total of 75% variance explained in the first axis and 14% in the second axis

CHAPTER 5: DISCUSSION

5.1. Water Quality Trend

5.1.1. Water Quality Trend on site 90194

The concentration of Ca^{2+} in the Crocodile-West River was influenced by seasonal variations in flow where the Ca^{2+} concentration in the surface water is high during low flow conditions in winter and spring and low during high flows in summer and autumn months (Lowies, 2014; Du Preez et al., 2018). Calcium dissolves easily in surface waters and sources of Ca^{2+} in surface water are limestone and gypsum from the geology (Chapman, 1996). Normally, Ca^{2+} concentration in freshwater was approximately 15 mg/l Ca^{2+} (Chapman, 1996). The average concentration of Ca^{2+} in site 90194 ranged between 20mg/l $Ca^{2+}$and 40 mg/l Ca^{2+}. Higher Ca^{2+} concentration is an indication that site 90194 was exposed to calcium enrichment (Walsh & Wepener, 2009). The Crocodile-West River on site 90194 is underlain with Meinhardskraal, granite, sand river gneiss, and dolomite geology which were sources of Ca^{2+}. Other possible sources of Ca^{2+} are detergents and surfactants from wastewater treatment works, mines, and industries (Walsh & Wepener, 2009; Lowies, 2014). The Ca^{2+} from geology and land activities dissolves into the river sediments and is released during low flow seasons (Lowies, 2014).

The natural concentration of Mg^{2+} in freshwaters ranges from 1 to 100 mg/l Mg^{2+} (Chapman, 1996). Site 90194 has shown temporal variations in Mg^{2+} concentrations from 1979 to 2018. The concentration of Mg^{2+} was between 32 mg/l Mg^{2+} and 89 mg/l Mg^{2+} in the 1970s and 1980s and 50 mg/l of Mg^{2+} from mid-1980s to 2018. The concentration of Mg^{2+} at site 90104 was below the 100 mg/l Mg^{2+} acceptable limit for freshwaters (Chapman, 1996). Generally, sources of Mg^{2+} in freshwaters are sedimentary rocks from limestone and chalk (Wagner et al., 2019). Sources of Mg^{2+} on site 90194 on the Crocodile-West River is from the Meinhardskraal, granite, sand river gneiss, and dolomite geology.

The concentration of K^{+} in freshwaters was less than 10 mg/l K^{+} (DWAF, 1996). Potassium concentration in site 90194 was 60mgl K^{+} in the 1970s and 1990s and 45 mg/l K^{+} from the mid-1990s to 2018. The high concentration of K^{+} at site 90194 was from irrigation return-flows from agricultural activities that occur along the Riverbank (Lowies, 2014; Du Preez et al., 2018). Potassium-based salts utilised in industries and as fertilisers enter freshwaters through industrial discharges and run-off from agricultural land (Chapman, 1996). Site 90194 of the Crocodile-West River is underlain with Meinhardskraal, granite, sand river gneiss which have a low erosion rate and K^{+} is found in rocks that are resistant to weathering (Chapman, 1996; Huizenga, 2004).

There were temporal variations in the concentration of Cl^- in site 90194 from 1979 to 2018. The Cl^- concentration was high in the 1970s (32 mg/l Cl^-) and mid-1980s (89 mg/l Cl^-) and decreased to 50mg/l Cl^- between 1985 to 2018. The ideal Cl^- concentration in pristine waters is less than 10 mg/l Cl^- and sometimes less than 2mg/l Cl^- (Chapman, 1996). Site 90194 is enriched with Cl^- concentrations (Du Preez et al., 2018). Sources of Cl^- at site 90194 Crocodile-West River are from weathering rock, agricultural run-off, and discharges from wastewater treatment works, and platinum mining activities (Walsh & Wepener 2009; Khatri & Tyagi, 2015). The discharge from platinum mining activities and sewage waste has been found to be the significant contributor of C Cl^- in the Crocodile-West River system (Nikanorov & Brazhnikova, 2009). The wastewater treatment works near site 90194 have a capacity of 14 Ml/d which is a small to medium-sized plant that can discharge effluent of high Cl^- concentration. There are wastewater treatment works that service the platinum mines near site 90194. The wastewater treatment works discharge ammonium chloride (NH_4Cl) from the platinum refining processes (Lowies, 2014).

Unpolluted freshwaters have NH_3 concentrations of less than 0.1 mg/l NH_3 and higher concentrations of NH_3 are caused by point and non-point sources such as domestic sewage, industrial waste, and fertiliser run-off (Chapman,1996). Pollution of NH_3 on site 90194 is due discharge from wastewater treatment works that service the Centurion, Krugersdorp, and Brits areas (Lowies, 2014). The concentrations of NH_3 at site 90194 were also influenced by flows in the Crocodile-West River. The NH_3 concentrations were higher in the drier winter months and spring because the effluents discharged into the Crocodile-West River are not diluted by natural run-off or stream flows (Lowies, 2014). Run-off that contains NH_3 from dissolved fertilisers from irrigated crops may cause an increase in NH_3 pollution in Crocodile-West River although it is very difficult to determine the level of concentration of NH_3 originating from agricultural run-off as it normally occurs during rainfall seasons and there is a dilution of nutrients during that period (Lowies, 2014).

The average NO_3^-/NO_2^- concentration in site 90194 was approximately 3mg/l NO_3^-/NO_2^- between the mid-1990s to 2018 where the highest NO_3^-/NO_2^- concentration was 14 mg/l NO_3^-/NO_2^- between the 1970s and mid-1990s. Nitrate/nitrite concentration that exceeded 5 mg/l NO_3/NO_2 indicated pollution from human and animal waste and run-off containing fertilisers (Chapman, 1996). Sources of NO_3^-/NO_2^- pollution at site 90194 were from fertilisers applied in agricultural croplands that leeched into the soil and effluent discharges from wastewater treatment works (Lowies, 2014). The high NO_3^-/NO_2^- concentrations at site 90194 are due to effluent discharge from wastewater treatment works that service the Krugersdorp, Centurion and Johannesburg areas and irrigation return flows that occur along the Crocodile-West River (Lowies, 2014).

The SO_4^{2-} concentration was high in the 1970s (50mg/l SO_4^{2-}) and mid-1980s (137 mg/l SO_4^{2-}) and decreased to an average concentration of 30 mg/l SO_4^{2-} between the 1990s and 2010s. Sulphate ions in natural water are between 2-80 mg/l SO_4^{2-} and the concentration of SO_4^{2-} may be higher in semi-arid regions for sites situated near industrial activities (Chapman, 1996). The source of SO_4^{2-} pollution at site 90194 was from mining activities (Davies, 2007). The high SO_4^{2-} concentration at site 90194 between 1979 and 1990s was due to the rising groundwater from deep mining activities that ceased to operate in the 1970s (Huizenga, 2004). The study by Du Preez et al. (2018) showed evidence of strong negative correlations between flow and the water quality variables which indicated that flow influences the concentration of water quality variables in the Crocodile-West River. The persistent dry conditions experienced by water resources due to drought in the 1980s and 1990s may have also influenced SO_4^{2-} concentrations in the study (Baudoin, 2017).

There was a temporal change in PO_4^{3-} concentration between 1979 and 2018 where the PO_4^{3-} concentration was high in the 1970s and mid-1980s (2.8 mg/l PO_4^{3-}) and declined to 0.16 mg/l PO_4^{3-} between the mid-1980s to 2018. Phosphate concentrations of between 0.005 mg/l PO_4^{3-} to 0.020mg/l PO_4^{3-} occur in freshwaters and PO_4^{3-} concentrations of 0.001 mg/l PO_4^{3-} are found in pristine waters (Chapman,1996). Sources of PO_4^{3-} pollution are from point sources such as domestic and industrial effluent and non-point sources such as urban run-off and agricultural run-off from land applied with fertilisers (Mosoa, 2013; Du Preez et al. 2018). The source of high concentration of PO_4^{3-} on site 90194 is due to the wastewater treatment works servicing the residential areas and the irrigation along the banks of the Crocodile-West River (Lowies,2014). High PO_4^{3-} concentrations are responsible for eutrophic conditions in rivers (Frost & Sullivan, 2010).

The pH levels in site 90194 increased from neutral (pH=7) to basic (pH=8.5) between 1979 to 2018. Possible sources of high pH values are the concentration of carbonates has leeching from geology and agricultural pollutants (Lalparmawii & Mishra, 2012; Kambwiri, et al., 2014). The study by Du Preez et al. (2018) showed that the pH in the Crocodile-West River was influenced by excessive algal and cyanobacterial growth. Electrical conductivity is an indicator to the total dissolved solids (TDS) of the Crocodile-West River. The EC represents the concentration of major ions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{+}, SO_4^{2-} and HCO_3^{-} which measures the salinity of Crocodile-West River (Chapman, 1996). There were no temporal variations in EC values in site 90194 and the changes in EC values where due to seasonal changes of flow in the Crocodile-West River (Du Preez et al., 2018). The average EC on site 90194 from 1979 to 2018 was 10 µS/cm. Possible sources of EC is geology and the Crocodile-West River is underlain with Meinhardskraal, granite, sand river gneiss geology. Granite is composed of inert materials that dissolve at a slow rate in freshwaters (DWAF, 1996; Packett et al., 2009).

5.1.2. Water Quality Trend on site 90167

The Crocodile-West River at site 90167 is underlain with Rashoop, Lebowa, and Rustenberg geology complex. The Rashoop group contains quartz and feldspar which is rich in calcite ($CaCO_3$) and dolomite $(CaMg)(CO_3)_2$ which were highly soluble in freshwaters and were the source of high calcium concentrations in the Crocodile-West River (Huizenga, 2004). Site 90167 drains informal settlements, mining areas such as platinum mining Xstrata Alloys, Eastplats, open cast chrome, and granites mining, crop irrigation, and industrial and urban areas which have limited contribution to calcium pollution in the Crocodile-West River (Lowies, 2014; Du Preez et al., 2018). The source of low K^+ concentration on site 90167 is due to the geology. Rashoop, Lebowa, and Rustenberg geology complex contain quartz, feldspar, granites, granophyre, and rhyolites which were sources of K^+ and Ca^{2+} concentration. It is noted that feldspar is richer in Ca^{2+} than K^+ (Wagner et al., 2019). The source of K^+ on site 90167 is granites of its low erosion rate properties and K^+ is found in rocks that are resistant to weathering (Huizenga, 2004).

Chapman (1996) indicated that the natural concentration of Mg^{2+} in freshwaters ranges from 1 to 100 mg/l Mg^{2+} and is dependent on the type of rock. Rivers that flow through quartz have low Mg^{2+} concentrations (Chapman, 1996). Site 90167 is underlain with the Rashoop, Lebowa, and Rustenburg geology complex which contains quartz which is Mg^{2+}poor (Huizenga, 2004). The high concentration of Mg^{2+} in the 1980s and 1990s was caused by drought conditions where low flow conditions caused a build-up of high concentrations of Mg^{2+} in the Crocodile-West River (Baudoin, 2017).

The source of high EC on site 90167 during the 1970s, 1980s and early 1990s was due to the combination of geological weathering of the Bushveld complex and the heavy-metal rich acid mine drainage from surrounding platinum mining activities in the area (Huizenga, 2004; Mutanga & Mujuru, 2016, Du Preez et al., 2018). The oxidation of sulphide-rich pyrite ores from mine water enriches the Crocodile-West River at site 90167 with SO_4^{2-} (Lowies, 2014; Mutanga & Mujuru, 2016). Another source of SO_4^{2-} in the Crocodile-West River is from run-off that contains SO_4^{2-} based fertilisers and pesticides from agricultural activities (Du Preez et al., 2018).

The source of NO_3^-/NO_2^- concentrations in the Crocodile-West River at site 90167 was from the return-flow of agricultural activities found in the catchment (Merolla, 2011; Lowies, 2014). The high concentrations of PO_4^{3-} at site 90167of the Crocodile-West River are due to impacts from land-use activities. Point sources of PO_4^{3-} in the Crocodile-West River are discharged effluent from wastewater treatment works servicing the surrounding urban areas and non-point sources of PO_4^{3-} in the Crocodile-West River from urban run-off, and drainage from agricultural fields where fertilisers are applied (Mosoa, 2013). The concentration of PO_4^{3-} is the driving force of eutrophic conditions in freshwaters (Oberholster & Ashton, 2008). Sources of high concentration of NH_3 on site 90167 of the Crocodile-West River are from agricultural run-off from the irrigation scheme that occurs along the Crocodile-West River, effluents from wastewater treatment works that services the Brits and Krugersdorp areas, and waste from livestock farming (Lowies, 2014). The presence of high NH_3 in the freshwater system limits the biodiversity of aquatic organisms and is a threat to animal and human health (Ballot et al., 2014).

Possible sources of high pH values are the concentration of carbonates leeching from geology and agricultural pollutants and excessive algal and cyanobacteria growth (Havens, 2008; Lalparmawii & Mishra, 2012; Kambwiri, et al., 2014).

5.1.3. Water Quality Trend on site 90203

The Ca^{2+} concentration at site 90203 was high in the 1980s and 1990s (60 mg/l Ca^{2+}) and the Ca^{2+} concentration decreased to 45 mg/l Ca^{2+} from 1997 and remained constant in the mid-2000s until 2018. Literature by Chapman (1996) indicated that rivers associated with carbonate-rich soils have Ca^{2+} concentrations of 30 to 100 mg/l. The high Ca^{2+} concentration in the Crocodile-West River on site 90203 is associated with inputs from the Ca-rich geology. Site 90203 of the Crocodile-West River is underlain with Rooiberg geology which consists of Transvaal Sediment supergroup. The sediments may contain Ca^{2+} from limestone or chalk which are responsible for the calcium enrichment in the Crocodile-West River (Mathebula, 2015). Geology is the main source of Mg^{2+} in the Crocodile-West River. The high concentration of Mg^{2+} in the mid-1980s and mid-1990s was due to the drought that impacted the flow of the Crocodile-West River system. Low flows increase the concentration of Mg^{2+} in the Crocodile-West River (Lowies, 2014; Baudoin, 2017).

Site 90203 was situated downstream of the Vaalkop dam and during drought the dam would have limited the release of water downstream to meet the ecological water requirements (Merolla, 2011; Baudoin, 2017; De Necker et al., 2020). Salinisation causes high Cl^- concentrations in South African Rivers which results in improper irrigation practices as is the case with the Crocodile-West River (Griffin et al., 2014). Site 90203 is situated downstream of the Hartebeespoort irrigation scheme, and the Crocodile-West River system receives Cl^- pollution from irrigation return-flows from the agricultural activities that occur along the banks of the Crocodile-West River (Lowies, 2014; Du Preez et al., 2018). Sodium chloride salts found in fertilisers used in crop farming are another major source of Cl^- pollution in the Crocodile-West River when it receives volumes of water through irrigation return-flows (Du Preez, 2018).

The irrigation return-flow from the irrigation schemes and pollution from mining activities in the Crocodile-West River is the source of high EC at site 90203 hence the high salinity of the river (Griffin et al., 2014; Lowies, 2014; Du Preez et al., 2018). Similarly, the source of NO_3^-/NO_2^- is from irrigation return-flow from agricultural croplands (Merolla, 2011). According to the study by Mosoa (2013), the source of high SO_4^{2-} concentration in the Crocodile-West River was due to mining activities as well. Site 90203 on the Crocodile-West River flows through the Bushveld complex that has platinum mine activities (Huizenga, 2004; Du Preez et al., 2018). Sulphide-rich pyrite ores from mine activities and run-off containing SO_4-based fertilisers and pesticides from agricultural activities enriches the Crocodile-West River with SO_4^{2-} (Lowies, 2014; Mutanga & Mujuru, 2016; Du Preez et al., 2018).

Sources of high NH_3 concentration on site 90203 are due to the ammonium-sulphate ($(NH_4)_2SO_4$) fertilisers that are applied in the crop farming that occurs along the Crocodile-West irrigation schemes (Du Preez, 2018). Discharging of untreated sewage from wastewater treatment works in the Brits area downstream of the Hartebeespoort Dam and the informal settlements situated along the banks of the Crocodile-West River are the source of nutrients especially NH_3 (Du Preez et al., 2018). There are many sources of PO_4^{3-} along the Crocodile-West River that are responsible for the PO_4^{3-} pollution on site 90203. Phosphate-based fertilisers that are applied in irrigation farming of crops along the banks of the Crocodile-West River are sources of PO_4^{3-} pollution through irrigation return flows (Du Preez et al., 2018). Untreated effluent from informal settlements and treated wastewater treatment works in the Rustenberg area are a source of PO_4^{3-} pollution in the Crocodile-West River (Du Preez, 2018; Tshivhase, 2019). Ammonia and phosphate-based fertilisers applied in irrigation farming of crops along the banks of the Crocodile-West River are sources of nutrients from irrigation return-flows (Du Preez, 2018). Nutrients from treated and untreated effluent from informal settlements and algal and cyanobacterial pollution along the Crocodile-West River are sources of high pH levels of site 90203 of the river (Walsh & Wepener, 2009; Tshivhase, 2019).

5.1.4. Water Quality Trend on site 90204

The average Ca^{2+} concentration in site 90204 was 40 mg/l Ca^{2+} from 1984 to 2018. Site 90204 The high Ca^{2+} concentration in the Crocodile-West River at site 90204 was associated with pollution from calcium-rich geology because Chapman (1996) indicated that rivers associated with carbonate-rich soils have Ca^{2+} concentrations of 30 to 100 mg/l. The source of carbonate (CO_3^{2-}) on site 90204 is from the dolomites of the Transvaal Super-group that underlain the Crocodile-West River (Eriksson et al., 2006). The carbonates at site 90204 originate from calcium sulphate ($CaSO_4$), magnesium sulphate ($MgSO_4$) and sodium hydrocarbonate ($NaHCO_3$) salts from irrigation return-flows (Grattan, 2002). The average K^+ concentration at site 90204 was 10 mg/l (Figure 4-2). The source of K^+ on site 90204 is from geology and then diffuse from a non-point source such as agricultural return-flows which have sodium enriched soils (Du Preez et al., 2018).

The source of Mg^{2+} pollution on site 90204 on Crocodile-West River is from Mg^{2+}-based salts found in fertilisers used in crop farming in the Crocodile-West River when it receives volumes of water through irrigation return-flows (Du Preez, 2018). The average concentration of Cl^- on site 90204 is 60mg/l Cl^- which indicates that the Crocodile-West River is impacted by pollution from land-use activities. Site 90204 is situated in platinum areas where mines operate small wastewater treatment works which discharge effluent containing ferrous chloride (Lowies,2014). The irrigation return flow from the irrigation schemes and the platinum mining activities on site 90204 of the Crocodile-West River are the source of high EC which indicates high salinity of the Crocodile-West River (Griffin et al., 2014; Lowies, 2014 & Du Preez, 2018). Sources of high NH_3 concentration at site 90204 are the $(NH_4)_2SO_4$ fertilisers that are applied in crop farming. The fertilisers dissolve into the return-flows from irrigation schemes (Du Preez, 2018). Discharged untreated sewage from wastewater treatment works and the informal settlements situated along the banks of the Crocodile-West River are possible sources of nutrients such as NH_3 on site 90204 (Du Preez, 2018).

5.1.5. <u>Water Quality Trend on site 90233</u>

The Crocodile-West River at site 90233 flows through the interface between the Rustenburg, Lebowa, Rashoop geology and the Transvaal, Rooiberg, and Griqualand-West sediment Super-group geology. The Rashoop group contains quartz and feldspar that is highly soluble in freshwaters and are sources of high Mg^{2+} and Ca^{2+} concentrations in the Crocodile-West River (Huizenga, 2004). The sediments may contain Ca^{2+} from limestone or chalk which are calcium enrichment in the Crocodile-West River (Mathebula, 2015). The major source of K^+ on site 90233 is from the Transvaal, Rooiberg, and Griqualand-West geology with contribution from diffuse non-point sources from agricultural return-flows (Du Preez, 2018). Site 90233 is situated in the Thabazimbi area where predominately iron mines operate small wastewater treatment works which discharge ferrous chloride-based effluent into the Crocodile-West River (Lowies,2014). Extensive irrigation activities that take place along the banks Crocodile-West River are a source of Cl^-. Site 90233 is downstream of the Hartebeespoort irrigation scheme and the Crocodile-West River system receives Cl^- pollution from irrigation return-flows (Lowies, 2014; Du Preez et al., 2018).

The source of NO_3^-/NO_2^- is from irrigation return-flow from agricultural croplands (Merolla, 2011; Soko, 2014). The irrigation return-flow from the irrigation schemes, platinum mining activities, discharge from untreated sewage from wastewater treatment works and the informal settlements situated close to site 90233 of the Crocodile-West River are sources of high EC, NH_3 and PO_4^{3-} (Griffin et al., 2014; Lowies, 2014; Soko, 2014; Du Preez et al., 2018; Tshivhase, 2019). Dolomite geology and excessive algal and cyanobacterial growth are sources of carbonates in the river that are responsible for increasing the pH of the Crocodile-West River (Du Preez et al., 208). In addition, NH_3 and PO_4^{3-}-based fertilisers applied in the irrigation of crops are sources of nutrients through irrigation return-flows (Du Preez, 2018). Nutrients from treated and untreated effluent from informal settlements and wastewater treatment works are responsible for elevating pH in the Crocodile-West River (Chapman, 1996; Du Preez, 2018; Tshivhase, 2019).

5.2. Water Quality Index

5.2.1. WQI on site 90194

There was a temporal variance in the calculated CCME WQI for site 90194 from 1979 to 2018. The calculated WQI trend of Crocodile-West River on site 90194 showed a change in the water quality status of the Crocodile-West River and generally the water quality of site 90194 can be classified as marginal to good and improved from 1979. The water quality variables responsible for the change in water quality status of the Crocodile-West River are pH, phosphate (PO_4^{3-}), and ammonia (NH_3). These water quality variables exceeded the target water quality guidelines for the protection of aquatic ecosystems. Site 90194 of the Crocodile-West River is situated on the upper reach of the Crocodile-West River upstream of the Hartebeespoort Dam. Site 90194 is situated near urban areas where the Crocodile-West River drains part of Johannesburg, Krugersdorp, Roodepoort, and Kempton Park (Mosoa, 2013; Tshivhase, 2019). These urban areas are serviced by Driefontein wastewater treatment works (WWTWs) which discharges into the Crocodile-West River (Roux & Oelofse, 2013). The Hartebeespoort Dam and Crocodile-West River are part of a complex irrigation scheme that is supplied by canals (Du Preez, 2018). The dominant irrigation activities close to site 90194 are citrus and sub-tropical fruits, tobacco, sunflower, soybeans, and cotton farming (Mosoa, 2013). The run-off from urban areas, wastewater treatment works, and irrigation return flow are the sources of PO_4^{3-} and NH_3 on site 90194 of the Crocodile-West River. The source of pH levels in site 901094 of the Crocodile-West River can be attributed to the underlying geology and algal and cyanobacterial growth (Walsh & Wepener, 2009).

The high influx of PO_4^{3-} and NH_3 in freshwater systems causes the water quality to be eutrophic. The concentration of PO_4^{3-} is the limiting agent in eutrophic freshwaters (Frost & Sullivan, 2010). The Crocodile-West River is hypertrophic because the average seasonal concentration on site 90194 is greater than 0.25 mg/l PO_4^{3-} (Griffin et al., 2014). Eutrophic rivers have high growth of blue-green algae which are toxic to aquatic species such as fish and limits biodiversity of macroinvertebrates (Frost & Sullivan, 2010). The Crocodile-West River on site 90194 is not desirable for drinking purposes as it affects the taste and odour of freshwater and impacts the irrigated crops due to the toxicity of water (Griffin et al., 2014).

5.2.2. **<u>WQI on site 90167</u>**

There was a temporal change in the water quality status of site 90167 in the Crocodile-West River. Figure 4-9 showed that the calculated water quality index (WQI) of site 90167 deteriorated from excellent water quality status (WQI=100) in 1976, 1987 to 1989, and 1990 to marginal water quality status in 2018 (WQI=64). Phosphate, ammonia, and pH levels comprised the water quality of site 90167. The water quality variables exceeded the target water quality guidelines for the protection of aquatic ecosystems. Site 90167 of the Crocodile-West River is situated on the section of the Crocodile-West River downstream of Roodekopjes dam. The Crocodile-West River at site 90167 drains part of Rustenburg and Brits areas (Du Preez, 2018). These urban areas are serviced by Madibeng WWTWs in Brits which discharges into the Crocodile River (Du Preez, 2018). Crop farming activities along the Crocodile-West River were a major driver of water quality deterioration of the river system (Du Preez, 2018). The combination of run-off from urban areas of Brits, effluent from Brits wastewater treatment works, and irrigation return flow from the Hartebeespoort irrigation scheme are the sources of PO_4 and NH_3 on site 90167 of the Crocodile-West River.

The pH of site 90167 of the Crocodile-West River is influenced by the Rashoop, Lebowa, and Rustenberg geology complex and dolomite geology which are sources of carbonates in the river and algal and cyanobacterial growth (Walsh & Wepener, 2009). The concentration of PO_4 and NH_3 in the Crocodile-West River causes the water quality at site 90167 to have mesotrophic to hypertrophic conditions (Griffin et al., 2014). Rivers with elevated concentrations of PO_4 and NH_3 have high growth of toxic blue-green algae which negatively impacts the biodiversity of aquatic species (Frost & Sullivan, 2010). The Crocodile-West River on site 90167 is not desirable for domestic purposes because of the taste and odour of freshwater and is potentially toxic to irrigated crops (Griffin et al., 2014).

5.2.3. WQI on site 90203

The calculated water quality index (WQI) trend showed temporal change in WQI over the years from 1985 to 2018. The WQI of 90203 deteriorated from water quality of excellent status (WQI=100) from 1987 to good water quality status in 2018 (WQI=83). The WQI flagged phosphates (PO_4) ammonia (NH_3) and pH as exceeding the target water quality guidelines for protection of aquatic ecosystems. Site 90203 of the Crocodile-West River was situated on the upper reach of the Crocodile-West River downstream of Vaalkop dam located on the Elands River and Roodekopjes dam (Mosoa, 2013). The Crocodile-West River at site 90203 drains part rural areas and the only major city was Rustenberg (Mosoa, 2013). The wastewater treatment works servicing the Rustenberg area discharges containing PO_4 and NH_3 into the Crocodile-West River (Roux & Oelofse, 2012). Agricultural and livestock farming activities along the Crocodile-West River were a major driver of water quality deterioration of the river system (Du Preez, 2018). The combination of run-off from urban and informal areas, effluent discharge from wastewater treatment works and irrigation return flows are the sources of PO_4^{3-} and NH_3 on site 90203 of the Crocodile-West River (Frost & Sullivan, 2010).

Sources of pollutants that influence pH in site 90203 of the Crocodile-West River are the Rashoop, Lebowa, and Rustenberg geology complex and dolomite geology which are sources of carbonates in the river (WHO, 2011). Site 90203 has high concentrations of SO_4^{2-} and Cl^- from pollution from agricultural activities and platinum mining activities. The SO_4^{2-} and Cl^- did not exceed the target water quality guideline from aquatic ecosystems but posed a threat to the future water use of the Crocodile-West River. Sulphate and chloride may impact the taste of domestic water (Chapman,1996).

The eutrophic state of the Crocodile-West River has become mesotrophic to hypertrophic conditions over time due to the high concentrations of PO_4^{3-} and NH_3 (Griffin et al., 2014). Elevated concentrations of PO_4^{3-} and NH_3 cause algae and cyanobacterial growth which is toxic and negatively impacts aquatic species and is not preferred for domestic use and irrigation of crops (Frost & Sullivan, 2010; Griffin et al., 2014).

5.2.4. WQI on site 90204

The WQI of 90204 deteriorated from excellent water quality status (WQI=100) from 1984 to fair water quality status in 2018 (WQI=74). The calculated WQI showed temporal decline from 1984 to 2018. Phosphate, ammonia, and pH levels exceeded the target water quality guidelines for the protection of aquatic ecosystems. Site 90204 is situated downstream of the confluence between Crocodile-West River and Pienaars River (Dubula, 2007). The Crocodile-West River at site 90204 drained parts of small villages and the only major city is Brits and surrounding platinum activities

(Mosoa, 2013; Lowies, 2014). Effluents containing PO_4^{3-} and NH_3 drained into the Crocodile River through land-use activities (Dubula, 2007). Crop farming activities along the Crocodile-West River were a major driver of water quality change of the river system (Du Preez, 2018). The combination of run-off from urban and informal areas, effluent discharge from wastewater treatment works and irrigation return flow are the sources of PO_4^{3-} and NH_3 on site 90204 of the Crocodile-West River (Du Preez, 2018). The Crocodile-West River has become hypertrophic over time (Griffin et al., 2014).

Elevated concentrations of PO_4^{3-} and NH_3 causes high growth of blue-green algae which would influence the biodiversity of aquatic species and impacts on the pH levels of the Crocodile-West River (Frost & Sullivan, 2010). The Dolomites of the Transvaal Super-group are sources of pH on site 90204 of the Crocodile-West River through leaching of carbonates which cause an increase in pH of rivers (Chapman, 1996). Site 90204 has high concentrations of SO_4^{2-} and Cl from pollution from agricultural and platinum mining activities. The SO_4^{2-} and Cl^- on site 90203 did not exceed the target water quality guidelines but do pose a threat to the integrity of the Crocodile-West River. High SO_4^{2-} and Cl^- concentrations have a possibility of impacting domestic and irrigation purposes (Chapman,1996; Du Preez et al., 2018).

5.2.5. WQI on site 90233

The calculated water quality index (WQI) showed a temporal variance between the years from 1990 to 2018. The calculated WQI of 90233 deteriorated from excellent water quality status (WQI=100) from 1990 to fair water quality status in 2018 (WQI=74). Phosphates, ammonia, and pH levels exceeded the target water quality guidelines for the protection of aquatic ecosystems. Site 90233 of the Crocodile-West River was situated on the confluence between the Crocodile-West River and Sands River (Mosoa, 2013). The Crocodile-West River at site 90233 drained part small villages and the only major city was Thabazimbi and surrounding mining activities and drains effluents containing PO_4^{3-} and NH_3 discharged into the Crocodile-West River (Mosoa, 2013; Dubula, 2007). The combination of run-off from urban and informal areas, effluent discharge from wastewater treatment works and irrigation return-flow are the sources of PO_4^{3-} and NH_3 on site 90233 of the Crocodile-West River (Mathebula, 2015, Du Preez, 2018).

The pH of site 90233 of the Crocodile-West River is influenced mostly by algal growth and the dolomites of the Transvaal Super-group are sources of carbonates in the river (Walsh & Wepener, 2009). Site 90233 also has high concentrations of SO_4^{2-} and Cl^- from pollution from irrigation return-flow. The SO_4^{2-} and Cl^- did not exceed the target water quality guidelines but are a threat to the future water quality status of the Crocodile-West River. Sulphate and chloride impact the taste of domestic water and are potentially toxic to aquatic species and crops (Walsh & Wepener, 2009; Chapman,1996). The eutrophic status of the Crocodile-West River deteriorated from mesotrophic to hypertrophic conditions over time (Griffin et al., 2014). It is expected that the elevated concentration of PO_4^{3-} and NH_3 will cause increased growth of blue-green algae which produces toxins that negatively impact the biodiversity of aquatic species (Frost & Sullivan, 2010).

5.2.6. Overall WQI

The Crocodile-West River has pollution of PO_4 and NH_3, and the pH of the Crocodile-West River is basic with pH levels of above 8 units. The pollution of PO_4^{3-}, NH_3, and elevated pH levels are prevalent at all the monitoring sites of the study with site 90167 being most impacted by the land use activities. The sources of pollution of the Crocodile-West River are partly natural from leeching of geology but can largely be attributed to sources from land-use activities such as irrigation return flow from the agricultural activities along the banks of the Crocodile-West River and the urban and informal settlements close to the Crocodile-West River (Mosoa, 2013).

Generally, rivers that flow through urban areas are prone to deteriorate in water quality because run-off from urban areas usually contained more pollutants than run-off in rural areas and less volumes of soil to drain the pollutants before the run-off influxes into the river (Dubula, 2007). Urban areas are likely to be serviced by wastewater treatment works which discharge effluent that has pollutants into the river system (Dubula, 2007). Mining activities also pollute the Crocodile-West River through effluent discharged by the small wastewater treatment works. Abandoned mines have a higher impact than operational mines because sulphide-rich groundwater from shafts in abandoned mines interacts with the surface water of rivers. The sulphide is oxidised to SO_4^{2-} in surface water in a phenomenon called AMD (Lowies, 2014; Mutanga & Mujuru, 2016). The Crocodile-West River has high SO_4^{2-}, Cl^-, and Ca^{2+} concentrations in a region of approximately greater than 60 mg/l from mining activities and sulphate-based fertilisers applied to crops along the Crocodile-West River (Lowies, 2014).

Phosphates and ammonia present in the Crocodile-West River have caused the river to be eutrophic over time (Frost & Sullivan, 2010; Ginkel et al., 2011). The cause of eutrophic conditions of the Crocodile-West River is two-fold. The first source of PO_4^{3-} and NH_3 is land-use activities such as run-off from urban, agricultural land, organic waste from informal settlements, presence of dams, and discharged effluent from wastewater treatment works, and from PO_4^{3-} rich geology that leeches from sediments in the river (Dubula, 2007). The PO_4^{3-} retention in sediments is flow dependent and hence high PO_4^{3-} will be released during low flow seasons of winter and spring and dissolved and diluted during high flow seasons of summer and autumn (Dubula, 2007; Mwangi, 2013).

Eutrophic conditions in the Crocodile-West River causes blooms of blue-green algae and hyacinths in dams (Du Preez et al., 2018). Eutrophic water is problematic because it impacts the odour and taste of potable water, impacts treatment of raw water, limits recreational activities, and impacts the crop quality of irrigated crops (Frost & Sullivan, 2010). The implementation of the 1 mg/l PO_4^{3-} effluent discharge limit in the Hartebeespoort Dam catchment was an important water management measure to limit the PO_4^{3-} pollution in the Hartebeespoort Dam catchment and Crocodile-West River downstream of the Hartebeespoort Dam. The Hartebeespoort Dam and Crocodile-West River remained eutrophic despite the implementation of 1 mg/l PO_4^{3-} effluent discharge limit (Mathebula, 2015).

The deteriorating of the WQI at all sites of the Crocodile-West River is linked to the changing land-use activities and persistent climate extremes such as the major droughts from 2015 to 2018. The Crocodile-West/Marico catchment has the second-highest population in the country and generates almost a third of the gross domestic product (GDP) of the country (Lowies, 2014). The population density of the Crocodile-West/Marico catchment is greatest in the Johannesburg and Pretoria areas and the towns such as Potchefstroom, Brits, Klerksdorp, and Rustenberg (Lowies, 2014). The population in the Crocodile-West/Marico catchment has increased over time and increased formal and informal settlements have caused pollution of the Crocodile-West River and its tributaries to increase (Lowies, 2014).

The capacity of the Hartebeespoort irrigation scheme has increased over the years which has resulted in growth in the agricultural sector along the Crocodile-West River to supply the populations demand for food (Du Preez, 2018). Increased usage of fertilisers has caused highly polluted irrigation return flow to the Crocodile-West River (Lowies, 2014). The Crocodile-West River is in the Bushveld Complex where extensive gold, platinum, and chrome mining activities takes place (Walsh & Wepener, 2009). The mining activities of Impala and Anglo have extensively increased due to the increase in demand and have negatively impacted the Crocodile-West River and has caused increased sprawl of informal settlements in the surrounding mining areas which are a source of pollution to the Crocodile-West River (van der Walt et al, 2012; Ololade & Annegarn, 2013; Huizenga, 2004). The CCME WQI of the Crocodile-West River was lowest in years where drought conditions persisted especially from 2014 to 2018 where the water quality for the Crocodile-West River was impacted by low flows of drought (Lowies, 2014; Baudoin, 2017).

The CCME WQI was excellent in indicating both the temporal and spatial water quality changes of the Crocodile-West River from 1976 to 2018. The CCME WQI was excellent in indicating the spatial changes in water quality between sites in the Crocodile-West River. The CCME WQI showed the water quality status of the Crocodile-West River was generally good from 1976 to

2018. However, sites 90194, 90167, and 90204 had slightly lower median WQI values than sites 90203 and 90233. This indicates that site 90194, site 90167, and site 90204 were impacted more by land-use activities than site 90203 and site 90233 (Nalado et al., 2017). The upper reach of the Crocodile-West River was impacted more by the land-use activities than the lower Crocodile-West River (Dubula, 2017).

The CCME WQI was sensitive to the changes in magnitude and number of water quality variables that exceeded the target water quality guidelines on the study. The years which had high frequency and magnitude of water quality variables that exceeded the target water quality guidelines have lower CCME WQI index values than years that have lower frequency and magnitude of water quality variables that exceeded the target water quality guidelines. The years which have lower F_1 scores and F_3 scores have the highest CCME WQI scores than the years which have higher F_1 scores and F_3 scores. Also, F_3 scores have more of an influence in determining the CCME WQI scores of years where the F_1 values were similar in magnitude. The CCME WQI can enable water quality managers to identify problematic water quality variables in the river system and enable managers to come up with effective monitoring programs to better manage the Crocodile-West River (Rangeti et al., 2013).

The application of the CCME WQI in the Crocodile-West River exhibited flexibility in incorporating water quality guidelines sourced from different sources to interpret the overall water quality status of the Crocodile-West River. The CCME water quality index is sensitive to the water quality variables applied in the index (Namugize & Jewitt, 2018). The usefulness of the CCME WQI was dependent on the frequency and quality of water quality variables of the monitoring programme. The 40-year data set was applied to the CCME WQI of the study and was useful in indicating the CCME WQI trend of the sites and the overall Crocodile-West River (Namugize & Jewitt, 2018). The approach of the WAWQI is similar to the CCME WQI and both methods have been extensively used globally to determine the health of water resources using multiple water quality variables (Tyagi et al., 2013; Khatri et al., 2020). The WAWQI is like the CCME WQI in that the WQI can accommodate multiple water quality variables and is not strict in the criteria and number of water quality variables and each require multivariate statistics such as PCA to evaluate the effectiveness of the WQI (Tyagi et al., 2013; Neswiswi, 2014; Calmuc et al., 2020). PAI was developed to determine the health of the water resource in South Africa. PAI also uses data from multiple water quality variables incorporated into a mathematical equation to classify the health of the water resources which is similar approach to WAWQI and CCME WQI (Kleynhans et al., 2005; Sutadian et al., 2016). The disadvantage of using PAI is that it is used in limited literature as compared to WAWQI and CCME WQI.

It is noted that the CCME WQI can be enhanced by ensuring that scientific and local knowledge of the river is well-understood to include appropriate water quality variables of the Crocodile-West River are included in the calculation of CCME WQI of the river (Namugize & Jewitt, 2018). For instance, the CCME WQI of the Crocodile-West River in the study may be slightly underestimated due to the exclusion of biological indicators such as chemical oxygen demand (COD), biological oxygen demand (BOD), *Escherichia coli (E. Coli*), turbidity, and trace metals (Namugize & Jewitt, 2018). The study of the land-use activities in the Crocodile-West River included informal settlements, livestock farming, and mining (Lowies, 2014). Informal settlements don't have formal sanitation infrastructure and run-off from such areas may cause an influx of organic waste into the Crocodile-West River (Mosoa, 2013; Mathebula, 2015). Similarly, the impact of run-off from livestock farming in the Crocodile-West River was a source of organic pollution. Trace metal pollution from mining activities has a toxic impact on aquatic ecosystems (Lowies, 2014). Sedimentation from geology of the Crocodile-West River and run-off from urban areas may impact the overall water quality of Crocodile-West River and the aquatic species such as macro-invertebrates and fish in the river system (Lowies, 2014).

5.3. Principal Component Analysis

5.3.1. PCA biplot of site 90194

The PCA biplot correlated well with the CCME WQI with regards to the impact of pH on site 90194 of the Crocodile-West River. The CCME WQI detected that pH, PO_4^{3-} and NH_3 exceeded the target water quality guidelines from 1988 to 2018 and PCA biplot indicated a similar temporal change of pH on site 90194 from 1989 to 2018 (Abdel-Fattah et al., 2020; Byambaa et al., 2019). CCME WQI and PCA biplot correlated in the prediction of temporal variation PO_4^{3-} in 1979 to 1985, 1991 and 1993 but the PCA biplot deviated from 1994 to 2018. This indicated that CCME WQI was more sensitive to temporal changes of PO_4^{3-} than the PCA biplot (Calmuc et al., 2020). It is noted that PCA biplot and CCME WQI did not accurately correlate the temporal changes of NH_3 on site 90194. The PCA biplot indicated high PC loadings of NH_3 in the mid-1990s, 2000s, and 2010s while the CCME WQI flagged NH_3 as problematic water quality variables from 1984 to 2018.

5.3.2. PCA biplot of site 90167

The PCA biplot for site 90167 indicated that NO_3^-/NO_2^- and pH have significantly influenced the water quality status of site 90167 over time but the CCME WQI indicated that the PO_4^{3-}, pH, and NH_3 were the water quality variables that exceeded the target water quality guidelines set in the study from 1979-2018 (Byambaa et al., 2019). The exclusion of NO_3^-/NO_2^- as a water quality variable that exceeded the target water quality guideline by the CCME WQI was because NO_3^-/NO_2^- had not exceeded the water quality range set in the study. However, site 90167 was situated in an area of expanding agricultural activities and typically water resources situated close to such land-use activities are prone to be polluted by NO_3^-/NO_2^- from return-flow of agricultural activities found in the catchment (Merolla, 2011). The PCA biplot has indicated NO_3^-/NO_2^- can potentially impact the water quality of site 90167 of the Crocodile-West River negatively in the future because its high PC loading.

5.3.3. PCA biplot of site 90203

The CCME WQI predicted that PO_4^{3-} and pH exceeded the target water quality range from 1985 to 2018 but PCA biplot indicated a temporal change of pH and PO_4^{3-} on site 90203 from 1996, 1999, 2002, 2009. However, the PCA biplot correlated with the CCME WQI in determining the temporal changes of pH and PO_4^{3-} for 2013 to 2018 (Abdel-Fattah et al., 2020). The PCA biplot indicated a high concentration of NO_3^-/NO_2^- 1996, 1999, 2002, 2009, and 2013- 2018. Analysis of the PCA biplot indicated that NO_3^-/NO_2^- and pH have significantly influenced the water quality status of site 90203 over time but the CCME WQI indicated that the PO_4^{3-}, pH, and NH_3 are the water quality variables that exceeded the target water quality guidelines in the study from 1985 to 2018. However, site 90203 was situated in an area of expanding agricultural activities. Water resources close to agricultural activities are prone to be polluted by NO_3^-/NO_2^- (Byambaa et al., 2019). The PCA biplot has indicated the negative potential of NO_3^-/NO_2^- on the water quality of site 90203 of Crocodile-West River in the future (Ferahtia et al. 2021).

5.3.4. PCA biplot of site 90204

The PCA biplot indicated that NO_3^-/NO_2^- and pollutants have significantly affected the pH levels of site 90204 over time but the CCME WQI indicated that the PO_4^{3-}, pH, and NH_3 are water quality variables that exceeded the target water quality guidelines set in the study from 1985 to 2018. CCME WQI correlated with PCA biplot in flagging pH, PO_4^{3-}, and NH_3 as problematic water quality variables that negatively impacted the water quality of site 90204 for the period of 1985 to 2018 (Ferahtia et al. 2021). CCME WQI may have flagged PO_4^{3-} and NH_3 as a problematic water quality variable at site 90204 but PCA biplot showed that its contribution to pollution of site 90204 was insignificant as compared to pH levels. Also, CCME WQI has flagged pH, PO_4^{3-} and NH_3 from 1985 to 2018 while PCA biplot flagged some years in the 1990s, 2000s, and 2012-2018 as years polluted by pH, PO_4^{3-} and NH_3. This has indicated the reliability of CCME WQI in indicating the temporal changes of water quality variables on site 90204.

5.3.5. PCA biplot of site 90233

CCME WQI correlated with PCA biplot in flagging pH, PO_4^{3-}, and NH_3 as problematic water quality variables of site 90233 from 1990 to 2018. CCME WQI may have flagged NH_3 and PO_4^{3-} as a problematic water quality variable on-site 90233 but PCA biplot has shown that the contribution of NH_3 and PO_4^{3-} to pollution of site 90233 was insignificant as compared to pH levels. Also, CCME WQI has flagged pH, PO_4^{3-}, and NH_3 as problematic water quality variables from 1990 to 2018 while PCA biplot flagged pH, PO_4^{3-}, and NH_3 as problematic water quality variables in the 2000s and 2012-2018. This indicates that CCME WQI is more reliable in indicating the yearly temporal changes of water quality variables on site 90233.

5.4. Overall PCA biplot

Analysis of the PCA biplot, it can be deduced that the pollutants found at each site were influenced by urban areas, water infrastructure such as dams, land use activities such as agricultural farming, and draining tributaries (Lowies, 2014). For instance, site 90194 was dominated by pollution of PO_4^{3-} and NH_3 in the 1980s and NO_3^-/NO_2^- and K^+ from the 1980s through to 2010s. Spatially, site 90194 was found to be upstream from the rest of the sites in the study and close to urban areas and surrounded by agricultural lands. Urban and agricultural lands are sources of PO_4^{3-}, NH_3, and NO_3^-/NO_2^- and metal pollutants (Du Preez et al., 2018; Calmuc et al., 2020).

Phosphates and ammonia have an insignificant contribution to the water quality status in sites 90167, 90203, and site 90233. These sites are spatially situated downstream to site 90194. Sites 90167, 90203, and site 90233 have low pollution loading from PO_4^{3-} and NH_3 because they are downstream to Hartebeespoort Dam and Roodekopjes dams (Du Preez et al., 2018; Calmuc et al., 2020). Dams typically impound nutrients and dilute pollutants when releasing water downstream during seasonal releases (Mosoa, 2013; De Necker et al., 2020). However, both site 90204 and site 90194 were impacted by PO_4^{3-} and NH_3 in the 1980s compared to site 90194 although site 90204 is downstream of site 90203. This shows that water quality status in each site is dynamic and that the water quality status in each site may change depending on the pollution that drains into the Crocodile-West River (Walsh & Wepener, 2009).

The presence of PO_4^{3-} and NH_3 pollution at site 90204 was possibly influenced by the confluence of the Pienaars River with the Crocodile-West River upstream of site 90204. The Pienaars/ Apies catchments drain pollutants from urban, industries, and mining activities in the Pretoria and Rustenburg areas which would drain PO_4^{3-} and NH_3 into the Crocodile-West River (Mosoa, 2013). Sites 90167, 90204, and 90233 were dominated by Cl^- and high pH levels due to the site situated around agricultural activities and receiving run-off from agricultural land. In addition, sites 90203, 90204, and 90233 are dominated by metal elements and SO_4^{2-} due to the presence of mining and industries that drain to the Crocodile-West River (Du Preez, 2018). In general, the PCA results indicate that the spatial distribution of the sites can influence the water quality variables being surveyed. The water quality status of upstream sites of the study were influenced by urban and agricultural activities and that the water quality status of downstream sites was also influenced by agricultural activities and by upstream impoundments and tributaries and mining activities as well (Lowies,2014).

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

CCME WQI has become useful and efficient method for assessing the suitability of water quality and to communicate the information on overall water quality of the Crocodile-West River. The CCME WQI allowed the integration of ten water quality variables and summarised the data into useful information that can be reported in a consistent manner for management of the water resource. The CCME WQI was sensitive to the water quality variables applied in the study. The usefulness of the CCME WQI was dependent on the frequency and quality of water quality variables of the monitoring programme. The 28 to 40-year data set was applied to the CCME WQI of the study and was useful in indicating the CCME WQI trend of the sites and the overall Crocodile-West River. The dataset of Ca^{2+}, NH_3, PO_4^{3-}, SO_4^{2-}, NO_3^-/NO_2^-, Mg^{2+}, K^+, Cl^-, EC, and pH per site from 1976 to 2018.

The CCME WQI in the study was successful in determining both the temporal changes in WQI per site and comparing the spatial changes in WQI between sites. Generally, CCME WQI depicted accurately the temporal changes per year in the WQI values over a period for all the sites and showed spatial comparison of WQI between sites. The CCME WQI results showed the water quality conditions on site 90203 deteriorated less as compared to site 90194, 90167, 90204 and 90233. The water quality of site 90167 and site 90194 deteriorated the most as compared to other sites. The CCME WQI was sensitive to the changes in magnitude and number of water quality variables that exceed the target water quality guidelines on the study. The years which had high F_1 and F_3 lower CCME WQI values than years did not. The CCME WQI was able to detect which water quality variables that exceeded the target water quality guidelines for aquatic ecosystems in the Crocodile-West River. The CCME WQI in the study flagged NH_3, PO_4^{3-} and pH as water quality variables which exceeded the water quality guidelines and are a threat to the water quality of the Crocodile-West River. The CCME WQI can enable water quality managers to identify problematic water quality variables in the river system and enable managers to come up with effective monitoring programs to better manage the water resources.

It was important to use appropriate multivariate statistics to corroborate findings from the CCME WQI in the study. The PCA method was used to corroborate the water quality results by CCME WQI. For instance, PCA flagged pH and NO_3^-/NO_2^- as water quality variables which had high pollution loading in the Crocodile-West River. In addition, PCA flagged NH_3, PO_4^{3-}, NO_3^-/NO_2^-, SO_4^{2-} and Cl^- as water quality variables which negatively impacted the water quality status of the Crocodile-West River. In general, the PCA results showed that the spatial distribution of the sites can influence the pollutants surveyed. The PCA in the study found that site upstream of

Hartebeespoort Dam had high PO_4^{3-}, NH_3 and NO_3^-/NO_2^- and metal pollutants downstream. PCA indicated temporal changes in the pollutants that affected each site over a period. There was variance in composition of water quality variables that contributed to the pollution between 1970s and 2010s. The CCME WQI correlated with PCA biplot in flagging pH, PO_4^{3-} and NH_3 as problematic water variables of each site over a period. The CCME WQI may have flagged NH_3, pH and PO_4^{3-} as a problematic water quality variable on a certain site for a certain year but PCA biplot has showed that the contribution of either pH, PO_4^{3-} and NH_3 to the pollution of each site was insignificant as compared to other pollutants. The CCME WQI was able to deduce the spatial difference in the water quality status for each site in the study.

The study has contributed to the research done globally on implementation of WQIs with regards to CCME WQI. The study has demonstrated the appropriateness of CCME WQI as a tool to evaluate surface water quality of the Crocodile-West River. Secondly, the study demonstrated the flexibility of the CCME WQI method and how it was applied to complex water quality data of the Crocodile-West River. Thirdly, the study demonstrated the usefulness of the CCME WQI in transforming complex water quality data into meaningful summaries of water quality information of the Crocodile-West River that can be used by managers and civil society. The study has proven to be useful in analysing and/or interpretating data to evaluate water quality over time. The CCME WQI is efficient in transforming the extensive historical physico-chemical and microbiological data collected by The DWS monitoring programmes into useful water quality information that can improve the management of our water resources. The CCME WQI is a possible WQI tool that can be implemented by DWS to determine the water quality status of water resources.

It is important to highlight that the implementation of CCME WQI should be enhanced by scientific and local knowledge of the river to ensure that the appropriate water quality variables are included in the calculation of CCME WQI of the Crocodile-West River. For instance, the calculated CCME WQI values of the Crocodile-West River in the study may be able to accurately reflect the true conditions of the water resources by inclusion of biological indicators such as COD, BOD, *E. Coli*, turbidity, and trace metals which represented the land-use activities impacting the Crocodile-West River.

Literature review has indicated that there are one or two WQIs that can be compared to CCME WQI. One is the Weighted Arithmetic Water Quality Index (WAWQI) and the Physico-chemical Driver Assessment Index (PAI). Both PAI and WAWQI has been applied to water quality studies in the Phongolo River and Jukskei River. Therefore, it is recommended that a future study should be pursued where the applicability of CCME WQI is compared to PAI and WAWQI. The study can incorporate the Ca^{2+}, NH_3, PO_4^{3-}, SO_4^{2-}, NO_3^-/NO_2^-, Mg^{2+}, K^+, Cl^-, EC, pH and COD, BOD, *E. Coli*, turbidity, and trace metals where the performance of WQIs will be compared. The proposed study will enable the integration of physico-chemical and biological variables into summaries of useful information that can be reported in a consistent manner for management decisions for the DWS and will establish the reliability of the WQIs as a method to summarise complex water quality data into useful information to better manage the Crocodile-West River. The proposed study can also evaluate the policy measure implemented by DWS to manage the Crocodile-West River. This may include the need to improve enforcement policy that are directed to manage land-use activities to ensure protection of Crocodile-West River.

BIBLIOGRAPHY

Abba, S.I., Said, Y.S. and Bashir, A. 2015. Assessment of Water Quality Changes at Two Location of Yamuna River Using the National Sanitation Foundation of Water Quality (NSFWQI). *Journal of Civil Engineering and Environmental Technology*, *2*(8):730-33.

Abbas, A.A.A. and Hassan, F.M. 2018. Water quality assessment of Euphrates River in Qadisiyah province (Diwaniyah River), Iraq. *The Iraqi Journal of Agricultural Science*, 49(2):251-261.

Abbaspour, S. 2011. Water quality in developing countries, South Asia, South Africa, water quality management and activities that cause water pollution. *IPCBEE*, 15:94-102.

Abdel-Fattah, M.K., Abd-Elmabod, S.K., Aldosari, A.A., Elrys, A.S. and Mohamed, E.S. 2020. Multivariate analysis for assessing irrigation water quality: A case study of the Bahr Mouise Canal, Eastern Nile Delta. *Water*, *12*(9): 2537.

Akoteyon, I.S., Omotayo, A.O., Soladoye, O. and Olaoye, H.O. 2011. Determination of water quality index and suitability of urban River for municipal water supply in Lagos-Nigeria. *European Journal of Scientific Research*, 54(2):263-271.

Alphayo, S.M. and Sharma, M.P. 2018. Water quality assessment of Ruvu River in Tanzania Using NSFWQI. *Journal of Scientific Research and Reports*, 20(3):1-9.

Al-Sabah, B.J. 2016. Application of water quality index to assessment of Tigris River. *International Journal of Current Microbiology and Applied Sciences*, 5(10):397-407.

Avenant, M.F. 2010. Challenges in using fish communities for assessing the ecological integrity of non-perennial rivers. *Water SA*, 36(4).

Ayobahan, S.U., Ezenwa, I.M., Orogun, E.E., Uriri, J.E. and Wemimo, I.J. 2014. Assessment of anthropogenic activities on water quality of Benin River. *Journal of Applied Sciences and Environmental Management*, 18(4):629-636.

Ballot, A., Sandvik, M., Rundberget, T., Botha, C.J. and Miles, C.O. 2013. Diversity of cyanobacteria and cyanotoxins in Hartbeespoort Dam, South Africa. *Marine and Freshwater Research*, 65(2):175-189.

Baudoin, M.A., Vogel, C., Nortje, K. and Naik, M. 2017. Living with drought in South Africa: lessons learnt from the recent El Niño drought period. *International Journal of Disaster Risk Reduction*, 23:128-137.

Byambaa, B., Yang, L., Matsuki, A., Nagato, E.G., Gankhuyag, K., Chuluunpurev, B., Banzragch, L., Chonokhuu, S., Tang, N. and Hayakawa, K. 2019. Sources and characteristics of polycyclic aromatic hydrocarbons in ambient total suspended particles in Ulaanbaatar City, Mongolia. *International journal of Environmental Research and Public Health*, 16(3):442.

Calmuc, M., Calmuc, V., Arseni, M., Topa, C., Timofti, M., Georgescu, L.P. and Iticescu, C. 2020. A Comparative Approach to a Series of Physico-Chemical Quality Indices Used in Assessing Water Quality in the Lower Danube. *Water*, 12(11):3239.

CCME. 2001. Canadian water quality guidelines for the protection of aquatic life. CCME water qualityindex1.0, User's Manual, Winnipeg, Manitoba, Canada. http://www.ccme.ca/files/Resources/calculators/WQI%20User's%20Manual%20(en).pdf Date of access 13 April 2020.

CCME. 2006. A sensitivity analysis of the Canadian water quality index http://www.ccme.ca/files/Resources/water/pn_1355_wqi_sensitivity_analysis_rpt.pdf Date of access 13 April 2020.

Chapman, D.V. ed.1996. Water Quality Assessments: A guide to the use of biota, sediments and water in environmental monitoring. CRC Press.

Cude, C.G. 2001. Oregon water quality index a tool for evaluating water quality management effectiveness 1. *JAWRA Journal of the American Water Resources Association*, 37(1):125-137.

Darapu, S.S.K., Sudhakar, B., Krishna, K.S.R., Rao, P.V. and Sekhar, M.C. 2011. Determining water quality index for the evaluation of water quality of River Godavari. *International Journal of Environmental Research and Application*, 1:174-18.

Davies, J.M. 2006. Application and tests of the Canadian water quality index for assessing changes in water quality in lakes and Rivers of central North America. *Lake and Reservoir Management*, 22(4): 308-320.

De la Rey, P.A. 2008. Evaluation of the applicability of diatom-based indices as bioindicators of water quality in South African Rivers. Potchefstroom: North-West University (Thesis-PhD).

de Necker, L., Neswiswi, T., Greenfield, R., van Vuren, J., Brendonck, L., Wepener, V. and Smit, N. 2020. Long-term water quality patterns of a flow regulated tropical lowland River. *Water*, 12(1): 37.

DEAP, W.C.I.W.R. 2011. Management (IWRM) Action Plan: Status Quo Report Final Draft. *Provincial Government, Department of Environmental Affairs and Development Planning, South Africa*.

Department of Water Affairs and Forestry. 1996. South African Water Quality Guidelines for freshwater. Edition 2. Volumes 1-7. Pretoria, South Africa.

Department of Water Affairs and Forestry. 1998. National Water Act (Act 36 of 1998). Pretoria, South Africa.

Dlamini, P.V. 2019. *Assessment of the current ecological integrity of the uMngeni River, KwaZulu-Natal, South Africa, using fish community structures and attributes of the Labeobarbus natalensis (Castelnau, 1861) populations.* Durban: University of KwaZulu-Natal (Thesis-PhD).

Du Preez, G.C. 2018. *Nematodes as bioindicators of irrigated soil health in the Crocodile (West) and Marico catchments*. Potchefstroom: North-West University. (Thesis-DPhil).

Du Preez, G.C., Daneel, M.S., Wepener, V. and Fourie, H. 2018. Beneficial nematodes as bioindicators of ecosystem health in irrigated soils. *Applied Soil Ecology*, 132:155-168.

Ebuete, A.W., Ebuete, I.Y., Bisong, A.E., Charles, E.E., Wodu, D.P., Ndiwari, L.E. and Chukuma, O. 2019. Spatial Temporal Water Quality of the Epie Creek in Niger Delta Region of Nigeria, Using Water Quality Index. *Journal of Environmental Science, Toxicology and Food Technology,*13:68-78.

Effendi, H. and Wardiatno, Y. 2015. Water quality status of Ciambulawung River, Banten Province, based on pollution index and NSF-WQI. *Procedia Environmental Sciences*, 24:228-237.

Enoch, C. 2018. *A spatial analysis of the threats to water quality of freshwater ecosystem priority areas in the upper crocodile catchment*. Johannesburg: University of Witswatersrand. (Thesis-PhD).

Ewaid, S.H. and Abed, S.A. 2017. Water quality index for Al-Gharraf River, southern Iraq. *The Egyptian Journal of Aquatic Research*, 43(2):117-122.

Ferahtia, A., Halilat, M.T., Mimeche, F. and Bensaci, E. 2021. Surface water quality assessment in semi-arid region (El Hodna watershed, Algeria) based on water quality index (WQI). *Studia Universitatis Babes-Bolyai, Chemia*, 66(1): 127-142.

Finotti, A.R., Finkler, R., Susin, N. and Schneider, V.E. 2015. Use of water quality index as a tool for urban water resources management. *International Journal of Sustainable Development and Planning*, 10(6):781-794.

Frost and Sullivan. 2010. Eutrophication Research Impact Assessment. WRC Report No. TT 461/10. Water Research Commission, Pretoria, South Africa.

Grattan, S. 2002. *Irrigation water salinity and crop production*. (Vol 9). [ebook] California: UCANR Publications 8066.p. 1-9. Available at: http://anrcatalog.ucdavis.edu Date accessed: 30 March 2021.

Gyamfi, C., Boakye, R., Awuah, E. and Anyemedu, F. 2013. Application of the CCME-WQI model in assessing the water quality of the Aboabo River, Kumasi-Ghana. *Journal of Sustainable Development*, 6(10):1-7.

Havens, K.E. 2008. Cyanobacteria blooms: effects on aquatic ecosystems. Cyanobacterial harmful algal blooms: state of the science and research needs. pp 733-747.

Huizenga, J.M. 2004*. Natural and anthropogenic influences on water quality: an example from Rivers draining the Johannesburg Granite Dome*. Johannesburg: Rand Afrikaans University. (Thesis-PhD).

Hurley, T., Sadiq, R. and Mazumder, A. 2012. Adaptation and evaluation of the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) for use as an effective tool to characterize drinking source water quality. *Water Research*, 46(11):3544-3552.

Ichwana, I., Syahrul, S. and Nelly, W. 2016. Water Quality Index by Using National Sanitation Foundation-Water Quality Index (NSF-WQI) Method at Krueng Tamiang Aceh. pp 110-117.

Kachroud, M., Trolard, F., Kefi, M., Jebari, S. and Bourrié, G. 2019. Water quality indices: Challenges and application limits in the literature. *Water*, 11(2):361.

Kambwiri, A.M., Changadeya, W., Chimphamba, J. and Tandwe, T. 2014. Land use impacts on water quality of Rivers draining from Mulanje Mountain: A case of Ruo River in the Southern Malawi. *Malawi Journal of Science and Technology*, 10(1):15-31.

Kankal, N.C., Indurkar, M.M., Gudadhe, S.K. and Wate, S.R. 2012. Water quality index of surface water bodies of Gujarat, India. *Asian J. Exp. Sci*, 26(1):39-48.

Kent, L.E. 1980. Stratigraphy of South Africa. I: Lithostratigraphy of the Republic of South Africa, Southwest Africa, Namibia and the Republics of Bophuthatswana, Transkei and Venda.

Keraga A.S., Kiflie, Z. and Engida A.N. 2017. Evaluating water quality of Awash River using water quality index. *International Journal of Water Resources and Environmental Engineering,* 9(11):243-53.

Khatri, N. and Tyagi, S. 2015. Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Frontiers in Life Science*, 8(1):23-39.

Khatri, N., Tyagi, S., Rawtani, D. and Tharmavaram, M. 2020. Assessment of River water quality through application of indices: a case study River Sabarmati, Gujarat, India. *Sustainable Water Resources Management*, 6(6):1-11.

Khwakaram, A.I., Majid, S.N. and Hama, N.Y. 2012. Determination of water quality index (WQI) for Qalyasan stream in Sulaimani city/Kurdistan region of Iraq. *International Journal of Plant, Animal and Environmental Sciences*, 2(4):148-157.

Kleynhans, C.J., Louw, M.D., Thirion, C., Rossouw, N.J. and Rowntree, K. 2005. River EcoClassification: Manual for EcoStatus Determination. *Department of Water Affairs and Forestry, Pretoria, South Africa*.

Kleynhans, C.J., Louw, M.D. and Moolman, J. 2007a. Reference frequency of occurrence of fish species in South Africa. *Report produced for the Department of Water Affairs and Forestry (Resource Quality Services) and the Water Research Commission*.

Kleynhans, C.J., Mackenzie, J. and Louw, M.D. 2007b. River EcoClassification: Manual for Ecostatus Determination (Version 2) Module F: Riparian Vegetation Response Assessment Index (VEGRAI). WRC Report No. TT 329/08. *Water Research Commission, Pretoria*.

Lalparmawii, S. and Mishra, B.P. 2012. Seasonal variation in water quality of Tuirial River in vicinity of the hydel project in Mizoram, India. *Sci Vis*, 12:159-163.

Levin, J.C., Woodford, D.J. and Snow, G.C. 2019. Evaluating the effectiveness of freshwater fishes as bio-indicators for urban impacts in the Crocodile (West) catchment, South Africa. *Water SA*, 45(3):477-486.

Lowies, M. 2014. *A comparative study of chemical and physical water quality along the Crocodile River in the Gauteng and North-West Provinces, South Africa*. Johannesburg: University of Johannesburg (Thesis-PhD).

Lumb, A., Halliwell, D. and Sharma, T. 2006. Application of CCME Water Quality Index to monitor water quality: A case study of the Mackenzie River basin, Canada. *Environmental Monitoring and Assessment*, 113(1):411-429.

Mahagamage, M.G.Y.L. and Manage, P.M. 2014. Water quality index (CCME-WQI) based assessment study of water quality in Kelani River basin, Sri Lanka. In *The 1st Environment and Natural Resources International Conference (ENRIC 2014). Mahidol University, Thailand*, (1):199-204.

Mathebula, B. 2015. *Assessment of the surface water quality of the main Rivers feeding at Katse Dam Lesotho*. Pretoria: University of Pretoria. (Thesis-PhD).

Merolla, S. 2011. The Effect of Floods and High Rainfall on the Water Quality in Selected Sub-areas of the Upper Vaal Catchment. Johannesburg: University of Johannesburg. (Thesis-PhD).

Mitchell, V.G. 2004. Integrated Urban Water Management: A review of current Australian practice. *Highett, Vic: CSIRO Manufacturing and Infrastructure Technology*. https://doi.org/10.25919/3bhs-5x02.

Mohseni-bandpey, A., Majlessi, M. and Kazempour, A. 2017. Evaluation of Golgol River water quality in Ilam province based on the National Sanitation Foundation Water Quality Index (NSFWQI). Journal of Health in The Field, 1(4):7-16.

Moshier, S.O.1989. Microporosity in Micritic Limestones: A review. *Sedimentary Geology*, 63(3-4):191-213.

Mosoa, M.W. 2013. *Assessment of approaches to determine the water quality status of South African catchments*. Pretoria: University of Pretoria. (Thesis-PhD).

Mozejko, J., 2012. Detecting and estimating trends of water quality parameters. *Water Quality Monitoring and Assessment*. pp 95-120.

Mujuru, M., Mutanga, S.S. and Dyosi, Z. 2016. The formation of acid mine drainage In: Mutanga, S.S. & Mujuru, M. (eds). *Management and mitigation of acid mine drainage in South Africa: input for mineral beneficiation in Africa*. Pretoria: Africa Institute of South Africa. pp 27-40.

Nalado, A.M., Kamarudin, M.K.A., Wahab, N.A., Rosli, M.H. and Saudi, A.S.M. 2017. Assessment of individual water quality index parameter in Terengganu River, Malaysia. *Journal of Fundamental and Applied Sciences*, 9(2S):430-442.

Namugize, J.N. and Jewitt, G.P.W. 2018. Sensitivity analysis for water quality monitoring frequency in the application of a water quality index for the uMngeni River and its tributaries, KwaZulu-Natal, South Africa. *Water SA*, 44(4):516-527.

Neswiswi, A.B. 2014. *Development of water quality index (WQI) for the Jukskei River catchment, Johannesburg*. Johannesburg: University of the Witwatersrand. (Thesis-PhD).

Nikanorov, A.M. and Brazhnikova, L.V. 2009. Water chemical composition of Rivers, lakes and wetlands. *Types and Properties of Water*, 2:42-80.

Oberholster, P.J. and Ashton, P.J. 2008. State of the nation report: An overview of the status of water quality and eutrophication in South African Rivers and reservoirs. *Parliamentary Grant Deliverable. Pretoria: Council for Scientific and Industrial Research (CSIR)*. *ReaserchGate*:1-15. https://www.researchgate.net/publication/242668373 Date accessed: 5 May 2020.

Oboh, I.P. and Agbala, C.S. 2017. Water quality assessment of the Siluko River, southern Nigeria. *African journal of aquatic science*, 42(3):279-286.

Ololade, O. and Annegarn, H. J. 2013. Contrasting community and corporate perceptions of sustainability: A case study within the platinum mining region of South Africa. Resources Policy, 38(4):568–576.

Packett, R., Dougall, C., Rohde, K. and Noble, R. 2009. Agricultural lands are hot-spots for annual runoff polluting the southern Great Barrier Reef lagoon. *Marine Pollution Bulletin*, 58(7):976-986.

Pollard, S. and Du Toit, D. 2008. Integrated water resource management in complex systems: How the catchment management strategies seek to achieve sustainability and equity in water resources in South Africa. *Water SA*, 34(6):671-679.

Rangeti, I., Dzwairo, B., Barratt, G.J. and Otieno, F.A.O. 2015. Ecosystem-specific water quality indices. *African Journal of Aquatic Science*, 40(3):227-234.

Riemann, K., McGibbon, D.C., Gerstner, K., Scheibert, S., Hoosain, M. and Hay, E.R. 2017. Water Resource Protection: Research Report: A Review of the State-of-the-art and Research and Development Needs for South Africa. Water Research Commission.

Samborska, K., Ulanczyk, R. and Korszun, K. 2012. Monitoring and Modelling of Water Quality. *Water Quality Monitoring and Assessment*. pp 1-602.

Sutadian, A.D., Muttil, N., Yilmaz, A.G. and Perera, B.J.C. 2016. Development of River water quality indices: A review. *Environmental monitoring and assessment*, 188(1):58.

Smith-Adao, L.B., Nel, J.L., Roux, D.J., Schonegevel, L., Hardwick, D., Maree, G., Hill, L., Roux, H., Kleynhans, C.J., Moolman, J. and Thirion, C. 2006. A systematic conservation plan for the freshwater biodiversity of the Crocodile (West) and Marico Water Management Area. *Contract report produced for the Department of Water Affairs and Forestry. CSIR Report No CSIR/NRE/ECO/2006/0133/C. CSIR Natural Resources and the Environment, Pretoria, South Africa.[online] URL: http://www. waternet. co. za/rivercons/docs/full_smith-adao_crocodile-west_marico_wma. pdf*.

Taylor, J.C., van Vuuren, M.J. and Pieterse, A.J.H. 2007. The application and testing of diatom-based indices in the Vaal and Wilge Rivers, South Africa. *Water SA*, 33(1).

Telci, I.T., Nam, K., Guan, J. and Aral, M.M. 2009. Optimal water quality monitoring network design for River systems. *Journal of Environmental Management*, 90(10):2987-2998.

Thirion, C., 2007. Module E: Macro-Invertebrate Response Assessment Index (MIRAI). River EcoClassification manual for EcoStatus determination (Version 2): *Joint Water Research Commission and Department of Water Affairs and Forestry report*.

Tshivhase, N.S. 2019. *Assessment of River health using in situ water quality parameters and MiniSASS protocol in the Marico and Crocodile Rivers, North-West Province, South Africa*. Pretoria: University of Pretoria (Thesis-PhD).

Tyagi, S., Sharma, B., Singh, P. and Dobhal, R. 2013. Water Quality Assessment in terms of Water Quality Index. *American Journal of Water Resources*, 1(3):34-38.

Van Eeden, A. 2017. *Long-term salinity changes in the Crocodile River catchment upstream of Hartebeespoort Dam*. Pretoria: University of Pretoria (Thesis-PhD).

Van Ginkel, C.E. 2011. Eutrophication: Present reality and future challenges for South Africa. *Water SA*, 37(5):693-702.

Venter, J.J., 2013. *An ecological integrity assessment of the lower Amatikulu, Thukela and Umvoti rivers, KwaZulu–Natal, South Africa.* Potchefstroom: North-West University (Thesis-PhD).

Von Bratt, C. 2008. *Biotic responses to alterations in habitat-flow as a result of water abstraction and release in the lower Elands (Mpumalanga) and Mvoti (Kwazulu-Natal) Rivers, South Africa*. Johannesburg: University of Johannesburg (Thesis-MSc).

Wagner, K., Häggström, G., Skoglund, N., Priscak, J., Kuba, M., Öhman, M. and Hofbauer, H. 2019. Layer formation mechanism of K-feldspar in bubbling fluidized bed combustion of phosphorus-lean and phosphorus-rich residual biomass. *Applied energy*, 248:545-554.

Walsh, G.W. and Wepener, V. 2009. The influence of land use on water quality and diatom community structures in urban and agriculturally stressed Rivers. *Water SA*, 35(5):579-594.

Wepener, V.V., Van Dyk, C., Bervoets, L., O'brien, G., Covaci, A. and Cloete, Y. 2011. An assessment of the influence of multiple stressors on the Vaal River, South Africa. *Physics and Chemistry of the Earth, Parts a/b/c*, *36*(14-15):949-962.

World Health Organization. 2011. Guidelines for drinking-water quality. *WHO Chronicle*, 38(4):104-108.

Zandbergen, P.A. and Hall, K.J. 1998. Analysis of the British Columbia Water Quality Index for Watershed Managers: A case study of two small watersheds. *Water Quality Research Journal*, 33(4):519-550.

APPENDICE

1. Average seasonal Water Quality Data per water quality variable per site per year

Site	Date	Ca (mg/l)	Cl (mg/l)	EC	K (mg/l)	Mg (mg/l)	NH_3 (mg/l)	NO_3/NO_2 (mg/l)	pH	PO_4 (mg/l)	SO_4 (mg/l)
90167	1976/02/25	35,4	42,1	55,66666667	4,95	23,33333333		1,02	7,363333333	0,028667	60,7
90167	1976/05/30	29,14	37,08	48,48	4,174	19,14	0,002	1,134	7,422	0,0222	51,52
90167	1976/08/30	40,15454545	45,5636364	63,28181818	3,405454545	27,17272727	0,003454545	2,732727273	7,637272727	0,017	59,83636
90167	1976/11/30	50,43333333	63,6333333	79,6	4,206666667	35,86666667	0,001	3,176666667	7,816666667	0,075	88,73333
90167	1977/05/30	39,9	36,2857143	55,31428571	4,132857143	24	0,000857143	1,455714286	7,382857143	0,042	54,91429
90167	1977/08/30	47,6	54,8818182	71,9	3,014545455	32,98181818	0,006272727	2,274545455	7,668181818	0,081636	75,28182
90167	1977/11/30	42,9	62,55	72,94	3,734	34,4	0,0016	0,656	7,523	0,0394	82,16
90167	1978/02/25	46,65	45,0444444	60,61111111	3,983333333	25	0,000444444	1,044444444	7,33	0,062222	66,88889
90167	1978/05/30	34,84285714	31,0285714	50,26666667	4,112857143	20,6	0,010142857	2,294285714	7,46	0,070286	52,71429
90167	1978/08/30	43,6	41,9	64,6	3,155	30,8	0,0015	3,495	7,45	0,018	64,1
90167	1978/11/30	45,75	62,5	69,8	3,5625	36,7	0,002	1,1675	7,66	0,036	87,025
90167	1978/02/25	44,1	51,2	79,225	3,24	27,7	0,001	0,69	7,48	0,032	77,5
90167	1979/05/30	53,5	77,95	85,25714286	3,335	40,3	0,001	0,46	7,835	0,0845	98,1
90167	1979/08/30	42,1	76	81,18181818	3,31	41,4	0	0,07	7,85	0,046	102,1
90167	1979/11/30			75,31111111	4,743333333						
90167	1980/02/25	40,2	46,7333333	60,83076923		26,1		4,75	7,253333333	0,135667	77,06667
90167	1980/05/30	44,35	55,8	67,71538462	4,455	28,75	0,0005	0,265	7,425	0,094	69,4
90167	1980/08/30	47,36666667	84,5333333	87,26666667	3,776666667	40,83333333	0,001	0,803333333	7,43	0,017	109,0333
90167	1980/11/30	56,85	96,6	87,8875	4,53	42,65	0	0,62	7,415	0,0375	112,9
90167	1981/02/25	51,05	58	68,4	5,18	31,05	0,0005	0,855	7,415	0,0445	82,2
90167	1981/05/30	49,325	58,975	70,29230769	5,15	29,9	0,00025	1,24	7,185	0,1835	85,975
90167	1981/08/30	58,56666667	85,2666667	92,6	4,133333333	41,56666667	0,000333333	1,706666667	7,613333333	0,118667	116,9
90167	1981/11/30	59,3	74,6	85,73636364	4,573333333	38,1	0,000666667	0,803333333	7,446666667	0,114	108,5333

90167	1982/02/25	51,13333333	67,8333333	74,70769231	5,486666667	30-Jan	00-Jan	0,853333333	7,653333333	0,197	94,33333
River 90167	1982/05/30	55,625	67,825	78,38461538	5,5425	02-Feb	00-Jan	1,085	7,8475	0,25775	104,875
90167	1982/08/30	60,13333333	76,8	85,02307692	5,133333333	05-Feb	00-Jan	1,253333333	7,963333333	0,292	112,9333
90167	1982/11/30	57,2	68	83,28181818	6,29	32,8	0,003	0,76	7,96	0,21	104,7
90167	1983/02/25	49,65	63,6	79,33333333	6,995	29,9	0,0035	0,695	8,285	0,349	100,4
90167	1983/05/30	60,63333333	83,3333333	87,14615385	5,823333333	05-Feb	00-Jan	0,84	7,8375	0,187667	123,4333
90167	1983/08/30	62,2	100,45	100,85	4,82	10-Feb	00-Jan	0,41	7,98	0,1115	123,35
90167	1984/05/30	62,5	117,3	113,7	6,57	18-Feb	00-Jan	0,02	8,15	0,015	148,6
90167	1984/08/30	64,5	135,75	114,1	6,16	44,8	0,0055	0,125	8,24	0,0355	162,55
90167	1984/11/30	56,82	100,12	96,14	7,946	38,34	0,0034	0,184	8,196	0,094	137,1
90167	1985/02/25	46,5	92,2	92,06	7,584	01-Feb	0,0176	0,07	8,406	0,0216	100,14
90167	1985/05/30	49,05	64,35	70,35	5,495	25-Jan	0,005	0,135	8,1	0,0105	80,65
90167	1985/08/30	52,25	80,9	84,5	5,6	29-Jan	0,001	0,125	7,485	0,023	80,4
90167	1985/11/30	38,68333333	63,5833333	63,75	6,718333333	21,95	0,0115	0,315	8,1	0,024	96,25
90167	1986/02/25	43,3	72,825	77,625	7,0475	26,775	0,0085	0,12	8,275	0,003	98,975
90167	1986/05/30	38,8	65	68	8,86	20,6	0,013	0,38	8,2	0,007	103,5
90167	1987/02/25	38,8	54	60,25	6,485	20,7	0,0055	0,33	7,84	0,038	81,2
90167	1990/02/25	32,05	88,3	69,2	8,315	30,7	0,014	0,0565	8,65	0,0065	103,85
90167	1992/11/30	48,08461538	104,1	92,15384615	9,926923077	37,58461538	0,019384615	0,162615385	8,383846154	0,020154	134,3231
90167	1993/02/25	46,28461538		90,37692308	9,16	34,49230769	0,019923077	0,256153846	8,308461538	0,030462	134,6846
90167	1993/05/30	49,1625		92,4	8,7375	37,4625	0,00875	0,143625	8,14625	0,027	139,5
90167	1993/08/30	56,73333333	110,9	101,2833333	8,51	35,95	0,008	0,3585	8,02	0,030667	131,7667
90167	1993/11/30	45,57142857	85,7857143	80,18571429	8,741666667	28,94285714	0,010428571	0,391142857	7,968571429	0,028429	114,1571
90167	1994/02/25	49,26666667	93,8333333	81,71666667	7,948333333	30,3	0,005333333	0,305	7,981666667	0,035667	115,55
90167	1994/05/30	51,91428571	80,2571429	77,38571429	8,694285714	28,34285714	0,011142857	0,453285714	8,144285714	0,065143	102,0143
90167	1994/08/30	53,5	87,2142857	82,84285714	8,965714286	31,35714286	0,013	0,381714286	8,414285714	0,032429	113,4

90167	1994/11/30	48,0166667	88,6833333	78,98333333	9,151666667	30,88333333	0,024166667	0,297	8,36	0,023833	108,35
90167	1995/02/25	38,6166667	76,1833333	71,81666667	8,61	27,01666667	0,010666667	0,242333333	8,133333333	0,0305	97,88333
90167	1995/05/30	48,7	97,5571429	81,12857143	8,067142857	29,2	0,008857143	0,373285714	8,165714286	0,034	102,6286
90167	1995/08/30	50,55714286	87,7857143	80,38571429	8,174285714	29,75714286	0,012	0,372285714	8,218571429	0,022857	116,3857
90167	1995/11/30	42,76666667	91,0833333	80,46666667	8,551666667	29,43333333	0,012	0,2755	8,158333333	0,042	113,3167
90167	1996/02/25	35,58571429	64,7	60,5	7,491428571	18,6	0,004	0,621428571	8,068571429	0,039143	76,25714
90167	1996/05/30	37,91666667	53,55	53,28333333	6,37	18	0,018166667	0,9735	8,22	0,0665	64,45
90167	1996/08/30	47,41428571	63,8714286	66,9	6,357142857	24,58571429	0,017	1,090571429	8,32	0,035286	79,24286
90167	1996/11/30	44,18333333	62,1	65,31666667	5,975	24,15	0,025166667	0,252666667	8,251666667	0,027	69,48333
90167	1997/02/25	36,97142857	58,4142857	57,71428571	6,38	21,94285714	0,015571429	0,371571429	8,144285714	0,028429	65,97143
90167	1997/05/30	33,96666667	44,1666667	47,85	5,273333333	16,98333333	0,007333333	1,649166667	8,258333333	0,068667	53,76667
90167	1997/08/30	44,05	49,3125	54,675	4,635	22,8125	0,01175	1,822875	8,29125	0,017375	56,6125
90167	1997/11/30	45,1	56,2166667	63,43333333	5,301666667	25,21666667	0,0235	1,1535	8,256666667	0,026667	71,18333
90167	1998/02/25	41,64285714	49,8	58,44285714	5,407142857	25,68571429	0,018	0,721714286	8,22	0,024	62,04286
90167	1998/05/30	37,97142857	63,2285714	63,04285714	6,85	26,04285714	0,016714286	0,432285714	8,194285714	0,026857	73,02857
90167	1998/08/30	40,25	66,9833333	68,53333333	6,598571429	28,2	0,014166667	0,37	8,311666667	0,023833	84,55
90167	1998/11/30	41,0375	72,4	71,55	6,72	29,5	0,017	0,387125	8,27125	0,024625	87,3125
90167	1999/02/25	34,28571429	57,2571429	59,07142857	6,987142857	21,85714286	0,019571429	0,544142857	8,182857143	0,026571	70
90167	1999/05/30	36,68571429	65,3714286	65,02857143	7,04	25,41428571	0,018428571	0,519857143	8,292857143	0,03	76,78571
90167	1999/08/30	36,25	68,05	67,5	7,113333333	25,88333333	0,0215	0,573166667	8,345	0,0215	81,91667

90167	1999/11/30	35,16757143	71,5231429	69,75714286	7,367	27,10914286	0,024142857	0,193142857	8,327857143	0,026286	86,626
90167	2000/02/25	30,0565	62,4643333	61,43333333	7,326333333	22,30233333	0,044666667	0,507666667	8,299	0,049167	66,861
90167	2000/05/30	33,839	40,0462857	49,94285714	5,828285714	17,24171429	0,014	1,191714286	8,247571429	0,037714	56,16414
90167	2000/08/30	43,61242857	50,1775714	61,54285714	5,558142857	23,77457143	0,029714286	1,620285714	8,372285714	0,025857	68,54057
90167	2000/11/30	42,896	53,2956	62,62	5,9644	25,5398	0,016	1,0568	8,2896	0,0242	71,0988
90167	2000/02/25	33,08814286	52,9901429	57,67142857	6,564714286	24,46157143	0,031	0,538285714	8,253857143	0,036143	68,82243
90167	2001/05/30	31,52433333	55,1161667	57,48333333	6,9325	23,9385	0,02	0,434833333	8,271333333	0,138167	64,619
90167	2001/08/30	35,33066667	58,5101667	61,93333333	6,654666667	26,56166667	0,026833333	0,4755	8,359	0,058	72,404
90167	2001/11/30	33,9685	61,2735	64,66666667	7,243166667	28,095	0,033	0,289	7,695833333	0,025833	68,79017
90167	2002/02/25	30,82185714	58,3435714	58,67142857	7,337714286	23,76114286	0,031	0,303857143	8,269714286	0,027714	61,97286
90167	2002/05/30	29,803	62,341	60,01666667	7,789166667	25,2985	0,013666667	0,080333333	8,308166667	0,024667	63,36683
90167	2002/08/30	37,275875	70,428875	67,8375	7,532375	28,251125	0,018375	0,40425	8,34125	0,020875	79,0195
90167	2002/11/30	37,88166667	70,569	69,51666667	8,513	27,69266667	0,026	0,1555	8,266	0,0255	74,02367
90167	2003/02/25	32,59285714	76,4295714	69,7	7,421571429	28,77057143	0,017142857	0,324857143	8,223857143	0,026143	77,77771
90167	2003/05/30	31,14883333	78,601	71,23333333	8,210666667	30,206	0,0095	0,151666667	8,162666667	0,031	80,31683
90167	2003/08/30	34,26475	89,742	78,6375	8,434875	32,473	0,007125	0,153	8,304	0,020125	92,1005
90167	2003/11/30	38,43983333	94,7918333	82,36666667	8,947166667	32,7135	0,004166667	0,146166667	8,148833333	0,037667	95,32133
90167	2004/02/25	39,71442857	102,164714	86,31428571	9,495285714	31,601	0,003571429	0,406428571	7,948857143	0,026571	114,9169
90167	2004/05/30	40,5955	66,0645	66,46666667	8,709333333	22,57883333	0,002333333	0,561333333	7,925333333	0,0315	75,39367
90167	2004/08/30	38,68585714	68,8148571	68,22857143	8,597142857	23,65057143	0,018285714	0,236428571	8,156142857	0,028429	77,80857
90167	2004/11/30	33,66466667	72,9355	67,73333333	8,732166667	24,28533333	0,006333333	0,055	8,044333333	0,017833	74,36783

90167	2005/02/25	33,648	80,0307143	68,67142857	9,285857143	24,23671429	0,019857143	0,218857143	7,994285714	0,031571	68,58286
90167	2005/05/30	32,6026667	73,541	66,03333333	8,863666667	22,94933333	0,011666667	0,307333333	8,022833333	0,029167	64,47117
90167	2005/08/30	35,30885714	75,6344286	69,44285714	8,964714286	24,63871429	0,018	0,204714286	8,104571429	0,022857	69,58514
90167	2005/11/30	30,72214286	81,4625714	70,88571429	9,162428571	26,33557143	0,007428571	0,064714286	8,124285714	0,025857	73,77914
90167	2006/02/25	30,51816667	79,8292857	67,2	9,0405	24,61	0,008666667	0,1515	8,02	0,0285	71,86783
90167	2006/05/30	33,878	61,2975714	57,08571429	7,601428571	18,93928571	0,009571429	0,606571429	7,802428571	0,049143	58,128
90167	2006/08/30	37,8855	63,4123333	62,18333333	7,512666667	22,48733333	0,025166667	0,527833333	8,162	0,0235	69,0335
90167	2006/11/30	35,42114286	64,4924286	62,25714286	7,474857143	23,13871429	0,024571429	0,120285714	8,112571429	0,040571	64,06114
90167	2007/02/25	32,8386	68,8814	62,22	8,5498	21,7122	0,022	0,12	8,2068	0,1034	58,3556
90167	2007/05/30	33,31428571	76,6828571	67,71428571	9,163	24,96842857	0,013857143	0,280714286	8,211571429	0,035714	63,997
90167	2007/08/30	35,11883333	83,2601667	73,35	9,2685	25,91416667	0,0155	0,428666667	8,1675	0,024833	72,6665
90167	2007/11/30	40,23314286	87,1997143	73,45714286	8,913428571	25,52142857	0,032857143	0,748142857	8,117428571	0,064	76,26757
90167	2008/02/25	34,57333333	71,9915	62,43333333	8,567166667	20,20533333	0,024	0,544666667	8,102666667	0,139167	61,22267
90167	2008/05/30	36,0865	62,3654286	57,41428571	7,8175	19,45166667	0,040857143	0,934428571	8,096571429	0,149714	58,719
90167	2008/08/30	40,3075	65,2175	63,51666667	7,121	23,5005	0,028333333	1,114333333	8,269833333	0,031667	69,2035
90167	2008/11/30	36,88357143	71,5762857	63,1	6,000714286	32,89071429	0,035285714		8,188571429	0,063857	68,04043
90167	2009/02/25	40,61128571	77,1112857	63,35714286	7,805571429	25,87357143	0,057571429	1,047	8,168857143	0,191	64,26714
90167	2009/05/30	39,6308	65,0212	61,22	7,1016	21,7382	0,0332	1,189	8,2394	0,1376	58,4458
90167	2009/08/30	38,35333333	68,2653333	62,16666667	7,487333333	21,58333333	0,017666667	0,743666667	8,141666667	0,005	66,71633
90167	2009/11/30	42,863	71,3716	67,83333333	7,388833333	25,75516667	0,029833333	1,5165	8,2735	0,025167	67,1134
90167	2010/02/25	34,49316667	60,7103333	58,15	7,438333333	20,19933333	0,055	1,004	8,280666667	0,213	54,60767

90167	2010/05/30	38,0395	63,1058333	57,97142857	6,576285714	21,64433333	0,017333333	1,405833333	7,971857143	0,104167	54,97733
90167	2010/08/30	45,03385714	74,2397143	67,8	6,592428571	24,115	0,015142857	2,126285714	7,908714286	0,027286	71,70629
90167	2010/11/30	38,0085	70,813	65,5	6,392666667	26,009	0,038666667	0,2065	8,150166667	0,0825	64,498
90167	2011/02/25	32,82983333	64,857	58,5	6,600333333	22,325	0,0105	0,918333333	8,0725	0,1305	56,18467
90167	2011/05/30	38,22442857	70,8905714	61,22	6,043714286	23,91385714	0,0028	1,897428571	7,928142857	0,044286	58,83843
90167	2011/08/30	46,25614286	75,8642857	72,36666667	6,427857143	26,609	0,0025	2,569285714	8,024571429	0,020857	81,77129
90167	2011/11/30	41,7326	82,1144	70,24	6,625375	27,8824	0,001	1,259	7,8054	0,033	78,03225
90167	2012/02/25	33,1048	68,7155	64,93333333	7,579333333	21,2515	0,001	1,033333333	7,733666667	0,108333	66,10733
90167	2012/05/30	34,5655	63,9985	63,6	7,357166667	21,71566667	0,023333333	0,897833333	8,029666667	0,06	58,72167
90167	2012/08/30	38,45771429	67,356	69,61428571	7,170714286	23,88366667	0,04	1,558571429	8,362857143	0,024571	66,46686
90167	2012/11/30	40,76016667	63,3136667	66,9	7,806	22,5666	0,017333333	1,5775	8,436	0,040167	65,77933
90167	2013/02/25	29,50085714	56,8734286	57,7	7,384857143	20,112	0,045714286	0,608285714	8,261	0,089143	55,74971
90167	2013/05/30	33,02766667	52,372	58,81666667	7,2565	19,29016667	0,049166667	1,457	8,35	0,051667	56,25367
90167	2013/08/30	38,56957143	56,5441429	62,59614286	7,455857143	20,89257143	0,037857143	1,782857143	8,163571429	0,015286	61,35571
90167	2013/11/30	29,108	62,0098333	60,58483333	7,332	22,90583333	0,016666667	0,357666667	7,999	0,0235	62,3375
90167	2014/02/25	29,7075	52,1703333	53,93	8,01	18,35083333	0,051666667	1,043833333	8,3045	0,085	56,99483
90167	2014/05/30	38,58483333	52,335	57,16666667		18,13433333	0,011666667	2,541833333	8,312666667	0,059167	62,23883
90167	2014/08/30	47,89333333	66,8933333	70,31666667		26,35066667	0,030166667	3,399166667	8,373166667	0,0215	75,44283
90167	2014/11/30	48,10466667	71,4668	72,03333333		26,3124	0,042166667	2,870666667	8,369	0,024833	81,72333
90167	2015/02/25	35,03266667	64,7311667	64,71666667	8,794	24,318	0,051666667	1,439666667	8,243166667	0,153167	74,868
90167	2015/05/30	36,04433333	62,9201667	63,41666667	8,204666667	20,01583333	0,045833333	1,583333333	8,3185	0,142167	72,2328

90167	2015/08/30	40,437	64,7711429	67,95714286	8,361285714	25,8542	0,016142857	1,660142857	8,304571429	0,127571	78,70657
90167	2015/11/30	36,38716667	69,6285	67,58333333	8,17	28,08166667	0,013833333	0,975833333	8,127	0,0835	78,1916
90167	2016/02/25	32,08025	73,4705	69,8	9,43925	27,291	0,007	0,7395	8,18375	0,109	81,09725
90167	2016/05/30	37,5	56,25	59,7	9,3	22,25	0,0135	1,811	8,75	0,333	65,2
90167	2016/11/30	35,3	52,9333333	55	7,833333333	18	0,038	1,178666667	8,4	0,173333	72,63333
90167	2017/05/30	46,94285714	54,3	59,3	7,314285714	20,7	0,059571429	2,131714286	8,371428571	0,163429	73,54286
90167	2017/08/30	46,46	65,1	71,5	7,233333333	23,78	0,0155	2,738333333	8,3	0,0925	78,025
90167	2017/11/30	51,7	70,975	70,76	7,78	26,175	0,0446	2,3896	8,48	0,1132	105,65
90167	2018/02/25	40,86666667	71,7	68,75	7,933333333	21,43333333	0,063333333	1,241833333	8,4	0,336667	83,36
90167	2018/05/30	42,2	65,25175	65,71666667	9,366666667	21,2	0,054166667	1,634666667	8,499166667	0,250667	81,52875
90194	30/05 1979	25,825	31,88	7,668	46,84	14,72	0	3,224	7,348	2,8612	54,4
90194	1979/08/30	26,8	31,65	7,15	46	15,75	0	3,785	7,255	3,142	53,9
90194	1979/11/30	22,075	22,45	5,57	36,35	11,925	0,00025	0,9825	7,055	1,2185	51,125
90194	1980/02/25	17,91818182	15,8090909	3,886363636	27,88181818	11,21818182	9,09E-05	3,935454545	6,963636364	0,470182	34,82727
90194	1980/05/30	21,45833333	22,9916667	5,0525	35,16666667	12,525	8,33E-05	0,615	6,918333333	1,947667	38,01667
90194	1980/08/30	30,02	37,43	7,065	51,04	16,02	0,0003	0,796	7,273	2,8464	70,93
90194	1980/11/30	30,58461538	53,6	9,793846154	58,90769231	15,68461538	7,69E-05	0,473076923	7,203846154	3,052615	71,32308
90194	1981/02/25	21,03333333	30,3	5,884444444	39,64545455	11,94444444	0,000222222	0,576666667	6,631111111	1,302667	45,15556
90194	1981/05/30	19,1	21,5333333	4,126666667	36,8	12,96666667	0	0,62	6,506666667	0,930667	34,96667
90194	1981/08/30	26,4	38,8	6,505	46,99090909	15,55	0	0,435	6,9	2,338	64,425
90194	1981/11/30	29,75	50	9,09	39,57	16,1	0	0,91	7,05	2,8535	76,9
90194	1982/02/25	26,13333333	46,4666667	9,356666667	39,14444444	12,23333333	0	2,626666667	7,18	2,569333	56,4
90194	1982/05/30	23,875	48,8	8,5825	44,37	11,7	0,00125	2,2725	7,4025	3,625	52,35
90194	1982/08/30	31,56666667	51,4333333	10,08	54,38571429	15,13333333	0,000333333	1,843333333	7,513333333	5,157667	79,63333
90194	1982/11/30	28,3	48,1	9,29	56,21818182	13,2	0	1,47	7,3	4,728	61,5

90194	1983/02/25	26,5	49,85	12,445	43,56666667	11,35	0,0005	1,086666667	7,473333333	4,581	60,1
90194	1983/05/30	28,775	59,3	13,2575	63,60714286	11,125	0,00025	3,22	7,1825	6,165	70,575
90194	1983/08/30	31,46666667	74,23333333	14,08	72,72307692	15,06666667	0	4,29	7,22	5,617	98,53333
90194	1983/11/30	28,3	68,06666667	14,57333333	68,31428571	13,46666667	0,001	2,706666667	7,45	3,095333	84,73333
90194	1984/02/25	23,825	46,3	10,6225	49	10,35	0,0135	1,4075	7,6425	3,5165	68,95
90194	1984/05/30	22,85	54,76666667	10,605	46,63333333	6,5	0,0005	6,185	7,18	11,214	54,7
90194	1984/08/30	34,1	55,7	13,4	59,8	10,1	0,002	2,93	7,26	5,228	99,8
90194	1984/11/30	25,8	47	11,325	48,4	7,2	0,005	1,39	7,905	4,185	48,45
90194	1985/02/25	21,65	32,5	7,365	31,25	6,75	0,002	1,045	7,605	3,0605	40,2
90194	1985/05/30	35,35	62,65	13,745	62,96666667	10,75	0,0015	5	7,51	3,0565	130,1
90194	1985/08/30	38,25	69,95	16,09	73	8,6	0,0035	6,88	8,015	6,4525	81,1
90194	1985/11/30	33,9	56,9	14,67	50,46666667	6,6	0,002	2,86	7,7	1,675	148,5
90194	1986/02/25	34,2	59,3	7,51	55,1	6,7	0,002	1,715	7,3	0,2015	137,35
90194	1986/05/30	33,65	48,95	12,02	50,9	8,3	0,001	5,51	6,85	0,0355	116,95
90194	1986/08/30	30,6	52,66666667	13,58666667	61,16666667	5,7	0,000666667	10,15666667	7	0,032667	116,8
90194	1986/11/30	29,06666667	44,23333333	11,78666667	51,9	5,266666667	0,001	4,913333333	7,336666667	0,075667	81,8
90194	1987/02/25	14,1	18,8	4,68	22,36666667	6,033333333	0,000666667	1,606666667	6,77	0,057667	27,7
90194	1987/05/30	24,275	32,65	7,075	42,225	10,575	0,001	3,255	7,23	0,11775	60,525
90194	1987/08/30	28,73333333	46,43333333	11,29	57,36666667	9,5	0,002	7,42	6,76	0,209333	87,86667
90194	1987/11/30	26,06666667	35,53333333	8,243333333	42,5	10,46666667	0,003	1,66	7,266666667	0,227667	56,46667
90194	1988/02/25	20,03333333	27,83333333	6,44	34,5	7,633333333	0,000666667	0,573333333	7,126666667	1,039333	35,1
90194	1988/05/30	27,96	45,42	7,91	48,22	13,24	0,0014	2,4	7,304	1,7894	48,72
90194	1988/08/30	33,35	50,05	9,865	55,25	10,1	0,0015	1,89	7,625	0,0545	67,15
90194	1988/11/30	29,7	53,36666667	10,50333333	54,16666667	7,533333333	0,001666667	4,543333333	7,186666667	0,293333	57,33333
90194	1989/02/25	19,85	27,075	6,72	33,7	8,475	0,0005	3,3225	7,0675	0,134	35,65
90194	1989/05/30	23,36666667	31,16666667	6,343333333	38,23333333	9,3	0,002666667	3,643333333	7,506666667	0,033	32,96667
90194	1989/08/30	31,06666667	45,83333333	9,173333333	50,4	10,1	0,009	7,576666667	8,28	0,108333	58,8

90194	1989/11/30	29,75	55,775	10,2825	51,8	10,325	0,01875	3,305	8,485	0,21375	58,175
90194	1990/02/25	21,85	31,825	7,865	36,9	8,725	0,005	2,27275	7,8475	0,176	47,5
90194	1990/05/30	24,16666667	34,6666667	9,975	38,1	8,366666667	0,001666667	4,953333333	7,753333333	0,542333	66,2
90194	1990/08/30	29,66666667	50,1333333	10,91333333	48,06666667	9,166666667	0,004	9,394666667	7,843333333	0,153667	82,3
90194	1990/11/30	23,425	35,9	8,955	40,925	9	0,00175	2,69	7,9025	0,075	56,2
90194	1991/02/25	20,675	30,3	9,0475	38,675	7,85	0,00125	5,26375	7,6875	0,10125	65,45
90194	1991/05/30	23,5	35,8333333	8,43	42	11,33333333	0,002	5,907	7,87	1,975	47,6
90194	1991/08/30	30,73333333	50,8666667	11,33	53,66666667	11,73333333	0,001	8,302333333	7,513333333	0,157333	92,73333
90194	1991/11/30	29,33333333	54	14,18333333	63,26666667	10,26666667	0,003	2,261666667	8,14	0,986333	97,83333
90194	1992/02/25	20,925	34,875	10,96	45,325	7,95	0,07325	2,93875	8,005	0,4495	51,925
90194	1992/05/30	25,6	49,1	15,14666667	63,4	8,166666667	0,241	5,885	7,933333333	0,312	76,4
90194	1992/08/30	27,16666667	50,6	14,11833333	62,66666667	8,3	0,01633333	10,02733333	8,03	0,333333	51,43333
90194	1992/11/30	25,2	48,4	12,35	55,1	7,7	0,006666667	3,837	8,156666667	0,847333	45,3
90194	1993/02/25	23,23333333	31,7333333	10,09	39,2	6,333333333	0,006666667	5,116	7,79	1,75	53,86667
90194	1993/05/30	29,36666667	39,5666667	11,81333333	48,9	5,033333333	0,003333333	7,810333333	7,83	1,004333	81,5
90194	1993/08/30	32,56666667	43,6	12,81333333	55,23333333	4	0,001333333	13,57433333	7,516666667	0,654333	76,9
90194	1993/11/30	25,14545455	37,1272727	8,004545455	36,85454545	6,690909091	0,005272727	3,915545455	7,489090909	0,483091	34,12727
90194	1994/02/25	21,06153846	33	6,989230769	32,3	6,415384615	0,003307692	3,007923077	7,688461538	0,213923	26,31538
90194	1994/05/30	28,5	48,75	9,124615385	43,89230769	8,238461538	0,003538462	3,567846154	7,934615385	0,209462	30,3
90194	1994/08/30	34,61538462	60,6571429	11,07538462	52,57692308	7,184615385	0,004	6,288076923	8,033076923	0,400692	38,70769
90194	1994/11/30	34,26153846	49,8307692	8,004545455	48,15384615	6,515384615	0,006076923	2,280384615	8,048461538	0,239769	35,43846
90194	1995/02/25	26,275	52,075	6,989230769	43,51666667	7,733333333	0,005333333	2,7375	7,903333333	1,373	34,75833
90194	1995/05/30	25,40769231	48,9615385	9,124615385	40,06923077	7,307692308	0,004307692	2,9955	7,823846154	0,162385	29,38462

90194	1995/08/30	31	68	11,07538462	50,925	7,625	0,002833333	5,684461538	7,9175	0,396833	32,29167
90194	1995/11/30	27,26923077	70,4230769	10,67769231	50,39230769	6,292307692	0,003153846	3,614615385	7,81	0,325	29,47692
90194	1996/02/25	22,64615385	24,8307692	11,02833333	31,44615385	10,36923077	0,001692308	1,722692308	7,913076923	0,132769	29,19231
90194	1996/05/30	25,15	27,2714286	8,510769231	35,4	12,99285714	0,005142857	1,821857143	8,112857143	0,080857	23,22143
90194	1996/08/30	30,27692308	39,2615385	10,74666667	44,10769231	11,57692308	0,003461538	2,633461538	8,084615385	0,124846	28,49231
90194	1996/11/30	32,03846154	52,4	10,32615385	47,92307692	9,961538462	0,005692308	2,095	8,019230769	0,198	31,35385
90194	1997/02/25	23,9	34,6785714	5,964285714	34,25714286	9,621428571	0,003642857	1,411785714	8,019285714	0,153071	23,75714
90194	1997/05/30	21,68461538	24,6230769	4,477692308	33,97692308	14,01538462	0,005538462	1,984153846	8,017692308	0,122154	26,62308
90194	1997/08/30	24,85384615	32,0076923	4,863846154	38,83076923	15,80769231	0,005384615	2,134846154	8,019230769	0,112923	29,13077
90194	1997/11/30	25,63333333	38,6333333	6,436666667	41,64166667	14,00833333	0,009833333	1,79475	8,015	0,425583	27,73333
90194	1998/02/25	22,20769231	33,4923077	5,833846154	35,38461538	11,31538462	0,004615385	1,969230769	8	0,180154	27,61538
90194	1998/05/30	23,65	48,7416667	6,9275	41,375	13,59166667	0,00275	2,992833333	7,936666667	0,08	26,34167
90194	1998/08/30	26,55714286	63,6428571	8,728571429	50,87142857	13,72857143	0,006285714	4,578	7,987142857	0,140857	34,87857
90194	1998/11/30	25,78181818	66,6	9,312727273	47,89090909	12,09090909	0,003363636	3,137818182	7,906363636	0,142364	35,61818
90194	1999/02/25	20,26363636	31,25	5,952727273	33,71818182	10,63636364	0,002818182	2,155181818	7,924545455	0,219455	24,3
90194	1999/05/30	23,11357143	51,1655714	7,391	42,78571429	11,09878571	0,002142857	3,464642857	7,9585	0,1275	27,435
90194	1999/08/30	23,83846154	57,4923077	9,04	48,87692308	12,17692308	0,004153846	4,091076923	8,09	0,295231	32,31538
90194	1999/11/30	23,48533333	54,94825	8,110916667	47,675	9,731333333	0,004166667	2,198333333	7,957	0,163917	33,86117
90194	2000/02/25	20,957	32,3932857	5,765	35,67142857	9,9015	0,003	1,899428571	7,913785714	0,250429	26,4925
90194	2000/05/30	24,1577	28,1055385	4,559692308	37,60769231	13,38469231	0,011153846	3,013538462	8,136	0,107615	25,88846

		6923									
90194	2000/08/30	28,19416667	36,5769167	5,644916667	43	11,60741667	0,002583333	2,0925	8,13775	0,095	25,7035
90194	2000/11/30	26,69761538	41,4672308	7,185692308	41,38461538	11,748	0,004692308	2,363230769	7,877153846	0,381615	25,76923
90194	2001/02/25	22,46	37,1000769	5,805461538	36,87692308	12,04676923	0,004230769	1,508076923	7,953153846	0,228846	24,36015
90194	2001/05/30	21,88223077	33,9464615	5,722846154	36,99230769	12,58223077	0,011846154	2,879076923	7,917384615	0,268154	22,86908
90194	2001/08/30	24,81827273	51,7877273	7,097363636	44,97272727	14,04518182	0,003727273	4,157	7,996090909	0,253182	26,49645
90194	2001/11/30	21,62676923	43,3442308	7,463615385	42,07692308	14,84230769	0,014692308	3,216923077	7,994615385	0,145231	27,60469
90194	2002/02/25	23,48584615	33,5279231	5,746307692	35,81538462	11,01207692	0,01	2,443384615	8,012076923	0,058769	20,80385
90194	2002/05/30	24,65425	36,2002	7,1342	77,43076923	9,767	0,003	4,363615385	7,969384615	0,194769	25,077
90194	2002/08/30		45,905	8,514666667	45,73333333	11,51333333	0,008416667	4,81625	7,9805	0,175	30,50067
90194	2002/11/30	21,10633333	38,6516667	7,977333333	48,6	8,483666667	0,005428571	2,987	7,963071429	0,2625	26,29167
90194	2003/02/25	20,2575	30,3795	6,3545	41,43846154	7,84025	0,001538462	2,673307692	7,762692308	0,132333	27,4405
90194	2003/05/30	25,21133333	58,1463333	10,07566667	49,28461538	7,193666667	0,001461538	3,030153846	7,769538462	0,212875	34,478
90194	2003/08/30	26,56833333	59,9226667	10,80933333	51,75384615	9,286	0,001230769	3,672692308	7,824	0,235385	37,32267
90194	2003/11/30	28,02766667	64,4723333	12,13066667	51,33846154	7,963	0,001384615	2,264230769	7,592692308	0,226615	37,977
90194	2004/02/25	25,27925	52,401125	9,145875	43,02307692	7,9275	0,000769231	3,350615385	7,737384615	0,137769	28,85125
90194	2004/05/30	24,91825	37,061	6,872	39,4375	9,068375	0,00075	2,87	7,761375	0,120375	26,12538
90194	2004/08/30	28,82557143	44,0004286	7,447142857	46,9	10,19571429	0,002857143	2,882142857	7,844428571	0,095429	34,89275
90194	2004/11/30	30,58383333	65,408	10,867	54,58333333	7,424833333	0,003	2,715833333	7,7075	0,140333	37,1642
90194	2005/02/25	24,36557143	37,9595714	7,662285714	38,7	7,452428571	0,003571429	2,831142857	7,786307692	0,107571	24,43129
90194	2005/05/30	26,5323	33,1856667	6,405333333	37,91666667	8,0565	0,003333333	2,564166667	7,825285714	0,066333	27,60333

		3333									
90194	2005/08/30	27,67357143	62,8394286	9,017714286	51,85714286	9,620142857	0,184571429	2,068	7,872285714	0,087571	29,36686
90194	2005/11/30	31,2635	47,8726667	9,9055	48,85	7,414166667	0,031833333	1,7105	7,899333333	0,1955	30,75183
90194	2006/02/25	25,11314286	30,9215714	6,994714286	37,52857143	8,216571429	0,002714286	3,142142857	7,650285714	0,202429	25,05571
90194	2006/05/30	29,65966667	31,5133333	5,576666667	38,5	11,0005	0,004333333	3,390333333	7,776833333	0,075667	26,24067
90194	2006/08/30	34,57457143	42,2024286	7,391285714	46,51428571	9,780142857	0,004714286	2,881428571	7,871714286	0,157857	29,67614
90194	2006/11/30	33,02266667	43,306	7,875333333	44,15	8,806333333	0,017166667	2,663166667	7,930666667	0,3195	32,28967
90194	2007/02/25	24,27033333	28,1608333	6,213333333	35,91666667	8,592666667	0,012666667	2,075	8,000666667	0,16	23,883
90194	2007/05/30	26,431	42,9218333	9,336	44,98333333	8,706333333	0,006166667	2,349833333	7,887	0,1045	33,85383
90194	2007/08/30	24,938	40,7532857	7,726285714	46,9	10,04185714	0,004285714	2,188	7,939857143	0,305714	32,35483
90194	2007/11/30	27,33116667	47,1206	7,719333333	45,21666667	9,099166667	0,0065	3,160666667	7,815333333	0,1725	36,8495
90194	2008/02/25	26,22142857	33,9577143	6,044857143	39,94285714	10,97457143	0,003142857	3,131285714	7,526714286	0,083286	29,78971
90194	2008/05/30	25,967	32,7838333	5,801	40,41666667	11,69666667	0,005333333	2,656166667	7,819833333	0,097833	25,06117
90194	2008/08/30	26,1292	41,5755714	7,2804	44,31666667	11,8722	0,0046	3,1322	7,932833333	0,0906	37,81186
90194	2008/11/30	29,7226	55,4714	7,2524	48,4	12,5394	0,01175	2,3	7,8564	0,2048	40,3396
90194	2009/02/25	27,9425	40,4735	5,413333333	39,51666667	13,21183333	0,018166667	4,008	7,9625	0,191333	26,84733
90194	2009/05/30	26,749	46,2493333	6,3	43,55	11,611	0,002	2,6445	7,980833333	0,043167	28,341
90194	2009/08/30	25,057	45,4495	7,35	45,35	10,8585	0,0005		8,00275	0,15	34,5425
90194	2009/11/30	26,67314286	48,2108571	7,287714286	44,75714286	11,02757143	0,005142857	0,909	8,096	0,211429	31,09214
90194	2010/02/25	22,912	29,9993333	4,2	34,11666667	12,2525	0,0022	2,273	7,8828	0,038333	22,95783
90194	2010/05/30	26,229	34,7405714	5,222857143	38,44285714	14,33242857	0,002428571	3,1065	7,79	0,058429	24,70914
90194	2010/08/30	27,91583333	44,4058333	6,52	44,34	14,34783333	0,005	3,059666667	7,831666667	0,154667	30,44733

90194	2010/11/30	30,67271429	48,4961429	7,915714286	46,21428571	11,56385714	0,008428571	1,596857143	7,939571429	0,130571	31,601
90194	2011/02/25	23,28325	26,729	4,1322	32,91	12,1182	0,003	3,1324	7,7886	0,0752	27,2554
90194	2011/05/30	28,07085714	31,1308571	5,177571429	36,19285714	17,13614286	0,001428571	3,468571429	7,907571429	0,055286	27,21514
90194	2011/08/30	32,17866667	37,4555	6,8545	45,41666667	13,07266667	0,0015	3,240666667	7,860833333	0,375833	31,66783
90194	2011/11/30	33,31166667	39,7976	8,839833333	46,83333333	15,62933333	0,000666667	4,059166667	7,566	0,118167	31,95325
90194	2012/02/25	22,331	30,7435	6,24025	37,2225	10,8535	0,00075	2,83325	7,57925	0,56225	26,66975
90194	2012/05/30	24,79571429	35,1337143	7,145428571	43,01428571	11,50414286	0,008	4,441857143	7,952142857	0,025571	26,18743
90194	2012/08/30	26,55683333	42,3258333	8,333833333	48,71666667	12,69466667	0,032666667	5,499666667	8,162666667	0,084833	31,14867
90194	2012/11/30	25,04466667	34,4365	6,642666667	39,275	10,89483333	0,012833333	3,561333333	8,062166667	0,0395	26,104
90194	2013/02/25	21,49866667	29,051	5,428833333	33,23833333	7,941166667	0,002	3,215	8,020166667	0,0225	20,57
90194	2013/05/30	25,56357143	39,6861429	7,729714286	43,51428571	10,773	0,019857143	4,850857143	8,169	0,043	30,70271
90194	2013/08/30	25,62066667	39,5215	7,597666667	45,50416667	11,26833333	0,014666667	4,9055	7,998166667	0,053833	35,04767
90194	2013/11/30	25,10128571	42,5744286	8,791571429	43,96842857	9,890714286	0,006285714	3,492142857	7,863142857	0,048857	34,55657
90194	2014/02/25	23,0378	33,478	6,063666667	37,5872	10,413	0,0178	3,0452	8,0482	0,0272	30,0788
90194	2014/05/30	25,5165	38,3314286		41,28233333	13,22383333	0,027333333	3,334333333	8,19	0,050167	31,53333
90194	2014/08/30	25,36316667	42,633		43,91666667	13,24533333	0,016166667	3,271666667	8,023666667	0,0475	34,88833
90194	2014/11/30	27,04214286	40,985		45,1	12,89957143	0,048285714	3,967571429	7,970285714	0,253	31,91671
90194	2015/02/25	23,5038	37,7162	8,898	38,832	7,99	0,0542	2,4174	8,1274	0,2372	27,6806
90194	2015/05/30	24,47066667	39,1586667	8,23375	42,95	12,71733333	0,018666667	3,0635	7,9475	0,481167	32,29317
90194	2015/08/30	28,70585714	53,5642857	9,3065	50,28571429	12,64566667	0,018571429	6,019428571	8,154714286	0,529	38,32986

90194	2015/11/30	28,74283333	58,802	10,0164	50,8	10,50233333	0,0022	4,883333333	7,869	0,220167	39,46017
90194	2016/02/25	26,04314286	53,9382857	7,987857143	43,8	9,462142857	0,004142857	5,288571429	7,910285714	0,218286	31,88057
90194	2016/05/30	28,457	53,194	7,249833333	46,21666667	12,0665	0,004666667	4,080166667	8,238	0,1425	35,614
90194	2016/08/30	30,22857143	56,4142857	6,928571429	48,88571429	11,92857143	0,004142857	4,449285714	8,085714286	0,183286	37,52857
90194	2016/11/30	27,44	53,46	8,86	45,32	9,66	0,004	4,2554	8,06	0,3586	35,96
90194	2017/02/25	27,58571429	53,2571429	7,257142857	43,17142857	10,64285714	0,011714286	4,361285714	8,257142857	0,183143	30,98
90194	2017/05/30	28,5	51	7,033333333	44,3	12,61666667	0,005333333	4,416714286	8,25	0,126167	30,875
90194	2017/08/30	26,4	61,9571429	9,2	48,87142857	11	0,007285714	3,3245	8,171428571	0,297286	40,12857
90194	2017/11/30	24,475	48,025	8,625	42,925	9,7	0,00625	4,117285714	8,075	0,0475	37,275
90194	2018/02/25	25,41428571	48,3833333	8,242857143	43,4	10,15714286	0,056428571	4,117285714	8,285714286	0,209143	30,96667
90194	2018/05/30		51,58375	7,75	45,83333333		0,006666667	4,480333333	8,2785	0,05	39,39075
90203	1985/02/25	31,03333333	43,0666667	45,53333333	4,5	15,4	0,002333333	0,116666667	8,07	0,019333	44,9
90203	1985/11/30	44,05	73,7	73,125	7,5625	25,575	0,008	0,3425	8,1175	0,02975	106,1
90203	1986/02/25	44,6	78,6	79,25	6,775	30,6	0,007	0,02	8,27	0,012	107,55
90203	1986/05/30	39	66,4	75,4	8,17	23,9	0,006	0,29	8,2	0,003	104,4
90203	1986/11/30	51	83,6	86	8,31	26,1	0,005	0,02	8,2	0,016	120,1
90203	1987/02/25	40,9625	59,725	66,2	6,40375	21,7	0,002875	0,06	7,98375	0,010375	76,375
90203	1987/05/30	44,3	70,325	76,5	6,3725	26,65	0,002	0,0575	7,7075	0,00725	83,675
90203	1987/08/30	49,48	83,7	79,3	7,621	27,3	0,0025	0,222	7,69	0,0138	114,8
90203	1987/11/30	43,69090909	75,1090909	71,3	7,015454545	25,8	0,003545455	0,156363636	7,908181818	0,010182	94,05455
90203	1988/02/25	43,91666667	89,5916667	81,825	6,43	28,48333333	0,002583333	0,113333333	7,9375	0,0105	95,93333
90203	1988/05/30	48,66	103,8	87,91	6,03	31,67	0,0019	0,164	7,858	0,0125	95,5
90203	1988/08/30	53,87777778	83,0444444	84,17777778	7,313333333	28,36666667	0,003444444	0,2	7,962222222	0,006111	97,04444
90203	1988/11/30	46	84,75	80,54166667	7,361666667	28,925	0,002083333	0,385833333	7,73	0,011583	89
90203	1989/02/25	45,33076923	104,253846	95,01538462	7,288461538	31,91538462	0,003307692	0,059230769	7,953846154	0,005692	97,53846

90203	1989/05/30	52,16153846	104,646154	88,23076923	7,163846154	34,54615385	0,006	0,110769231	8,239230769	0,004462	105,4154
90203	1989/08/30	54,82142857	102,55	89,62142857	8,060714286	34,47142857	0,006714286	0,281428571	8,218571429	0,069357	114,6923
90203	1989/11/30	47,07692308	86,3923077	74,71538462	7,736923077	30,32307692	0,010923077	0,071769231	8,414615385	0,015077	90,26923
90203	1990/02/25	44,50833333	85,1333333	74,33333333	6,721666667	27,39166667	0,0025	0,042916667	8,056666667	0,018917	78,84167
90203	1990/05/30	53,16666667	109,766667	83,03333333	6,363333333	34,575	0,007833333	0,163416667	8,3875	0,011583	103,2667
90203	1990/08/30	50,41818182	101,736364	85,3	7,544545455	33,00909091	0,005090909	0,283363636	8,183636364	0,020545	105,3545
90203	1990/11/30	44,35384615	94,3846154	77,94615385	7,216923077	33,01538462	0,003846154	0,125153846	8,287692308	0,008231	99,86154
90203	1991/02/25	42,67777778	94,8333333	75,2	7,553333333	30,35555556	0,004222222	0,140111111	8,323846154	0,016444	99,86667
90203	1991/05/30	52,43333333	101,7	83,2	6,98	31,46666667	0,002666667	0,5	8,12	0,011	101,7667
90203	1991/08/30		119,452941		9,176153846						
90203	1992/02/25		129,53		8,826						
90203	1992/05/30		128,466667		8,782		0,0045				
90203	1992/11/30	51,92307692	131,914286	97,57692308	8,704285714	39,29230769	0,005076923	0,126923077	8,370769231	0,019769	133,8231
90203	1993/02/25	52,03	129,9625	102,22	7,955	39,69	0,0104	0,0391	8,426	0,032	141,47
90203	1993/05/30	51,8	122,916667	96,11666667	7,523333333	39,81666667	0,0045	0,075166667	8,228333333	0,027833	141,8167
90203	1993/08/30		120,858333	95,93333333	8,079166667	37,8	0,00325				
90203	1993/11/30	58,27142857	120,008333	101,3428571	8,505833333	37,28571429	0,014857143	0,294285714	8,181428571	0,035571	148,5143
90203	1994/02/25	52,45	103,416667	92,5375	8,039166667	32,675	0,00325	0,245	8,1925	0,032375	108,1125
90203	1994/05/30	58,61666667	122,916667	96,11666667	7,555	35,38333333	0,004666667	0,1605	8,273333333	0,022167	120,7667
90203	1994/08/30	61,075	120,858333	100,4833333	7,410769231	37,8	0,0055	0,475916667	8,388333333	0,029667	126,85

90203	1994/11/30	55,09166667	120,008333	94,85833333	7,712307692	37,58333333	0,006083333	0,12675	8,290833333	0,017833	116,8333
90203	1995/02/25	48,63333333	103,416667	85,075	7,752307692	33,21666667	0,009333333	0,040583333	8,2675	0,021917	102,775
90203	1995/05/30	60,18333333	142,636364	106,85	6,206153846	40,44166667	0,002666667	0,390416667	8,190833333	0,01575	123,4167
90203	1995/08/30	60,61538462	130,364286	100,9	6,081538462	37,11538462	0,004846154	0,547769231	8,273846154	0,026154	127,7769
90203	1995/11/30	53,35384615	121,915385	98,29230769	5,672307692	37,61538462	0,004769231	0,125461538	8,326923077	0,037769	120,1231
90203	1996/02/25	37,86923077	75,4769231	62,23846154	5,966153846	20,51538462	0,002615385	0,350461538	8,198461538	0,034	73,35385
90203	1996/05/30	45,48461538	78,7153846	68,00769231	5,212307692	23,66923077	0,004	1,235461538	8,236923077	0,038769	75,59231
90203	1996/08/30	51,66153846	83,7769231	75,09230769	4,946153846	28,5	0,003615385	1,117	8,262307692	0,020231	83,78462
90203	1996/11/30	48,18461538	75,0538462	71,14615385	4,899090909	27,03846154	0,003230769	0,455538462	8,302307692	0,017923	77,05385
90203	1997/02/25	41,43846154	68,5846154	65,29230769	6,007692308	24,53076923	0,003769231	0,467076923	8,246923077	0,018077	70
90203	1997/05/30	34,96923077	47,2769231	50,93846154	5,212307692	18,01538462	0,003846154	1,300846154	8,093846154	0,043385	54,68462
90203	1997/08/30	41,42307692	53,4076923	56,11538462	4,946153846	21,84615385	0,004846154	1,811461538	8,175384615	0,017462	65,37692
90203	1997/11/30	48,39090909	67,3636364	67,99090909	4,899090909	26,85454545	0,003818182	1,285727273	8,248181818	0,017364	75,01818
90203	1998/02/25	43	64,4384615	64,37692308	6,007692308	26,38461538	0,003461538	0,845307692	8,332307692	0,019462	75,87692
90203	1998/05/30	47,96923077	87,5538462	78,34615385	5,956923077	31,66923077	0,002923077	0,691384615	8,290769231	0,017538	85,94615
90203	1998/08/30	47,54545455	81,3181818	73,76363636	5,977272727	31,78181818	0,004090909	0,663	8,303636364	0,025091	90,22727
90203	1998/11/30	48,12727273	89,3454546	80,5	6,041818182	33,16363636	0,003727273	0,571727273	8,270909091	0,022909	94,68182
90203	1999/02/25	38,99230769	66,6538462	65,83846154	7,050769231	25,07692308	0,002846154	0,818076923	8,286923077	0,024154	77,13846

90203	1999/05/30	46,21428571	93,1714286	81,69285714	6,677857143	31,75714286	0,003	0,656071429	8,393571429	0,045643	90,57143
90203	1999/08/30	45,311	87,8765333	79,71333333	6,3076	30,03853333	0,003933333	0,795533333	8,293533333	0,021533	92,42567
90203	1999/11/30	39,2982	80,5797	75,38	6,863333333	28,8566	0,0047	0,3456	8,3036	0,0188	85,7377
90203	2000/02/25	36,33964286	73,1350714	67,67142857	6,669571429	24,43314286	0,009142857	0,630785714	8,351428571	0,062571	74,19386
90203	2000/05/30	37,40653846	47,7475385	54,47692308	5,154461538	19,40469231	0,006923077	1,321846154	8,327846154	0,050154	59,05538
90203	2000/08/30	45,53807692	56,901	65,5	5,159	25,45584615	0,003923077	1,643692308	8,293769231	0,027231	71,05669
90203	2000/11/30	45,18892308	60,7846923	66,69230769	5,846076923	26,98330769	0,004384615	0,979615385	8,250230769	0,022538	73,99115
90203	2001/02/25	35,08361538	59,5630769	61,16923077	6,060538462	24,96407692	0,004769231	0,519384615	8,250307692	0,030231	67,72769
90203	2001/05/30	40,30654545	74,2461818	71,1	5,905	28,444	0,004090909	0,634545455	8,287	0,051818	79,20945
90203	2001/08/30	41,48384615	68,8611539	68,94615385	6,377230769	28,95661538	0,009538462	0,766692308	8,274538462	0,212538	77,45892
90203	2001/11/30	38,99715385	66,7456154	68,16153846	6,572	28,43576923	0,007307692	0,561538462	8,222846154	0,034	71,05785
90203	2002/02/25	31,31169231	60,0245385	58,86923077	6,425923077	23,74092308	0,005615385	0,578461538	8,196846154	0,050846	60,38862
90203	2002/05/30	40,7572	87,9618	140,3	6,4904	32,0918	0,008230769	0,589076923	8,252846154	0,029538	77,1972
90203	2002/08/30	47,331	99,7313333	79,4	6,130666667	34,99633333	0,005272727	0,675818182	8,216454545	0,038545	87,52167
90203	2002/11/30	32,88633333	67,3713333	69,06923077	5,817333333	24,81633333	0,007	0,321307692	8,261769231	0,045	60,39567
90203	2003/02/25	37,65575	86,139	75,75384615	7,168	31,305	0,004	0,333153846	8,202461538	0,025923	79,761
90203	2003/05/30	48,8805	135,726	98,03	6,7235	43,69	0,004533333	0,4715	8,2002	0,0235	114,102
90203	2003/08/30	43,944	96,4785	86,8	8,9355	32,0715	0,002888889	0,316555556	8,222666667	0,068778	91,752
90203	2003/11/30	44,826	115,415667	98,73846154	7,723	40,338	0,004692308	0,355384615	8,259461538	0,036692	104,6733
90203	2004/02/25	54,51475	163,91875	103,0428571	7,3375	42,52	0,003142857	0,363142857	8,405571429	0,025	124,3855
90203	2004/05/30	47,167125	110,54875	86,2375	7,455375	29,587125	0,001625	0,873125	7,971125	0,066625	90,66925
90203	2004/08/30	48,53475	91,59775	80,875	7,75425	28,25475	0,002375	0,624625	8,107625	0,022125	86,416

90203	2004/11/30	41,33771429	89,3788571	77,85714286	7,964714286	27,97014286	0,004714286	0,258428571	8,100428571	0,041429	74,62586
90203	2005/02/25	41,61316667	101,376	79,23333333	8,590333333	29,27816667	0,003333333	0,377666667	8,154166667	0,036333	79,51917
90203	2005/05/30	43,659	105,892857	84,68571429	8,006285714	30,757	0,003428571	0,57	8,027857143	0,037286	83,24243
90203	2005/08/30	41,9415	96,4986667	80,45	8,057166667	28,90883333	0,0045	0,476333333	8,074666667	0,093	78,56383
90203	2005/11/30	37,81314286	97,0017143	78,97142857	8,848714286	29,06171429	0,004142857	0,181428571	8,207285714	0,031857	80,55414
90203	2006/02/25	38,77683333	92,9988333	76,23333333	8,746666667	26,38716667	0,007	0,435333333	8,155	0,033333	76,71833
90203	2006/05/30	38,51885714	80,0878571	66,7	6,905428571	23,85071429	0,003428571	0,714285714	7,947857143	0,042571	69,50729
90203	2006/08/30	45,347	86,7423333	72,38333333	7,235	28,04583333	0,005833333	0,891666667	8,221833333	0,020667	76,63233
90203	2006/11/30	39,639625	80,459875	68,4625	7,384375	25,822875	0,005875	0,372125	8,1525	0,03375	79,45225
90203	2007/02/25	37,38166667	77,6203333	68	8,0895	23,4145	0,005333333	0,461166667	8,1165	0,069333	65,12033
90203	2007/05/30	52,24366667	142,8605	98,41666667	7,828	38,078	0,0095	0,578833333	8,148166667	0,075667	98,50533
90203	2007/08/30	50,07733333	122,725333	92,25	8,082833333	35,36233333	0,010833333	0,640166667	8,1585	0,032667	100,536
90203	2007/11/30	45,94857143	116,327429	88,97142857	8,279857143	31,17242857	0,027714286	0,626714286	8,203142857	0,131143	92,14271
90203	2008/02/25	37,12316667	86,659	71,06666667	8,8995	22,4045	0,006833333	0,733	8,040333333	0,086333	72,57983
90203	2008/05/30	44,439125	82,81575	68,15	7,7305	23,671375	0,0095	1,223125	8,116125	0,097125	72,68338
90203	2008/08/30	45,22625	86,0446	69,2	7,322	28,202	0,007666667	1,174	8,045	0,049	88,2856
90203	2008/11/30	42,40214286	92,7751667	71,92714286	9,671857143	28,45242857	0,004333333	0,63475	8,246833333	0,013167	83,14967
90203	2009/02/25	40,57116667	86,0266667	67,51666667	7,776166667	25,95483333	0,005666667	1,177	8,338166667	0,116833	69,18817
90203	2009/05/30	46,3974	75,24575	71,94	7,325	28,1694	0,0046	1,27175	8,0676	0,0746	73,2182
90203	2009/08/30	45,793	83,028	66,8	7,4049	29,708	0,003	1,1445	8,35	0,01	71,71333

90203	2009/11/30	46,64685714	90,1951429	76,62857143	7,35	27,52128571	0,011857143	0,3535	8,268285714	0,014571	78,30957
90203	2010/02/25	35,203	64,9936	65,86666667		20,4856	0,0038	1,373666667	8,185	0,0968	59,2792
90203	2010/05/30	40,1945	71,7098333	62,92857143	6,685714286	22,84383333	0,002	1,264666667	7,916428571	0,065167	65,28383
90203	2010/08/30	49,355	92,6965714	73,62857143	6,72	26,05842857	0,003428571	1,991	7,958	0,014857	81,80529
90203	2010/11/30	41,527	84,759	73,51666667	6,907166667	26,1655	0,0028	0,679	8,223166667	0,04	75,27033
90203	2011/02/25	33,564	68,6396667	58,1	6,483333333	21,5694	0,0035	0,827166667	7,963333333	0,0625	58,64017
90203	2011/05/30	36,92285714	67,0688333	59,61666667	5,928571429	20,895	0,001666667	1,501142857	7,869285714	0,036714	56,65471
90203	2011/08/30	48,45771429	84,5634286	72,81428571	6,260285714	24,209	0,001857143	2,213428571	7,933142857	0,005857	83,42886
90203	2011/11/30	46,03416667	85,0296667	74,15	6,2285	29,52583333	0,001	0,896833333	7,743166667	0,006833	86,3765
90203	2012/02/25	36,91842857	70,6721429	67,1	7,3	23,68285714	0,001571429	0,382714286	7,631142857	0,032429	62,86086
90203	2012/05/30	39,97283333	77,3591667	71,25	7,351666667	22,92033333	0,006666667	0,926333333	8,150833333	0,044	67,034
90203	2012/08/30	45,88371429	84,7108571	76,32857143	7,186	26,86916667	0,008571429	1,641428571	8,349428571	0,016857	77,92233
90203	2012/11/30	43,9956	72,6578	68,65	7,842666667	24,148	0,006833333	1,748166667	8,245166667	0,043333	68,4214
90203	2013/02/25	34,052	62,667	62,18571429	7,772285714	20,26814286	0,005	1,080857143	8,257	0,083	58,81814
90203	2013/05/30	36,88133333	74,467	68	7,5795	24,801	0,012833333	1,108166667	8,383333333	0,0405	64,9375
90203	2013/08/30	42,6225	76,8856667	73,779	6,996166667	23,70483333	0,005166667	1,932833333	8,2755	0,013667	74,02533
90203	2013/11/30	35,45683333	75,4725	68,27016667	7,8535	26,39683333	0,006166667	0,7325	8,003833333	0,017833	70,11283
90203	2014/02/25	38,906	60,1015	57,27883333	7,906	20,97366667	0,003	1,198333333	8,172	0,049833	59,18833
90203	2014/05/30	39,893	59,8843333	59,12916667		19,28283333	0,004166667	2,100166667	8,235833333	0,043	63,32367
90203	2014/08/30	50,86742857	85,0807143	78,45714286		28,11928571	0,006142857	3,255714286	8,350285714	0,013571	93,06614
90203	2014/11/30	46,57633333	83,4933333	79,08333333		30,43583333	0,018166667	2,044	8,457166667	0,016333	87,99117
90203	2015/02/25	43,5228	76,2532	73,82	8,34	30,1856	0,009	1,8418	8,3982	0,115	83,9296
90203	2015/05/30	47,7626	93,8455	83,26666667	8,00675	32,1355	0,0065	1,030666667	8,368666667	0,155167	91,83567

		6667									
90203	2015/08/30	47,26671429	91,486	80,2	6,360666667	28,24016667	0,006	1,704	8,311285714	0,016571	92,70733
90203	2015/11/30	38,77133333	76,1643333	72,3	8,0266	26,38933333	0,0045	1,03	8,128833333	0,062	85,75
90203	2016/02/25	41,324	80,2748	74,16	8,7804	26,25425	0,0062	1,434	8,3426	0,0766	82,902
90203	2016/05/30	49,038	83,8908571	78,1	7,875714286	25,92657143	0,007142857	1,475857143	8,41	0,101286	86,99686
90203	2016/08/30	50,51666667	80,2873846	75,96666667	8,266666667	27,18333333	0,005333333	1,9905	8,183333333	0,155333	80,15
90203	2016/11/30	44,58333333	67,65	70,31666667	8,733333333	26,56666667	0,009	1,424666667	8,25	0,132	77,61667
90203	2016/02/25	33,88	61,4818182	54,54	7,64	19,7	0,0068	1,164	8,38	0,1176	63,48
90203	2017/05/30	48,31666667	73,8666667	70,73333333	6,15	25,55	0,008333333	2,298166667	8,483333333	0,119833	82,16667
90203	2017/08/30	55,4	83,28	77,6	7,32	28,33333333	0,0138	2,691	8,52	0,0744	96,8
90203	2017/11/30	54,1	81,9	75,9	7,28	27,06	0,0068	1,7386	8,36	0,0614	91,16
90203	2018/02/25	44,23333333	79,3	71,71666667	8,45	24,21666667	0,011833333	1,5685	8,416666667	0,248833	91,3
90203	2018/05/30	49,225	93,9	77,62857143	8,566666667	25,9	0,008166667	1,972833333	8,566666667	0,173833	84,22
90204	1984/05/30	17,9	26,1	28,8	7	8,5	0,006	0,23	7,5	0,144	30,6
90204	1984/11/30	33,11111111	76,6555556	63,12222222	12,18666667	17,3	0,014222222	1,703333333	7,849	0,670778	80,3
90204	1985/02/25	29,78181818	56,5727273	49,79090909	9,776363636	13,6	0,007909091	0,29	8,084545455	0,085	56,41818
90204	1985/05/30	23,95		34,9	7,9725	9,3	0,01125	0,74	7,9575	0,4465	34,525
90204	1985/08/30	49,2	49,42	96,1	15,34	24,1	0,003	1,04	7,99	0,467	100,3
90204	1985/11/30	41,6	89,075	76,025	12,075	20,8125	0,016375	0,36625	8,41	0,174	82,575
90204	1986/02/25	34,16666667	59,3166667	58,21666667	8,523333333	16,43333333	0,003833333	0,353333333	7,838571429	0,081167	62,66667
90204	1986/05/30	42,6	75,65	71,5	8,81	24,1	0,002	0,02	7,7	0,084	105,2
90204	1986/08/30	16,88	27,18	28,38	6,7	7,16	0,001	0,65	7,282	0,1384	23,56
90204	1987/02/25	25,97692308	43,7692308	42,28461538	7,996153846	11,34615385	0,000923077	0,321538462	7,441538462	0,136231	41,16154
90204	1987/05/30	29,2	49,85	50,6	8,29375	12,8875	0,0015	0,39625	7,55625	0,0355	48,525
90204	1987/08/30	42,1833	72,9833333	70,5	8,458333333	22,01666667	0,002333333	0,156666667	7,55	0,023833	91,13333

		3333										
90204	1987/11/30	37,56153846	80,2153846	66,03846154	11,33	17,46923077	0,002230769	0,465384615	7,603846154	0,081615	71,76154
90204	1988/02/25	34,175	70,4	64,51666667	10,53166667	16,88333333	0,00325	0,495	7,653333333	0,140583	63,73333
90204	1988/05/30	41,75454545	79,3909091	74,91818182	8,439090909	23,19090909	0,001181818	0,188181818	7,546363636	0,059818	75,85455
90204	1988/08/30	46,29	95,2	83,7	8,245	26,34	0,0022	0,076	7,818	0,1612	93,8
90204	1988/11/30	44,51538462	91,8384615	81,71538462	12	22,40769231	0,004307692	0,376153846	7,776153846	0,193	82,86154
90204	1989/02/25	39,44615385	86,2384615	78,23846154	11,71615385	20,98461538	0,004076923	0,486153846	7,688461538	0,156923	77,43846
90204	1989/05/30	35,90833333	68,375	61,75454545	9,494166667	18,41666667	0,002583333	0,251666667	7,638333333	0,050333	59,15
90204	1989/08/30	40,69285714	82,0857143	68,05714286	9,990714286	21,43571429	0,020083333	0,238571429	8,592857143	0,049143	69,55714
90204	1989/11/30	38,575	79,25	68,05	10,0525	21,09166667	0,0195	0,221583333	8,269166667	0,081333	66,33333
90204	1990/02/25	37,01666667	73,8333333	60,20833333	9,813333333	18,78333333	0,02	0,362083333	8,300833333	0,108583	58,95833
90204	1990/05/30	40,475	83,1416667	63,50833333	10,34666667	21,60833333	0,004	0,12	8,133333333	0,058818	67,575
90204	1990/08/30	45,59166667	93,275	73,83333333	9,771666667	26,73333333	0,009333333	0,14475	8,316666667	0,089846	85,94167
90204	1990/11/30	41,85384615	88,8307692	72,22307692	12,06769231	22,01538462	0,012230769	0,379076923	8,424615385	0,219615	75,18462
90204	1991/02/25	37,73333333	84,5444444	66,5	12,01777778	20,44444444	0,007111111	0,325222222	8,363076923	0,181444	66,71111
90204	1991/05/30	29,9	61,6666667	55,375	10,75	18,66666667	0,013333333	0,365666667	8,3175	0,138333	53,73333
90204	1992/11/30	46,65384615	100,623077	87,35384615	11,11692308	30,63846154	0,016846154	0,161615385	8,386666667	0,055077	110,5077
90204	1993/02/25	35,74615385	72,3416667	67,53846154	11,58769231	19,24615385	0,014384615	0,257583333	8,470769231	0,162769	75,05385
90204	1993/05/30	36,54615385	77,2785714	67,79230769	11,35384615	20,09230769	0,005230769	0,109461538	8,321538462	0,158154	71,93846
90204	1993/08/30	39,78333333	92,5833333	81,55	11,48833333	21,75	0,003166667	0,045666667	7,935	0,054833	75,73333
90204	1993/11/30	39,4923	77,7692308	70,48461538	13,32153846	18,31538462	0,015846154	0,378769231	8,298461538	0,332615	73,19231

		0769									
90204	1994/02/25	37,01538462	66,2230769	63,11538462	10,53153846	17,92307692	0,005461538	0,202538462	8,254615385	0,199077	65,16154
90204	1994/05/30	38,65384615	64,4769231	62,11538462	9,701538462	20,53846154	0,015769231	0,400538462	8,432307692	0,147846	60,10769
90204	1994/08/30	46,4	77,1733333	75,04666667	10,44133333	23,2	0,0698	1,631933333	8,514	0,141333	84,78
90204	1994/11/30	41,54615385	77,5	71,22307692	11,65923077	22,79230769	0,010538462	0,248307692	8,425384615	0,138154	71,03077
90204	1995/02/25	36,03333333	77,2166667	69,93333333	11,425	21,95833333	0,00675	0,0835	8,4	0,181083	75,525
90204	1995/05/30	41,42142857	79,9857143	68,90714286	9,665714286	20,88571429	0,007857143	0,272857143	8,437142857	0,177929	73,06429
90204	1995/08/30	46,51666667	87,0333333	74,80833333	9,024166667	25,875	0,00825	0,249416667	8,368333333	0,141667	91,29167
90204	1995/11/30	41,36153846	76,7692308	70,80769231	10,27615385	21,86923077	0,009384615	0,283307692	8,313846154	0,262846	74,90769
90204	1996/02/25	32,05384615	55,5384615	52,04615385	8,630769231	15,63846154	0,001923077	0,170461538	8,071538462	0,095077	58,27692
90204	1996/05/30	41,71538462	65,1461539	60,58461538	6,706923077	21,68461538	0,003076923	0,774076923	8,200769231	0,065	63,33077
90204	1996/08/30	49,17692308	73,5307692	70,75384615	6,855384615	26,43846154	0,005230769	0,723923077	8,386923077	0,049231	77,73077
90204	1996/11/30	46,37692308	70,1153846	69,1	6,869230769	26,11538462	0,004538462	0,325769231	8,386153846	0,064385	72,48462
90204	1997/02/25	39,92307692	61,9	61,70769231	7,558461538	21,88461538	0,009461538	0,470384615	8,345384615	0,147462	63,86154
90204	1997/05/30	34,19230769	44,5153846	50,53076923	5,855384615	17,50769231	0,003615385	1,036615385	8,171538462	0,068538	52,13846
90204	1997/08/30	42,11538462	54,1076923	58,13846154	5,751538462	22,19230769	0,011692308	1,441076923	8,252307692	0,044	64,15385
90204	1997/11/30	47,9	65,3	67,53636364	6,235454545	25,71818182	0,008727273	0,956818182	8,321818182	0,117909	71,1
90204	1998/02/25	42,03333333	59,5916667	64,55	7,323333333	24,09166667	0,006833333	0,655333333	8,343333333	0,193	66,18333
90204	1998/05/30	46,11538462	81,4384615	72,26923077	7,014615385	29,60769231	0,004461538	0,385461538	8,419230769	0,123308	78,96154
90204	1998/08/30	46,9230	77,3	73,53076923	7,119230769	29,76153846	0,005538462	0,355307692	8,512307692	0,120538	84,05385

		7692									
90204	1998/11/30	46,00833333	76,8166667	74,45833333	8,32	28	0,0075	0,3675	8,431666667	0,175167	79,48333
90204	1999/02/25	37,53076923	58,5153846	61,50769231	7,804615385	21,65384615	0,003692308	0,609307692	8,300769231	0,162769	63,62308
90204	1999/05/30	41,08461538	85,1230769	75,18461538	7,276153846	27,27692308	0,003230769	0,283230769	8,447692308	0,069846	76,57692
90204	1999/08/30	42,51538462	78,5	74,75384615	7,370769231	26,2	0,006692308	0,374076923	8,473076923	0,108077	78,31538
90204	1999/11/30	38,9575	72,5793333	72,89166667	7,7815	26,01033333	0,006416667	1,027	8,419166667	0,15875	75,98175
90204	2000/02/25	33,12925	63,7175	61,95	8,39625	19,64583333	0,005	0,318583333	8,313083333	0,13875	60,67817
90204	2000/05/30	33,65153846	40,3556923	49,75384615	5,507384615	16,79146154	0,003	1,005846154	8,203538462	0,066308	47,21908
90204	2000/08/30	44,16530769	57,8897692	65,14615385	5,587076923	23,85684615	0,006	1,158769231	8,320384615	0,051462	64,23146
90204	2000/11/30	46,17363636	62,3880909	67,18181818	6,496818182	25,83690909	0,006727273	0,695545455	8,161545455	0,075455	67,18409
90204	2001/02/25	35,40761538	52,8682308	58,31538462	6,561769231	22,92623077	0,003923077	0,396846154	8,251307692	0,115846	55,67362
90204	2001/05/30	38,63366667	63,5901667	65,35833333	7,16775	24,09191667	0,005666667	0,374833333	8,317416667	0,24775	63,06975
90204	2001/08/30	42,123	68,4971818	68,74545455	7,135	26,89236364	0,011272727	0,479545455	8,374454545	0,182091	73,35809
90204	2001/11/30	38,94923077	65,3667692	68,29230769	6,898307692	27,29576923	0,009846154	0,378461538	8,287384615	0,135615	69,34154
90204	2002/02/25	32,85464286	57,0214286	57,82857143	7,2735	21,76414286	0,004642857	0,414214286	8,203071429	0,155	54,42479
90204	2002/05/30	41,83308333	84,39575	75,23333333	6,989166667	32,42641667	0,004166667	0,15025	8,440833333	0,051167	74,05933
90204	2002/08/30	44,62790909	81,1261818	74,59090909	8,182363636	28,898	0,008090909	0,245545455	8,363818182	0,100545	76,66773
90204	2002/11/30	35,92192308	68,5373077	66,08461538	7,909230769	23,83046154	0,010384615	0,158615385	8,475692308	0,136769	62,262
90204	2003/02/25	38,12261538	75,2157692	73,6	9,786307692	24,35523077	0,006230769	0,234153846	8,373	0,240769	67,004

90204	2003/05/30	44,61427273	92,3740909	81,35454545	9,946454545	30,28354545	0,004363636	0,092545455	8,342727273	0,143727	79,09409
90204	2003/08/30	43,30516667	91,7994167	82,84166667	9,7065	31,14266667	0,00375	0,147583333	8,460166667	0,16025	87,37033
90204	2003/11/30	42,50469231	96,5154615	85,91538462	9,970615385	30,84538462	0,002076923	0,054692308	8,276153846	0,199385	87,50169
90204	2004/02/25	42,95816667	92,0539167	81,90833333	11,43791667	25,55241667	0,00225	0,171666667	8,235666667	0,267167	81,15633
90204	2004/05/30	34,39866667	59,9453333	58,91666667	7,475333333	18,68733333	0,001	0,367833333	7,947666667	0,137333	56,92967
90204	2004/08/30	40,86142857	73,6178571	71,31428571	8,150571429	23,51071429	0,004	0,200142857	8,216571429	0,107143	68,46714
90204	2004/11/30	39,83057143	76,4542857	72,52857143	9,342714286	23,827	0,003666667	0,558714286	8,215285714	0,239	66,86643
90204	2005/02/25	34,69733333	71,6953333	65,65	9,632833333	19,63016667	0,004166667	0,240833333	8,2445	0,311833	52,76767
90204	2005/05/30	38,38085714	78,5787143	71,24285714	9,063428571	22,60971429	0,001714286	0,214857143	8,070571429	0,221857	64,77029
90204	2005/08/30	41,54783333	83,6606667	75,33333333	9,523833333	24,69933333	0,0055	0,2405	8,201666667	0,201167	67,682
90204	2005/11/30	39,97542857	82,8898571	77,52857143	10,24742857	24,77385714	0,003428571	0,105428571	8,252142857	0,320714	69,03929
90204	2006/02/25	32,07216667	64,7775	60,16666667	8,913333333	18,6825	0,0025	0,1575	8,031	0,253333	52,25417
90204	2006/05/30	34,50228571	59,6154286	56,85714286	7,048285714	19,655	0,001571429	0,463285714	8,110285714	0,145	51,62586
90204	2006/08/30	42,87483333	74,9935	69,26666667	7,936666667	25,16533333	0,006166667	0,451333333	8,229166667	0,2305	64,71633
90204	2006/11/30	42,25	77,3042857	70,5	8,257285714	24,405	0,006142857	0,282285714	8,268285714	0,351857	65,41757
90204	2007/02/25	34,969	75,3538	67,46	8,6856	23,294	0,0066	0,367	8,1866	0,202	60,935
90204	2007/05/30	46,20685714	106,013429	86,84285714	9,019142857	33,81642857	0,010714286	0,085142857	8,3014	0,181	76,51429
90204	2007/08/30	49,227	100,146	86,7	11,15733333	29,49516667	0,012666667	0,218666667	8,374333333	0,403667	89,25767
90204	2007/11/30	42,22628571	89,9021429	80,98571429	11,06571429	24,84571429	0,022571429	0,680571429	8,257285714	0,520571	72,53843

90204	2008/02/25	32,5406667	56,2193333	54,63333333	8,77	16,24316667	0,004333333	0,4475	7,963166667	0,361	47,07733
90204	2008/05/30	38,85814286	66,5094286	60,2	7,964142857	21,84757143	0,009428571	0,979285714	8,077	0,217714	61,38443
90204	2008/08/30	44,38675	74,3725	70,32	7,5005	26,13175	0,009	0,968	8,2356	0,109	70,7795
90204	2008/11/30	43,74933333	78,4286	67,04285714	7,586714286	26,97316667	0,004833333	0,5005	8,331428571	0,300667	75,41333
90204	2009/02/25	34,96433333	66,078	61,63333333	8,054333333	21,9312	0,011333333	0,6346	8,296166667	0,5708	53,5615
90204	2009/05/30	41,21866667	68,2085	62,66666667	7,598333333	21,56066667	0,004166667	0,798333333	8,321166667	0,291	54,11017
90204	2009/08/30	43,778	72,1395	68,55	7,4055	23,4365	0,003	1,004	8,3255	0,2105	64,6575
90204	2009/11/30	41,532	73,9211667	70,75714286	8,289142857	24,67383333	0,005	0,414	8,214428571	0,491	67,45057
90204	2010/02/25	37,11483333	61,8455	59,3	7,459833333	23,6365	0,002333333	0,827	8,143833333	0,389	52,65867
90204	2010/05/30	37,8585	62,579	59,15714286	7,149714286	21,00466667	0,002666667	0,753166667	7,973571429	0,257667	51,78317
90204	2010/08/30	43,768	73,1034286	68,45	7,076857143	25,609	0,002333333	1,185571429	7,939428571	0,261714	62,391
90204	2010/11/30	40,99616667	70,6855	68,38333333	7,360666667	27,64916667	0,002833333	0,632833333	8,201833333	0,438333	58,90267
90204	2011/02/25	34,8028	60,0296	57,1	6,7588	20,7754	0,0028	1,2662	7,9262	0,1996	52,0168
90204	2011/05/30	38,51585714	61,209	56,8	6,354	18,98366667	0,000833333	0,891714286	7,788571429	0,08	57,05971
90204	2011/08/30	46,11928571	71,5941429	70,72857143	6,886428571	24,89571429	0,001857143	1,698714286	7,982	0,091	66,70657
90204	2011/11/30	50,027	76,0216667	73,83333333	7,1055	29,4764	0,001166667	1,130666667	7,895166667	0,186	74,0445
90204	2012/02/25	35,04985714	67,9471429	66,32857143	8,193428571	21,75542857	0,000857143	0,401428571	7,659142857	0,220857	60,14486
90204	2012/05/30	44,07316667	72,3604	71,55	8,253333333	21,54516667	0,008333333	0,849833333	8,1955	0,176833	59,4094
90204	2012/08/30	46,41857143	74,5287143	76,58571429	8,418428571	26,69928571	0,013142857	1,094571429	8,504428571	0,262571	69,08933
90204	2012/11/30	41,3185	68,5906667	70,55	8,772166667	22,94	0,007666667	1,097166667	8,415333333	0,300833	61,95267
90204	2013/02/25	32,95785714	60,3937143	61,71428571	8,631428571	21,90114286	0,006	0,907142857	8,404	0,248571	53,519

90204	2013/05/30	38,5645	64,522	64,81666667	8,366	23,77966667	0,010333333	0,859666667	8,383666667	0,165333	56,5412
90204	2013/08/30	42,52285714	75,5204286	73,12857143	8,934	24,19857143	0,025571429	1,086285714	8,687	0,145429	63,31867
90204	2013/11/30	35,26716667	68,2841667	67,44316667	9,5585	22,98916667	0,021	0,535	8,3285	0,256333	60,8035
90204	2014/02/25	31,328	57,6573333	57,03433333	8,667	19,449	0,005166667	0,8475	8,300333333	0,149167	53,73417
90204	2014/05/30	36,121	52,7075	54,91333333		18,34683333	0,004666667	1,517166667	8,274666667	0,086333	57,94567
90204	2014/08/30	47,21971429	74,0764286	72,74285714		25,545	0,006714286	2,390571429	8,393714286	0,054714	74,81486
90204	2014/11/30	45,84766667	77,5503333	74,85		28,99833333	0,008333333	1,426833333	8,494	0,144667	74,5745
90204	2015/02/25	37,1202	68,1564	67,5	9,658	23,39975	0,0066	0,5292	8,3122	0,3382	69,56
90204	2015/05/30	41,2055	71,3896667	71,08	9,932	26,03416667	0,0074	0,442666667	8,309	0,486833	61,56467
90204	2015/08/30	46,093	75,2518571	75,25714286	9,587428571	26,3475	0,013285714	1,032714286	8,318428571	0,208	72,11971
90204	2015/11/30	40,253	74,4081667	72,71666667	9,749	26,47816667	0,005333333	0,516666667	8,187	0,337833	77,88233
90204	2016/02/25	35,657	75,568	72,025	10,63175	25,028	0,0075	0,4167	8,44425	0,2575	63,78875
90204	2016/05/30	41,954	67,857	68,61428571	9,918285714	22,75928571	0,025	0,485857143	8,321714286	0,414429	64,45614
90204	2016/08/30	46,46666667	70	72,15	9,283333333	25,61666667	0,0115	1,821333333	8,15	0,303667	73,45
90204	2016/11/30	46,18333333	67,0666667	70,56666667	10,03333333	25,46666667	0,010666667	0,7875	8,316666667	0,212667	74,41667
90204	2017/02/25	32,96	51,98	52,46	8,06	17,1	0,013	0,8434	8,44	0,243	58,72
90204	2017/05/30	42,25	68,85	65,55	7,466666667	21,61666667	0,0095	1,511	8,566666667	0,1385	69,81667
90204	2017/08/30	48,65714286	76,1142857	74,72857143	8,185714286	25,38571429	0,011857143	1,990571429	8,457142857	0,134571	81,02857
90204	2017/11/30	48,675	71,125	73,025	7,4125	26,675	0,00825	1,77625	8,475	0,224	94,2
90204	2018/02/25	43,8	75,9833333	71,76666667	9,883333333	23,23333333	0,008333333	0,999833333	8,483333333	0,286	84,96667
90204	2018/05/30	43,4	73,94	68,06666667	10,15	22,06666667	0,008166667	1,524666667	8,4	0,256667	71,8
90233	1990/02/25	37,36363636	77	62,79090909	9,666363636	19,27272727	0,006181818	0,112727273	8,114444444	0,036545	61,18889
90233	1990/05/30	41,36666667	83,8416667	67,61666667	10,36333333	21,35	0,009583333	0,068166667	8,3775	0,021833	67,19286
90233	1990/08/30	46,29166667	96,1166667	73,49166667	10,21166667	26,43333333	0,006416667	0,101416667	8,320833333	0,021167	83,30833

90233	1990/11/30	40,50769231	95,8923077	77,87692308	12,05230769	24,06153846	0,008307692	0,058615385	8,395384615	0,0595	78,82308
90233	1991/02/25	36,98333333	81,8833333	66,02307692	11,75666667	20,03333333	0,007166667	0,089166667	8,442307692	0,013143	66,4
90233	1991/05/30	33,9	56,0333333	55,875	10,46666667	16,8	0,005333333	0,186	8,464666667	0,042667	50,3
90233	1992/08/30	49,89090909	109,318182	93,52727273	12,17636364	31,95454545	0,00425	0,022272727	8,464666667	0,029818	117,7909
90233	1993/02/25	32,87692308	66,0076923	63,54615385	11,33153846	18,19230769	0,023923077	0,057461538	8,793076923	0,078231	64,23846
90233	1993/05/30	37,14615385	82,2153846	69,74615385	10,40923077	21,55384615	0,007153846	0,024538462	8,443076923	0,048077	78,43077
90233	1993/08/30	36,7	99,9	78,55	10,95333333	25,28333333	0,008666667	0,074	8,343333333	0,074333	97
90233	1993/11/30	38,58333333	78,3416667	71,51666667	13,4375	19,1	0,009666667	0,08475	8,505	0,178833	77,60833
90233	1994/02/25	35,10769231	62,7538462	61,62307692	10,23	17,68461538	0,004307692	0,117153846	8,230769231	0,104538	64,02308
90233	1994/05/30	38,21538462	68,0538462	64,8	9,495384615	20,90769231	0,010923077	0,059846154	8,353846154	0,055769	60,43077
90233	1994/08/30	44,77857143	80,8428571	75,13571429	10,37214286	24,58571429	0,007571429	0,110214286	8,283571429	0,046143	82,02857
90233	1994/11/30	40,26923077	86,2923077	76,07692308	11,88769231	25,03846154	0,013307692	0,104461538	8,494615385	0,035692	70,19231
90233	1995/02/25	35,23636364	86,9636364	73,56363636	11,76454545	23,80909091	0,020454545	0,043818182	8,343636364	0,047545	76,66364
90233	1995/05/30	38,70714286	70,8357143	65,62142857	10,11	20,04285714	0,004642857	0,120571429	8,189285714	0,041857	67,21429
90233	1995/08/30	48,53076923	99,0384615	80,38461538	8,943076923	27,5	0,002615385	0,045307692	8,15	0,034846	96,18462
90233	1995/11/30	42,48	80,9	74,8	10,717	23,49	0,0029	0,0312	8,265	0,0366	77,68
90233	1996/02/25	30,58333333	52,7666667	50,41666667	8,656666667	14,83333333	0,0025	0,106	8,193333333	0,046167	57,8
90233	1996/05/30	43,35714286	65,6428571	60,64285714	6,784285714	20,97142857	0,002	0,723285714	8,255714286	0,037143	63,75714
90233	1996/08/30	55,07142857	90,3714286	79,31428571	7,171428571	29,57142857	0,005571429	0,780571429	8,364285714	0,115143	88,41429
90233	1996/11/30	49,05	84,5	76,36666667	7,121666667	29,31666667	0,006833333	0,177166667	8,51	0,043167	81,48333

90233	1997/02/25	44,51428571	71,5714286	66,54285714	7,368571429	24,02857143	0,005142857	0,244714286	8,411428571	0,069714	68,1
90233	1997/05/30	33,98333333	43,65	50,28333333	5,736666667	17,48333333	0,004166667	1,126	8,161666667	0,0685	51,7
90233	1997/08/30	44,41428571	61,4	63,78571429	5,984285714	23,84285714	0,004285714	1,471571429	8,242857143	0,037429	68,12857
90233	1997/11/30	51,68333333	75,5333333	72,35	6,465	28,88333333	0,007	0,94	8,348333333	0,090667	76,75
90233	1998/02/25	43,45	62,1333333	65,03333333	7,316666667	25,2	0,003833333	0,612833333	8,29	0,135167	68,66667
90233	1998/05/30	53,61428571	102,8	87,27142857	7,144285714	35,08571429	0,004714286	0,422714286	8,454285714	0,067429	92
90233	1998/08/30	55,18333333	106,116667	82,88333333	6,686666667	37,25	0,0035	0,117833333	8,531666667	0,024833	95,90769
90233	1998/11/30	50,28571429	88,4857143	80,57142857	7,995714286	30,25714286	0,006428571	0,157571429	8,455714286	0,076429	89,88571
90233	1999/02/25	38,95	61,9333333	63,96666667	8,053333333	22,63333333	0,003	0,532666667	8,351666667	0,116167	66,88333
90233	1999/05/30	48,15714286	101,857143	83,55714286	7,398571429	33,12857143	0,004	0,145571429	8,477142857	0,049571	91,22857
90233	1999/08/30	50,51666667	107,316667	90,16666667	7,328333333	34,26666667	0,005	0,2805	8,425	0,033333	92,66667
90233	1999/11/30	43,25533333	84,3213333	79,45	7,856	29,50416667	0,004333333	0,160166667	8,536666667	0,077	83,21767
90233	2000/02/25	36,3448	73,4364	68,72	7,7488	23,1368	0,0032	0,2026	8,3224	0,0784	66,9538
90233	2000/05/30	34,655	43,6618571	51,54285714	5,805	17,62357143	0,003714286	0,950428571	8,244857143	0,067429	49,10571
90233	2000/08/30	49,21142857	66,4308571	71,87142857	5,865714286	27,41757143	0,006142857	1,340428571	8,356571429	0,043571	71,10929
90233	2000/11/30	50,426	72,01	73,58333333	6,454833333	29,52566667	0,004	0,889333333	8,260666667	0,0505	74,05867
90233	2001/02/25	39,16271429	58,8548571	62,47142857	6,563571429	24,76985714	0,003428571	0,350285714	8,354571429	0,079429	60,28071
90233	2001/05/30	46,0895	76,742	74,01666667	6,7845	29,00783333	0,009666667	0,521	8,344166667	0,11	70,69133
90233	2001/08/30	50,172	88,5106	80,52	6,9176	31,7248	0,0114	0,5934	8,4098	0,0762	83,1184
90233	2001/11/30	41,80516667	76,8513333	74,21666667	7,713833333	30,6025	0,011333333	0,317833333	8,376	0,107167	73,18433
90233	2002/02/25	36,53814286	61,7635714	62,22857143	7,567142857	23,82642857	0,005285714	0,245571429	8,167	0,116571	54,91357

90233	2002/05/30	46,304	107,431	89,03333333	6,8135	39,23525	0,007333333	0,097666667	8,444833333	0,038333	86,91675
90233	2002/08/30	53,04933333	117,289333	90,95	7,305333333	40,54033333	0,01	0,139333333	8,488666667	0,038833	99,22167
90233	2002/11/30	39,49633333	80,0413333	77	7,998	26,841	0,005666667	0,143	8,393	0,0575	70,00267
90233	2003/02/25	37,79025	77,76125	73,61428571	9,68925	25,34775	0,004142857	0,158857143	8,348428571	0,085143	74,20175
90233	2003/05/30	37,166	73,415	77,76666667	9,457	25,69	0,002	0,054333333	8,239333333	0,068333	66,208
90233	2003/08/30	46,4605	103,4935	88,475	10,53	31,932	0,003	0,06325	8,242	0,03275	93,739
90233	2003/11/30	43,382	95,9515	86,92	10,4085	29,364	0,002	0,0712	8,2824	0,083	90,8835
90233	2004/02/25	30,66875	80,7595	75,88571429	9,944	22,3785	0,003428571	0,055	8,265	0,103	69,85975
90233	2004/05/30	39,9765	67,857	60,36666667	7,58475	22,66475	0,000833333	0,306333333	7,929333333	0,109	57,49
90233	2004/08/30	50,26666667	97,4435	82,76666667	7,993333333	29,22683333	0,003666667	0,199833333	8,320166667	0,046	81,67483
90233	2004/11/30	43,95771429	91,9012857	80,67142857	9,079857143	27,52628571	0,003571429	0,055	8,357857143	0,093571	73,48586
90233	2005/02/25	38,80083333	79,9361667	71,9	9,640166667	22,42666667	0,0025	0,116	8,261666667	0,209667	59,53617
90233	2005/05/30	42,39983333	84,8568333	75,95	9,107833333	25,34883333	0,002166667	0,1865	8,248166667	0,130333	62,30667
90233	2005/08/30	47,8694	107,523	85,56	8,664	30,208	0,005	0,1	8,2538	0,0654	78,8234
90233	2005/11/30	43,31042857	95,0061429	82,02857143	10,36614286	26,62642857	0,003	0,04	8,205285714	0,106286	76,15514
90233	2006/02/25	34,5408	67,1294	63,74	8,9304	19,6864	0,0018	0,0824	7,9218	0,1674	53,718
90233	2006/05/30	36,68585714	64,5495714	59,58571429	7,005857143	21,18671429	0,001285714	0,6488	7,942714286	0,110857	56,99443
90233	2006/08/30	53,7874	102,0006	80,32	7,7782	31,3276	0,0072	0,5204	8,358	0,0838	81,25
90233	2006/11/30	49,46442857	95,6097143	78,15714286	8,318	28,82842857	0,008857143	0,377285714	8,341	0,274714	76,87214
90233	2007/02/25	42,45	91,7078	76,04	8,7558	26,9498	0,0112	0,3752	8,4028	0,1442	74,8666
90233	2007/05/30	47,2434	117,2734	90,24	9,1954	31,3488	0,0152	0,1034	8,358	0,0886	81,5636
90233	2007/08/30	51,0505	102,7085	88,35	11,416	29,8975	0,0145	0,4365	8,1965	0,265	101,3575
90233	2007/11/30	44,26833333	104,9445	84,11666667	10,9585	28,3855	0,024833333	0,751333333	8,3395	0,254167	83,78983

90233	2008/02/25	34,96183333	63,4281667	59,26666667	8,739833333	18,59966667	0,006333333	0,494333333	7,974	0,325667	52,4835
90233	2008/05/30	42,22266667	76,9218333	67,15714286	8,0055	22,23	0,0115	0,882666667	8,094857143	0,198167	62,95783
90233	2008/08/30	59,75166667	99,2466	79,35	8	39,092	0,013333333	0,928333333	8,184	0,118	99,31175
90233	2008/11/30	53,23457143	118,721857	81,78333333	7,8198	38,39028571	0,0125	2,374	8,322	0,176333	98,497
90233	2009/02/25	42,20683333	85,435	68,73333333	8,783	23,9258	0,003333333	0,319	8,222833333	0,3635	65,821
90233	2009/05/30	46,46383333	83,075	68,31666667	7,816666667	28,65466667	0,002833333	0,790666667	8,160833333	0,234167	62,0335
90233	2009/08/30	51,38733333	99,4123333	79,03333333	7,744444444	29,35733333	0,004333333	1,6405	8,535333333	0,181	95,32133
90233	2009/11/30	47,82114286	93,3577143	81,82857143	8,601428571	27,081	0,003142857		8,374285714	0,319429	69,48043
90233	2010/02/25	38,02016667	62,6276667	61,58333333	7,916666667	22,04683333	0,0025	0,902	8,215833333	0,362	52,59917
90233	2010/05/30	41,166	70,1648333	62,45714286	7,405714286	25,25666667	0,001666667	0,6015	7,986	0,217833	54,73117
90233	2010/08/30	50,34971429	100,296571	79,15714286	6,996142857	28,86714286	0,003857143	1,555	8,233857143	0,187571	79,96829
90233	2010/11/30	50,31866667	105,273333	84,36666667	7,9945	30,10583333	0,884	0,985	8,216333333	0,333	72,9072
90233	2011/02/25	36,1058	68,0878	59,56	6,7396	25,011	0,0022	0,5598	8,0782	0,1706	55,7802
90233	2011/05/30	41,69542857	79,7715714	62,75714286	6,188285714	23,11085714	0,001571429	0,946428571	7,981571429	0,099	58,74229
90233	2011/08/30	51,81685714	92,9054286	75,48571429	6,786571429	26,70514286	0,002	1,951714286	7,969	0,060286	79,25171
90233	2011/11/30	51,857	101,283833	81,98333333	6,941	32,64883333	0,001833333	1,011666667	7,939	0,149	74,2338
90233	2012/02/25	40,41128571	74,74	71,6	8,193714286	23,90814286	0,001285714	0,944142857	7,838857143	0,239714	64,72714
90233	2012/05/30	48,4022	100,114333	84,9	7,987	28,33683333	0,0055	1,636	8,289666667	0,294667	78,26383
90233	2012/08/30	61,38728571	124,873714	95,45714286	8,453428571	30,193	0,013	1,7	8,374142857	0,196571	91,54617
90233	2012/11/30	46,3193	84,4695	77,33333333	9,086666667	25,3205	0,009166667	1,200333333	8,4025	0,214833	71,35467

		3333									
90233	2013/02/25	39,71142857	72,1312857	70,48571429	8,616428571	22,091	0,01	1,014857143	8,341142857	0,197857	59,80543
90233	2013/05/30	44,14033333	87,8173333	75,5	8,436666667	26,2965	0,0155	1,088833333	8,516333333	0,128	68,454
90233	2013/08/30	45,50114286	97,6965714	86,52857143	8,314285714	29,534	0,015	1,788142857	8,572714286	0,077571	77,85829
90233	2013/11/30	41,38016667	89,117	76,18	9,098166667	26,27133333	0,010333333	0,857833333	8,157833333	0,145167	66,696
90233	2014/02/25	40,14783333	77,6958333	66,48983333	9,032	23,38633333	0,0085	1,147833333	8,165166667	0,1185	62,719
90233	2014/05/30	42,7686	66,3524	66,12		22,3408	0,0048	1,5814	8,2574	0,071	62,6338
90233	2014/08/30	55,591	97,4254286	86,78571429		29,93885714	0,006714286	2,423714286	8,371142857	0,023571	89,62486
90233	2014/11/30	52,4416	107,5996	92,96		34,2528	0,011	1,7516	8,5308	0,087	90,6136
90233	2015/02/25	45,1735	92,0993333	80,96666667	9,162	33,8195	0,0095	0,661833333	8,491166667	0,114167	84,991
90233	2015/05/30	51,7496	106,54	89,78333333	9,066666667	33,1745	0,0115	0,878166667	8,4555	0,158667	78,57233
90233	2015/08/30	54,238	108,382667	91,2	9,128666667	32,75875	0,013	1,029833333	8,497	0,037167	91,49125
90233	2015/11/30	45,25175	89,71375	81,15	9,336	27,8455	0,00625	0,76325	8,21125	0,1555	86,81275
90233	2016/02/25	27,5	49,9	49,8	11,8	14,6	0,004	1,172	8,2	0,136	46,4
90233	2016/05/30	49,58333333	94,4166667	81,9	9,316666667	26,85	0,009	0,582666667	8,533333333	0,179667	73,9
90233	2016/08/30	49,78333333	89,6	76,025	9,216666667	28,06666667	0,006	2,1735	8,2	0,265167	73,2
90233	2016/11/30	45,025	79,425	60,24	10,3	26,025	0,00875	0,4915	8,4	0,18225	76,5
90233	2017/02/25	36,82	63,12	76,04285714	12,82	20,26	0,0122	0,5434	8,58	0,2282	63,34
90233	2017/05/30	50,88571429	87,4428571	97,6	7,285714286	27,31666667	0,008571429	1,523857143	8,485714286	0,112571	80,35
90233	2017/08/30	63,125	125,18	88,1	8,34	35,05	0,032	2,22	8,5	0,0808	105,86
90233	2017/11/30	55,46	101,55	85,6	8,7	33,04	0,0078	0,8814	8,44	0,0612	98,18
90233	2018/02/25	49,14	95,7	81,96666667	9,84	29,92	0,0188	1,2022	8,52	0,1608	98,3
90233	2018/05/30	50,76666667	107	82,83333333	9,933333333	30,1	0,0085	1,695166667	8,5	0,201833	80,72

2. CCME QWI Water Quality Calculator

Parameters	CALCIUM_TOTAL_mgL	CHLORIDE_mgL	ELECTRICAL CONDUCTIVITY	POTASSIUM_TOTAL_mgL	MAGNESIUM_TOTAL_mgL	AMONNIA_UNIONIZED_mgL_N	NITRATE + NITRITE_TOTAL_mgLasN	pH	PHOSPHATE_TOTAL_mgL	SULPHATE_TOTAL_mgL
WQ Upper Range	100	250	300	100	125	0,007	10	8	0,15	400
WQ Lower Range								6		
Summer 90167	35,46666667	42,1	55,666667	4,95	23,3333333	-	1,02	7,363333	0,028666667	60,7
Autumn	29,14	37,08	48,48	4,174	19,14	0,002	1,134	7,422	0,0222	51,52
Winter	40,15454545	45,56363636	63,281818	3,40545455	27,1727273	0,003454545	2,732727273	7,637273	0,017	59,83636364
Spring	50,43333333	63,63333333	79,6	4,20666667	35,8666667	0,001	3,176666667	7,816667	0,075	88,73333333
Summer 90194										
Autumn										
Winter										
Spring										
Summer 90203										
Autumn										
Winter										
Spring										
Summer 90204										
Autumn										
Winter										
Spring										
Summer 90233										
Autumn										
Winter										
Spring										

	CODE	CCME DATA
NUMBER OF FAILED VARIABLES (PARAMETERS)	X	0
TOTAL NUMBER OF VARIABLES (PARAMETERS STUDIED)	Y	10
TOTAL NUMBER OF TESTS	Z	39
TOTAL NUMBER OF FAILED TESTS (ALL PARAMETERS EXCEEDING)	E	0

F 1 = $\frac{\text{Number of Failed Variables}}{\text{Total Number of Variables}}$ X 100

F 2 = $\frac{\text{Number of Failed Tests}}{\text{Total Number of Tests}}$ X 100

F1	0
F2	0

Step 3.1

EXCURSION excursion = $\frac{\text{Failed Test Value}}{\text{objective}}$ -1

FAILED TEST VALUE	A	
OBJECTIVES	B	0
	A/B	0
C= excursion	C =A/B Value Minus 1	0

Step 3.2

NORMALISED SUM EXCURSION (nse)

$$nse = \frac{\sum_{i=1}^{n} excursion}{\text{Total Number of Tests}}$$

nse	[C]/Z	0

Step 3.3

F3 = $\frac{nse}{0.01\ nse + 0.01}$

nse value	0.01x nse	0.01xnse+ 0.01	F3
0	0	0,01	0

Overall Calculations

CCME WQI = $100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right)$

Component of CCME WQI	Value	Square Value
F1	0	0
F2	0	0
F3	0	0
	Sum	0
	Square Root Value	0
	Divide by 1.732	1,732
		0

CCME WQ $100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right)$

CCME WQI FOR STATION			
	100	60,000175	100
	CCME WQI VALUE OF STATION		100

3. CCME WQI boxer-and-whisker plot

Year	Site	CCME WQI
1976	Site 90194	100
1976	Site 90167	100
1976	Site 90203	100
1976	Site 90204	100
1976	Site 90233	100
1977	Site 90194	100
1977	Site 90167	100
1977	Site 90203	100
1977	Site 90204	100
1977	Site 90233	100
1978	Site 90194	100
1978	Site 90167	100
1978	Site 90203	100
1978	Site 90204	100
1978	Site 90233	100
1979	Site 90194	64.3654182
1979	Site 90167	100
1979	Site 90203	100
1979	Site 90204	100

1979	Site 90233	100
1980	Site 90194	66.5077866
1980	Site 90167	100
1980	Site 90203	100
1980	Site 90204	100
1980	Site 90233	100
1981	Site 90194	68.2085144
1981	Site 90167	94.0400074
1981	Site 90203	100
1981	Site 90204	100
1981	Site 90233	100
1982	Site 90194	57.5972699
1982	Site 90167	90.3189654
1982	Site 90203	100
1982	Site 90204	100
1982	Site 90233	100
1983	Site 90194	55.4444979
1983	Site 90167	86.2485397
1983	Site 90203	100
1983	Site 90204	100
1983	Site 90233	100

1984	Site 90194	51.9635416
1984	Site 90167	91.6915488
1984	Site 90203	100
1984	Site 90204	83.2882373
1984	Site 90233	100
1985	Site 90194	59.0749323
1985	Site 90167	86.0448619
1985	Site 90203	80.6286635
1985	Site 90204	77.4984861
1985	Site 90233	100
1986	Site 90194	94.0283859
1986	Site 90167	83.3798657
1986	Site 90203	86.1218196
1986	Site 90204	100
1986	Site 90233	100
1987	Site 90194	93.5028092
1987	Site 90167	100
1987	Site 90203	100
1987	Site 90204	100
1987	Site 90233	100
1988	Site 90194	80.8017782

1988	Site 90167	82.725155
1988	Site 90203	100
1988	Site 90204	93.5241771
1988	Site 90233	100
1989	Site 90194	87.2452737
1989	Site 90167	100
1989	Site 90203	87.0650519
1989	Site 90204	80.5757902
1989	Site 90233	100
1990	Site 90194	91.846435
1990	Site 90167	86
1990	Site 90203	86.3787001
1990	Site 90204	79.8110204
1990	Site 90233	85.5310409
1991	Site 90194	91.846435
1991	Site 90167	81.4120696
1991	Site 90203	92.4831837
1991	Site 90204	77.2117868
1991	Site 90233	85.560462
1992	Site 90194	60.068916
1992	Site 90167	81.4120696

1992	Site 90203	92.712862
1992	Site 90204	82.1039169
1992	Site 90233	91.8279901
1993	Site 90194	77.9762837
1993	Site 90167	83.8124763
1993	Site 90203	85.6989466
1993	Site 90204	78.5851838
1993	Site 90233	77.8530511
1994	Site 90194	84.979455
1994	Site 90167	84.6345088
1994	Site 90203	91.8322002
1994	Site 90204	75.6235184
1994	Site 90233	84.4740356
1995	Site 90194	85.0730714
1995	Site 90167	83.3700419
1995	Site 90203	86.3666183
1995	Site 90204	77.2896573
1995	Site 90233	91.8330142
1996	Site 90194	85.5572769
1996	Site 90167	83.0378931
1996	Site 90203	91.8328139

1996	Site 90204	77.4523061
1996	Site 90233	86.3812132
1997	Site 90194	79.7088305
1997	Site 90167	82.6859142
1997	Site 90203	91.8336357
1997	Site 90204	84.531662
1997	Site 90233	86.3812132
1998	Site 90194	88.0937691
1998	Site 90167	82.224845
1998	Site 90203	91.8319572
1998	Site 90204	79.92005
1998	Site 90233	91.8288833
1999	Site 90194	92.478247
1999	Site 90167	80.9981343
1999	Site 90203	91.8315672
1999	Site 90204	85.5572054
1999	Site 90233	91.8284774
2000	Site 90194	80.2595793
2000	Site 90167	79.4294821
2000	Site 90203	86.367075
2000	Site 90204	91.8328196

2000	Site 90233	91.8320189
2001	Site 90194	85.4938803
2001	Site 90167	79.7101302
2001	Site 90203	79.9024491
2001	Site 90204	78.9956687
2001	Site 90233	84.4531269
2002	Site 90194	80.467465
2002	Site 90167	80.5972743
2002	Site 90203	86.3764028
2002	Site 90204	79.9107652
2002	Site 90233	85.5351655
2003	Site 90194	92.4875603
2003	Site 90167	84.4280551
2003	Site 90203	86.3818911
2003	Site 90204	84.5667062
2003	Site 90233	91.8323464
2004	Site 90194	100
2004	Site 90167	87.4601878
2004	Site 90203	92.782064
2004	Site 90204	86.2322909
2004	Site 90233	92.7809163

2005	Site 90194	72.6856662
2005	Site 90167	83.7178098
2005	Site 90203	91.8343668
2005	Site 90204	83.1396172
2005	Site 90233	91.8329347
2006	Site 90194	87.1616527
2006	Site 90167	83.0279364
2006	Site 90203	87.0893247
2006	Site 90204	84.2421448
2006	Site 90233	80.5457607
2007	Site 90194	86.7824125
2007	Site 90167	80.9848681
2007	Site 90203	85.5476413
2007	Site 90204	74.4478951
2007	Site 90233	75.8638513
2008	Site 90194	88.0070281
2008	Site 90167	77.2645663
2008	Site 90203	86.3332957
2008	Site 90204	78.6504181
2008	Site 90233	77.7000366
2009	Site 90194	80.2719989

2009	Site 90167	76.8632242
2009	Site 90203	86.3332957
2009	Site 90204	76.6315364
2009	Site 90233	83.0275973
2010	Site 90194	88.0924863
2010	Site 90167	78.5231132
2010	Site 90203	93.5444194
2010	Site 90204	84.194545
2010	Site 90233	83.0275973
2011	Site 90194	93.6908865
2011	Site 90167	87.0690616
2011	Site 90203	100
2011	Site 90204	88.0695967
2011	Site 90233	88.0953901
2012	Site 90194	78.6311565
2012	Site 90167	85.4432952
2012	Site 90203	87.0816645
2012	Site 90204	76.9266758
2012	Site 90233	77.8287487
2013	Site 90194	86.4922833
2013	Site 90167	76.7031468

2013	Site 90203	87.0206227
2013	Site 90204	75.9345551
2013	Site 90233	77.782405
2014	Site 90194	76.582764
2014	Site 90167	75.8940874
2014	Site 90203	85.8227596
2014	Site 90204	86.0519171
2014	Site 90233	81.7607179
2015	Site 90194	72.8334329
2015	Site 90167	77.6681577
2015	Site 90203	86.3685606
2015	Site 90204	76.1465605
2015	Site 90233	78.1478684
2016	Site 90194	84.3964856
2016	Site 90167	81.3644161
2016	Site 90203	85.5512606
2016	Site 90204	73.723976
2016	Site 90233	77.3249788
2017	Site 90194	79.0000093
2017	Site 90167	72.0415257
2017	Site 90203	84.7695476

2017	Site 90204	76.9935917
2017	Site 90233	79.026262
2018	Site 90194	64.6690845
2018	Site 90167	64.0083741
2018	Site 90203	83.448363
2018	Site 90204	74.9050762
2018	Site 90233	74.7098093

4. PCA raw data

	All sites	Site 90194	Site 90167	Site 90203	Site 90204	Site 90233
Axis 1(%)	75	66	44	47	71	43
Axis 2 (%)	14	17	28	38	16	31
Total (%)	89	82	72	85	87	74