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UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG, FACULTY OF SCIENCE

THE EFFECTS OF CHROME MINING ACTIVITIES ON THE WATER QUALITY OF THE HEX RIVER IN THE RUSTENBURG AREA: CASE STUDY ON KROONDAL CHROME MINE

by

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Research Report Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Environmental Sciences

Date: May 2016

DECLARATION

I declare that this Research Report is my own, unaided work. It is submitted for the Degree of Master of Science in Environmental Sciences at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

_____

(Signature of Candidate)

_____day of _____20_____in_____

ABSTRACT

This study assesses the water quality status of the Hex River downstream of Kroondal Mine (KMS15, sampling point located downstream of Kroondal Mine) and the effects of mining activities (Kroondal Chrome Mine) on the water quality of the Hex River in Rustenburg, which is in the North West Province of South Africa. Potential pollutants were identified, quantified and their distribution was determined over seven years (2007 to 2013) along different sampling points upstream and downstream to the mine. Water quality-monitoring data was obtained from the mine. The surface and underground water was sampled on a monthly basis and analysed by Aquatico, (a water quality service provider of Kroondal Chrome Mine) at SANAS Accredited Testing Laboratory (No T0374).

Data was collected for the Hex River and its tributary; the nearby discharge from Crocodile Farm and Farm Dam; as well as mine containment dams, slimes dams, run-off from the processing plant and water dams within the mine. Descriptive statistics (mean/average, minimum and Maximum) and box plots are used to explain the water quality at all sampling points. Water quality from sampling location points was compared against the Total Water Quality Guideline Range (TWQGR) for irrigation, livestock watering, ideal domestic use, aquatic ecosystem limits and the exemption permit issued to the Kroondal Chrome Mine by the Department of Water Affairs and Forestry (DWAF) in 2007, now Department of Water and Sanitation (DWS).

The water quality of the Hex River, downstream of Kroondal, was described as neutral, alkaline, saline and very hard with a high pH, and a high concentration of Electric conductivity (EC), Total Dissolve Solids (TDS), Chlorine (Cl), Sulphate (SO_4), Nitrate (NO_3), Ammonium (NH_3), Hardness ($CaCO_3$) and Orthophosphate (PO_4). Pollution sources and pathways were identified using the study area layout and by conducting an impact pathway analysis using annual descriptive statistical (annual mean or average values) of water quality tables generated by SAS enterprise 6.1 (a software used to analysed descriptive statistics of the mine water quality data) for a period 2007 until 2013, and box pots graphs showing monthly water-quality data for pH, EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$ and PO_4 at 15 monitoring localities between Kroondal Chrome Mine, the Hex River and its tributaries (Kroondal tributary and Sandspruit) over seven years. It was concluded that the surface/groundwater of the Kroondal Chrome Mine process – such as seepage from slimes dams, plant run-off and the vent shaft underground water dam – had an influence on the water quality of Hex River with regard to the discharge of pH modifying pollutants, EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$ and PO_4. Other pollution sources were discharge from Crocodile Farm and Hex River, as well as the Sandspruit upstream sources such as mining (platinum and chrome), industries' municipal sewage treatment works, agricultural activities and informal settlements activities.

Mine pollutants or constituents were identified as a unique example of the compound impact of weathering, hydrologic and anthropogenic processes such as the increased use of explosives containing NO_3 and NH_3 underground. The chemical compositions of surface

water in the mine sampling location were strongly influenced by rock water in tractions, dissolution and dilution, as well as anthropogenic inputs. Key insights drawn from the study is that, cumulative impacts in the Hex River catchment present different issues, roles and responsibilities for industries, government/ regulators and community stakeholders. Practical and cooperative management of cumulative impacts by catchment stakeholders can benefit regional environments and communities of Rustenburg and the North West Province at large. This study demonstrates the usefulness of descriptive statistical techniques for analysis and interpretation of complex data sets, water quality status of the Hex River catchment, influence of the Kroondal Chrome Mine (KCM) waste water to the Hex River catchment, pollution sources and pathways from different activities around Hex River catchment. Best practice water management was recommended to form part of the Kroondal Chrome Mine environmental objects, target and management plan as well as the mine risk profile. Cumulative management dimensions, approaches and/or methods were recommended for all Hex River catchment stakeholders including Department of Water and Sanitation (DWS), mines, farmers, industries and disadvantage communities along the catchment.

DEDICATION

This dissertation is dedicated to the following people:
My loving husband – Mr Victor Hlulani Mbele
My children – Paris and Perth Mbele
My loving parents – Mr Wilson and Mrs Maggie Mavunda

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I wish to express a deep sense of gratitude and indebtedness to my supervisor ***Ingrid Watson*** *at Centre for Sustainability in Mining and Industry (CSMI), Department of Mining Engineering, Wits University, for her inspiring guidance, constructive criticism and valuable suggestions throughout this project.*

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  - *Former SHEQ Manager Martiens Prinsloo*
  - *Environmental Superintendent Patrick Sibuyi*
  - *Water Specialist Kenneth Milanzi, and*
  - *All members of staff who also assisted in this research*
- *Finally, yet most importantly, my deepest gratitude goes to my husband and my two children for their love and patience when I was carrying out this Study; my family as a whole, relatives and friends for their strong encouragement, perseverance and support. I cannot mention all as the list is endless; however, my heartfelt thanks are extended to all those who – in one way or another – contributed to making the completion of this Study possible.*

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Note: Appendices provided separately

LIST OF ABBREVIATIONS

Abbreviation	Definition
AMD	Acid Mine Drainage
$CaCO_3$	Hardness
CAGR	Compound Annual Growth Rate
Cl^-	Chloride
CMA	Catchment Management Agency
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electric Conductivity
EMP	Environmental Management Plan
FeCr	Ferrochrome
GDP	Gross Domestic Product
IQR	Interquartile Range
IWRM	Integrated Water Resources Management
IWWMP	Integrated Wastewater Management Plan
KCM	Kroondal Chrome Mine
l/s	Litre per second
LG	Lower Group
LOM	Life of Mine
MG	Medium Grade

mg/l	Milgram per litre
MPRDA	Mineral Petroleum Resource Development Act
MRD	Mine Residue Deposits
mS/M	Millisiemens per metre
Mt/a	Million tonnes per annum
NEMA	National Environmental Management Act
NGOs	None-Government Organizations
NH_3	Ammonia
NO_3	Nitrate
NWA	National Water Act
O_2	Oxygen
PGEs	Platinum Group Elements
PGMs	Platinum Group Minerals
pH	Power of Hydrogen
PO_4	Orthophosphate
RWD	Return Water Dam
SAR	Sodium Absorption Rate
SO_4	Sulphate
TDS	Total Dissolve Solids
TWQGR	Total Water Quality Guideline Range
UG2	Upper Group 2 Reef
WUL	Water Use Licence

INTRODUCTION

1.1 Background information

It is estimated that South Africa produced about 9 600 000 tonnes of chromite bearing ore in 2009. This attests to the fact that South Africa is the world's largest producer of ferrochrome (Mbedi, 2014). According to Beukes et al. (2010), chromite was mined from the Upper Group 2 Reef (UG2), Lower Grade (LG) and Medium Grade (MG) chromitite seams. The UG2 also contains significant amounts of PGEs. This means that several platinum mines produce chromite as a by-product. KCM mines primarily from the UG2 in the western limb of the Igneous Bushveld Complex. There was several chrome mines specifically maintained to provide a chromite feed to the developing ferrochrome industry (Beukes et al., 2010). The South African ferrochrome smelting industry produces approximately 46% of the global production volume of ferrochrome (FeCr) (Beukes et al., 2010). In line with an expected increase in stainless steel demand for FeCr is expected to increase (Fossay, 2012) and chrome mining activities will be expected to continue to operate and new shafts to open in the area. Gumede (2012) has described Rustenburg as one of the fastest-growing towns or cities in the last ten years as a result of the platinum and chrome mining activities as stated by Van der Walt et al. (2006). This has implications or can have an influence on the water quality of the Hex River Catchment AH22 (Department of Water and Sanitation catchment code).

It is acknowledged by different studies that water quality is adversely affected by mining activities including chrome mining activities in Rustenburg (Hobbs et al., 2008; Nkuli, 2008; Funke et al., 2007; Ashton et al., 2001; Colagiuri et al., 2012; Tutu, 2012; Kishan, 2010). Water is one of the most essential components of the human environment (Nkuli, 2008). According to Hobbs et al. (2008), South Africa is classified as one of the most water-scarce countries (Conley, 1996; Turton et al., 2006); the North West, Northern Cape and Limpopo are the most of the areas classified as arid provinces in South Africa. Escalating mining activities are regarded to be placing tremendous pressures on water resources of the North West Province. This results in an increase of water pollution, which in turn may contribute to a rise in water-related diseases. The World Health Organization (1998) rates poor water quality, together with inadequate sanitation, as the leading cause of death in poorer communities.

The quality of water used and the protection of water resources, particularly in water-scarce countries such as South Africa, are everyone's concern and should be managed according to scientific principles (DWAF, 1998). It should be accepted that an abundance of water is of no use if the quality is of such a nature that makes it unfit for any usage (Parsons and Tredoux, 1995a). The quality of water is not an intrinsic characteristic of the water, but it is related to the intended use thereof. Water may be fit for one use but completely unfit for another (Parsons and Tredoux, 1995a). Water quality requirements will therefore differ for different user groups, such as domestic, agriculture, industrial or aquatic life. Fitness for

water use plays an important role in the management of water resources and in turn forms an integral part of water quality management (Parsons and Tredoux, 1995b).

Examples of the primary mining activities that have the potential to contaminate surface and ground water are: heavy usage of water in processing ore, polluted water from discharged mine effluent and seepage from tailings, mine fallout dust or particulate matter and waste rock dumps. Increasingly, mining actions portend the water sources on which society depend on. The presence of water in mining sites creates a range of operational and stability problems and requires a drainage plan to avoid slope stability problems, oxidation of metallic sulphides and corrosion of mining machinery and equipment (Tiwary et al., 2000). The quality of the drainage water depends on a series of geological, hydrological and mining factors which vary from mine to mine. The quality of the mine water depends on numerous factors that include – but are not limited to – physical characteristics of the ore (chrome), net acid-generating potential, groundwater characteristics, backfill practice, mining practice and age of mine. (Tiwary et al., 2000).

The chemical and physical composition of surface water and its properties is normally driven by natural processes such as precipitation rate, weathering processes, soil erosion and anthropogenic effects such as point or non-point sources of pollution including mining, industrial and agricultural activities (Jarvie et al., 1998; Giridharan et al., 2009; Nouri et al., 2009). Cyclical dissimilarities in precipitation, surface run-off, groundwater flow, interception and abstraction significantly affect river discharge and subsequently change the concentrations of chemical composition of the river water (Vega et al., 1998; Khadka and Khanal, 2008; Mtethiwa et al., 2008; Juang et al., 2009; Pejman et al., 2009). Normally, pollutants enter a river system from many transport pathways including storm water run-off, effluent discharge, groundwater seepage and atmospheric deposition (Ouyang et al., 2006; Nouri et al., 2008b; Jha et al., 2010). These pathways are also cyclical dependent (meaning seasonal rotation or changes, dependant on precipitation, surface run-off, groundwater flow,) therefore, cyclical changes in surface water quality must be well thought out when establishing a water quality management programme (Ouyang et al., 2006).

The Hex River (catchment A22H, DWS catchment code) is regarded as the one of the major surface water bodies in the Rustenburg area (Mogakabe and Van Ginkel, 2008) as it was part of the water source that supplied the community of Rustenburg area. The Hex River is part of the Limpopo River System in the northern part of the Crocodile River West (Du Plessis, 2006). It was suspected that KCM discharges its effluent intermittently into the Hex River through direct surface and underground seepage channels, which flow and accumulate into the Bospoort Dam. The Bospoort Dam is a small state-owned impoundment situated on the Hex River upstream of the Vaalkop Dam, north east of Rustenburg in the Crocodile West/Marico in the North West Province. The land uses in the catchment include intensive chrome and platinum mining areas, as well as agricultural activities and informal settlements (Mogakabe and Van Ginkel, 2008).

A major concern raised by Van der Walt et al. (2006) and Du Plessis (2006) is that in the Hex River Catchment there was an increase in chlorides, sulphates and general salinity in the Hex and Elands rivers, sub-catchments of the Crocodile-Marico Catchment area. Van der Walt (2008) and Du Plessis (2006) reveal that there were number of human activities within the Hex River catchment vicinity that have likely resulted in impacts on aquatic resources, including activities associated with mining (chrome and platinum), agriculture and informal settlement. Van der Walt (2006) and Du Plessis (2006) suggested that these activities could have increased sedimentation of rivers, and may have contributed to high-levels of nutrient rich water from agricultural run-off to aquatic systems. However, mining may pose the most serious local threat to the environment owing to the nature of mining process and water management within mining. Figure 1 shows the land use (mining, agriculture and settlements) activities within the Hex River Catchment AH22 area.

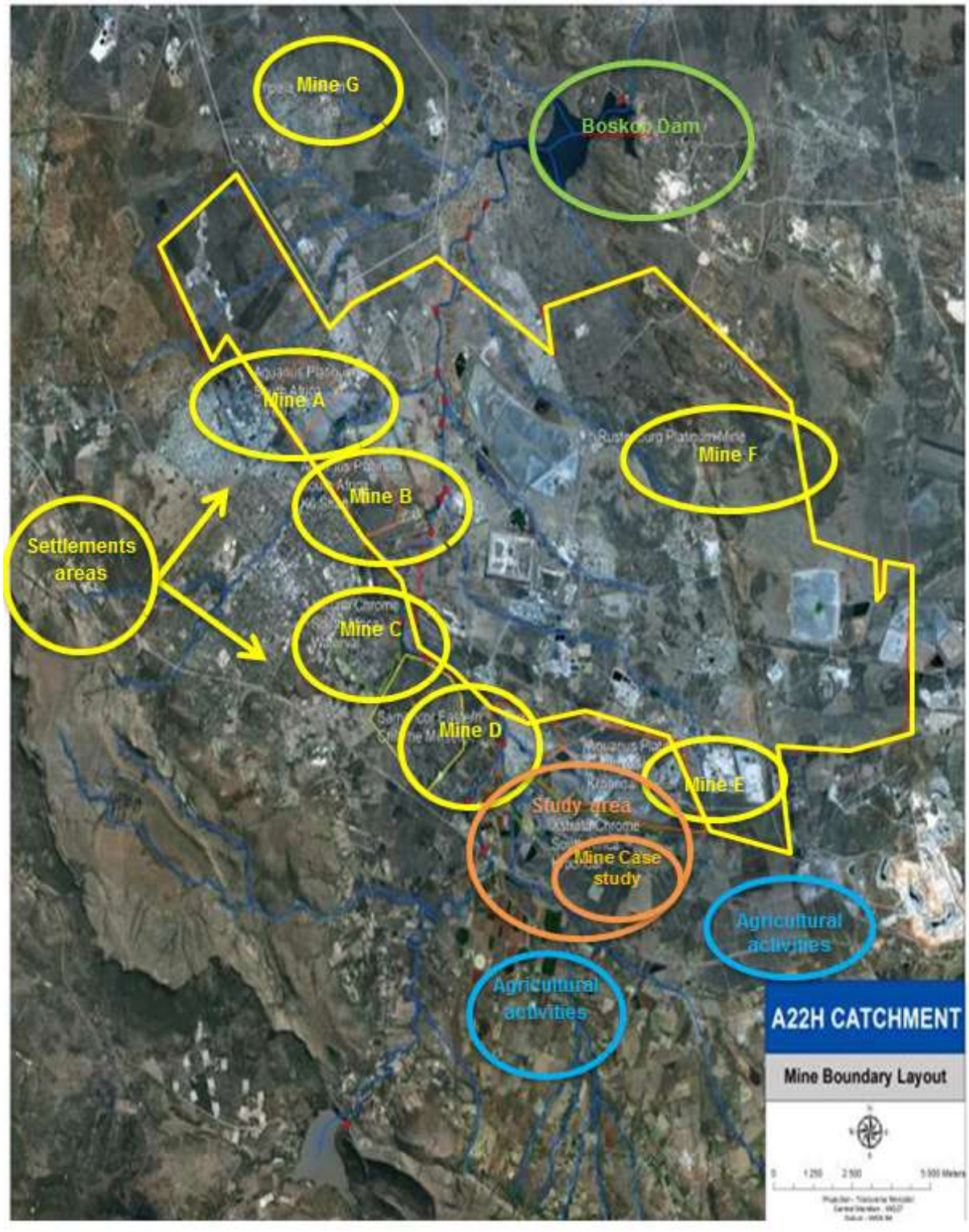


Figure 1: Bospoort Dam on the Hex River, Mines Boundary Layout, study area, KCM, and different activities in the area (Aquatico, 2013)

The upstream portion of the Hex River is mainly characterised by smallholdings and cultivated land. The downstream of the river is dominated rural settlements, some agricultural activities as well as formal and informal settlements. In close proximity to the Hex River are residential and industrial areas including mining activities taking place. Du Plessis (2006) confirms that different land uses and activities taking place within the Hex River catchment are responsible for a variety of pollutant influxes into the Hex River and its associated tributaries.

1.2 Aim and objectives

The main aim of this Study is to investigate the water quality of the Hex River (upstream and downstream of KCM), to determine the role of chrome mining activities on the water pollution predicament of the Hex River Catchment – using KCM as a case study – and to identify the pollution source as well as pollution pathways. Other objectives of the study are as follows:

- To describe the biophysical environment (climate, land use, KCM infrastructure layout and drainage system and geology) that could have an influence on the water quality of the mine area, Hex River and its tributaries.

- To assess the water quality status at monitoring point KMS15 – downstream of the Hex River – by comparing the physical and chemical water-quality data of 2007 to 2013 with the Total Water Quality Guideline Range (TWQGR) for irrigation, livestock watering, ideal domestic use class1, aquatic ecosystem and KCM exemption permit for waste water discharge into the rivers.

- To determine how KCM can have an impact on the water quality of the Hex River by conducting an impact pathway analysis of physical and chemical water-quality data between 2007 and 2013 from the downstream Hex River monitoring point KMS15 to Sandspruit, Kroondal tributary to KCM monitoring points.

- To identify potential pollution sources of the Hex River from KCM and surrounding area using the study areas site layout map and impact pathway analysis.

- To identify pollution pathways from the source to the Hex River using the study areas' site layout map and impact pathway analysis; and

- To propose a waste water management plan for pollution sources and Kroondal Mine pathways in the form of recommendations stemming from this research report and to propose a Hex River catchment waste water management plan to catchment stakeholders.

1.3 Problem statement

It is generally acknowledged that water quality can deteriorate because of the discharge of partially, or untreated, mine effluents and/or accidental discharges. These can change the chemistry of water (McKinnon, 2002; Kaye, 2005).

Currently, various mining operations and other activities within the Hex River catchment A22H are contributing to pollution, irrespective of the accidental and direct mine effluent discharges from KCM into the environment. There are limited assessments or interpretation done regarding water-quality data of KCM's water infrastructure (canals/channels, dam, slime) and the pathways of the mine's waste water to the Hex River.

In order to determine how KCM may have contributed to the Hex River Catchment problem, the following questions needed investigation:

1. What is the biophysical environment of the study area that can have an influence on the water quality of the mine, Hex River and its tributaries?

2. What is the Hex River's water quality status?

3. How is the Hex River catchment water quality impacted by pollution from KCM and other land use?

4. What are the possible pollution sources from KCM – and other land use – into the Hex River?

5. What are the possible pollution pathways from KCM and other land use into the Hex River?

6. What could be done to manage pollution sources and pathways of KCM and other land users within the Hex River catchment?

1.4 Rationale

KCM is located in the vicinity of the polluted Hex River, in the Rustenburg region of North West Province in South Africa (Figure 1). The Rustenburg region is generally arid with water shortages problems as South Africa is a water-scare country. The Hex River Catchment experiences challenges of low water quality owing to direct and indirect effluents discharged from many possible sources, for example mining, agriculture, industrial processing, sewage treatment works and formal and informal settlements (Du Plessis, 2006). KCM mines chrome ore from underground, process the chrome in the spiral plant – producing different chrome grades – and sells it to chrome smelters in Rustenburg. It exports some of their production.

As a responsible mine, KCM has implemented their Environmental Management System (EMS) to manage the environmental impact of its operation. As part of the mine's annual environmental objectives, it has been monitoring the water quality of its operation since its inception by current management around 2000. However, the mine water quality monitoring programme came into its own around 2007 as – at this stage – it covered all the mine boundaries including downstream and upstream of the nearby rivers. For more than 10 years, the water-quality data has not been analysed in detail to determine the mine's contribution to the Hex River water quality problem.

KCM is a responsible mine that cares for the environment and the society/communities where it operates. It understands that its operation has environmental aspects that can potentially impact the water quality of the Hex River Catchment. Kroondal Mine implemented their own environmental management system that helped in identifying the negative environmental aspects of its operation. Hence, the management of the mine supported – or gave approval for – this research to be conducted. The mine understood that they operate in the catchment where there are number of different possible pollution sources such as mines, agricultural activities, industries and human settlement. However, it was the mine's desire to distance itself from its contribution to the poor water quality of the catchment in order to cooperate with other stakeholders or role players in solving the Hex River water quality problem. This is because the protection and management of natural resources has become vital in achieving sustainability in the mining sector. Adequate water quality management can be achieved through the implementation of legislative requirements and current best practices. The project or study conveys the benefits, to the mine and its stakeholders or other land users, which are derived from the systematically laid-out plans, supportive stringent regulatory environments and decision-making processes that are based on sound scientific information.

The Department of Water and Sanitation states that the water quality of South African water bodies is very poor owing to the increase of anthropogenic activities – such as mining activities – which will have an impact on water resources they are not properly managed or if the mine does not implement a properly integrated water management plan during its operations. Therefore, it is important for the mine operations to investigate the effects of its activities on the Hex River water catchment. It is required by environmental legislation (National Water Act, Section 21(g)) for water users to ensure that the quality of water – in relation to downstream – does not deteriorate because of the water use (KCM) activities. During this case study, KCM was operating its water-use activities under the exemption permit (No 16/2/7/A220/C4) that was issued in October 2007. The permit was issued for the following water use according to the National Water Act:

- 21(a) Taking water from a water resource (1,900,000 m^3) per month
- 21(f) Discharging water/water containing waste into a resource (390,000 m^3) per month

- 21(g) Disposing of waste water in any manner that may detrimentally impact on a water resource (various dams)

- 21(j) Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people (4,520,800 m^3) per month

Conducting this Study will assist the mine to understand the effect of the pollutants emanating from its activities and/or its biophysical environment on the water resource (Hex River catchment) and to understand the contribution of the mine's activities to the mass balance of the water resource in order to cooperate with other water users in the catchment to determine the mass balance for the water resource reserve. The outcomes of the study will able the mine to work towards complying with the National Water Act, South African Water Quality Standards (domestic use, agriculture, general water quality discharge to the environment) and the conditions of the exemption permit (No 16/2/7/A220/C4). Since the mine has a pending application with DWA, this Study can be submitted to DWA as additional information for consideration when they process the Water Use License (WUL) application for the mine.

The proactive disclosure and action by KCM in addressing water quality could be seen as a positive contribution to enhance the mine's position with the Department of Water and Sanitation. The study outcomes will have a positive impact on the mine's water management system and the overall environmental management system. This study is important because the water quality of Hex River is of primary concern as it supports activities such as aquatic ecosystem, agriculture and domestic use for the population around the town of Rustenburg. Communities depend on water from this catchment for domestic use, which is potentially prone to contamination from mining and other activities.

1.5 Scope of the Study

For the purpose of this Study, only physical and chemical parameters in the exemption permit (No 16/2/7/A220/C4) and Kroondal mine water quality programme will be investigated for water quality status in the Hex River with respect to chrome mining activities. Refer to Table 1 for the list of physical and chemical parameters. The inclusion of other parameters – such as biological parameters – was feasible, but was beyond the Scope of this Study. The study focuses more on the referred chemical parameters above because of the reported water quality problems of Hex River submitted by the Department of Water Affairs (2008) and the nature and activities of the suspected point sources and non-point sources of pollutants from drainage and other upstream activities within the catchment.

1.6 Study layout

The research report consists of six chapters; reviews of the related, appropriate or significant literature and results of the previous water quality, environmental and social cumulative

impact studies conducted in the Rustenburg area that have been referenced throughout this report. The layout of the research report is as follows:

Chapter 1.

- Presentation of an introductory background to the South African chrome mining industry specifically referring to the Rustenburg area and its potential to influence the water quality of the Hex River Catchment; description of the Hex River Catchment AH22 and land use surrounding the catchment, main aim of the research project or study, primary objectives of the study, research problem statement, research questions, rationale or relevance of the study, scope and the layout of the research report.

Chapter 2.

- Outline of the literature review that deal with the cumulative mining impacts on the water quality of the water shared resource, point sources, non-point sources and pathways of pollution to the shared water resources; water as a shared resource; cumulative impacts and cumulative dimensions of mining and other industries; the influence of geochemistry on the water quality; a legal review of South African water quality management and factors influencing the water quality of the Hex River.

Chapter 3.

- Presentation of the methods and approach used to answer research questions one to six, limitation components of the study, data and sampling locations description.

Chapter 4.

- Presentation of the answers to questions one to five, which includes a description of the locality of case study [Hex River catchment and Kroondal Chrome Mine (KCM)], mine operations, mining infrastructure, water process flows, the biophysical environment of the study area and factors that have the potential to influence the water quality of the Hex River. The chapter also outlines the results of the water quality status of the Hex River downstream point based on physical and chemical parameters of concern assessed in the Hex River referred to as water quality monitoring locality KMS15, Hex River associated tributaries and Kroondal Chrome Mine (KCM). Pollution sources and impact pathway analysis from Kroondal Chrome Mine to the Hex River is presented.

Chapter 5.

- Discussion of the results in Chapter 4 – which concern the Hex River and its tributaries from KCM water quality status point of view – and how the Hex River was impacted by the effluent from the mine. This chapter discusses about the meaning of the results for different stakeholders, such as other mines, farmers, communities around the study

area, regulators or decision makers, South African policies and legislation, and the region of Rustenburg.

Chapter 6.

- Outline of the conclusion and answers to research Question 6 in the form of recommendations for consideration by KCM in order to improve their water quality management and their environmental management system. Other stakeholders in the Hex River catchment should also consider these findings and possibly implement them.

The last section of the report present the list of references used to review the appropriate literature that has been deemed relevant to this Study.

LITERATURE REVIEW

2.1 Water

2.1.1 A shared resource

According to Mukheibir and Sparks (2003), South Africa is a water-stressed country with an average annual rainfall of about 500mm, while 65% of other parts of the country – like the North West Province (Rustenburg) and others – receives less than 500 mm per year (DWAF, 1994). Because of the water situation in South Africa, water resources legislations, regulations, policies and standards are integrated around watershed management principles with the objective of achieving equity in access to fresh water resources that is sustainable and resourceful (water resources that are not polluted and fit to be use for different purposes) (Mukheibir and Sparks, 2003). The integrated management framework – of aspects of surface and groundwater quality and quantity – cater for water protection, water use and conservation in combination with the management of land use and cumulative impact of water resources (Mukheibir and Sparks, 2003). Legislation, policies and frameworks alone are not sufficient to address the water problems in South Africa. According to Boakye and Akpor (2012), the lack of meaningful participation by disadvantaged communities, developers and Non-Governmental Organisations (NGOs) in water resource management decisions results in the poor implementation of catchment management strategies and water policies or poor catchment impact management.

According to Mukheibir and Sparks (2003), the issues of domestic and economic development related to the service delivery of water – most especially to poor communities that are dependent on the polluted rivers to access water for domestic purpose – as a key to a logical development strategy. Access to good water quality or clean water is the most significant reserve for dipping poverty and disease, as well as enlightening the life of poor, disadvantaged South Africans (Mukheibir and Sparks, 2003). The combination of attaining equity and economic growth by government depends on the adequate supply of water for economic activities and clean water to all South Africans for domestic purposes, together with our catchments already under stress owing to pollution problems (Mukheibir and Sparks, 2003). Current water pollution in South Africa pose a major challenge to water policy in South Africa when it comes to the protection of water quality versus economic development and sustainable water management (Mukheibir and Sparks, 2003). The involvement of private sectors or developers, as well as communities in all areas (including the poorest of the poor in the rural communities, NGOs and other stakeholders in water resources including government on the catchment management agencies or water decision-making) will facilitate the implementation of water laws and policies.

2.2 Impacts of mining on water resources

According to Finlayson et al. (2008), the purpose of mining is to meet the demand for metals and minerals resources and to contribute to the quality of life for society by creating

employment or jobs. The mined minerals ore are used as the raw materials for manufacturing of goods and materials (Finlayson et al., 2008). Because of mining operations, water pollution encounters has become a severe risk to people for many years (Kishan, 2010).The shared sources of water pollution are drainage from the mines, industrial effluents and domestic sewage. The natural weathering of rocks – which supplies a significant amount of toxic elements and compounds to surface and ground water – is a background to the pollution effect in the mining operation.

According to Koryak, (1997), generally, is known that mining operations generate waste water discharges comprising physical and chemical pollutants, which adversely have an influence of the quality of surface and groundwater resources that frequently cause significant pollution to the water bodies. However, Ellis (1989) as cited in Nkuli, (2008) argues that the effect of degraded water quality or polluted water not only affects the local area of the mine, but is often felt downstream of the mine far away from the source of pollution. Harrison (1990) as cited in Nkuli, (2008), argues that, as pollutants are discharged into a water source such as a river, the concentration of pollutants is initially high owing to the ability of a river to disperse these pollutants. However, it can be more difficult in a situation where there are multiple pollution sources along the water course such the Hex River (refer to Figure 1). Cumulative impacts of difference pollution sources increase the stress on the ability of a river to disperse pollutants from influencing the water quality of the catchment.

According to the 2002 State of the Environment Report for North West Province, mining has major negative impacts to the North West Province's water resources (NWPSoER, 2002). Most mines and other industries discharge waste water products into the used water, which is discharged as effluents into rivers and other surface water (NWPSoER, 2002). Mining and associated industries also have an effect on the water resources through waste water discharges (NWPSoER, 2002). Often, the mines have associated "mining villages" with their own sewage and water provision infrastructure. These associated services are not part of a mining entity's core business and they are operated under severe financial restraints, which compromise the quality or effective operations that could contribute to the poor water quality within the mining areas and informal settlements near the mines.

2.3 Cumulative impacts

According to Franks et al (2010a), the cumulative impacts of mining comes from the doings of an individual operation or numerous mining, industrial operations, farming and the cooperation of mining, industries and farming impacts with the past, current and future activities that may not be linked to mining, industries and farming activities. Cumulative impacts are visible in the numerous mining operations in an recognized mining province such as the North West Province in Rustenburg and through the cooperation of mining activities with other activities and industries such as agriculture, sewage treatment plants and many more (Franks et al., 2010a). This study considers the site localised cumulative impacts from a single chrome mining operation and other activities in the immediate vicinity

of the impacted Hex River Catchment A22H. A special cumulative impact in the study area includes the cumulative effects from operations that are in the close proximity to cause probable significant effects on the environment. Significant effects can include but not limited to: dust deposition, mine effluent or waste water discharge to a water catchment, groundwater and surface water quality, and transport where the source of impacts comes from the several mine sites and other activities. The Hex River Catchment A22H receives numerous impacts of water quality that may be more complex to each distinct water quality impact, than if it was experiencing them in isolation. The presence of waste water discharge from mining activities may change how waste water discharge from agricultural and other activities (industries and settlements) may be experienced in the Hex River Catchment A22H, independent of how water quality impacts were generated (Franks et al , 2010b).

It is imperative to study and comprehend the connection of impacts that comes from numerous sources in order to avoid, mitigate and enhance impacts effectively to the Hex River Catchment A22H. The impact pathway analysis is adopted in this research to map the connections of direct and indirect impacts of Kroondal chrome activities and their interface. By plotting how impacts are generated, interact and combine within the Hex River Catchment A22H, the pathway of impacts from nearby activities (mining, agriculture, informal settlements, industries) will be predicted.

According to Franks et al., (2010), the environmental and social impacts assessments requires the entirety of impacts on the water catchment to be understood. The impacts can be created or generated directly from chrome mining or agriculture, informal settlements and other industries activities, indirect and direct pathways, the mixture and interface of direct and indirect impacts with cumulative impacts, and the feedback of cumulative impacts to produce further indirect and cumulative impacts. A conceptual framework of cumulative impacts of mining by Franks et al (2010) has been adapted to this Study (Figure 2) in the context of receiving environment being the Hex River Catchment water quality that is influenced by the past, current and reasonably foreseeable future impacts of KCM and the other activities surrounding the catchment.

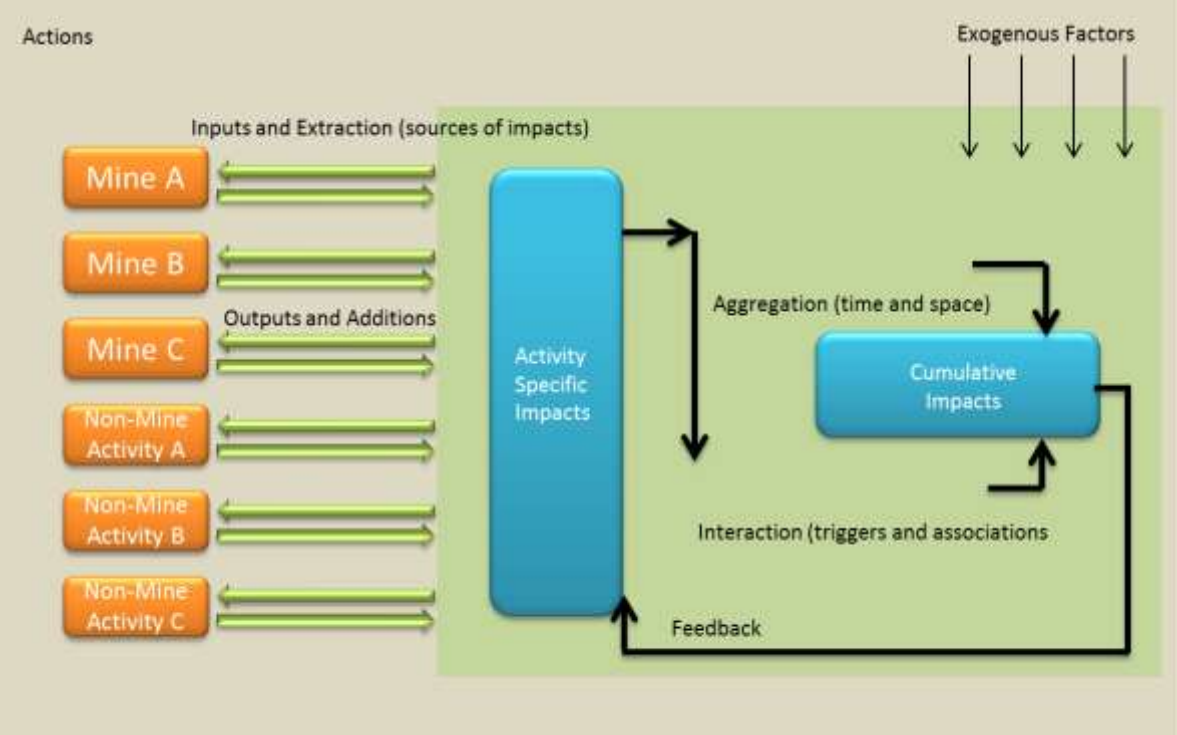


Figure 2: Conceptual framework of the cumulative impacts of mining (Franks et al., 2010a)

Figure 2 illustrates the model of cumulative impacts in mining in the context of Kroondal Mine's impacts aggregating and interacting with other activities impacts within the Hex River Catchment. The model is interpreted as follows: KCM (Mine A), other mining activities (Mine B and Mine C), Agricultural activities (non-mine activity A), informal settlements (Non-mine activity B), Municipal sewage plants (non-mine activity C), industries (exogenous factors) and the Hex River Catchment (Receiving environment).

According to Franks et al (2013), Figure 2 progresses other opinions and/or positions that place the mining and other impacts at the centre of analysis, which means cumulative impacts are the consequences of the combination and interface of impacts on a receiving environment and may be a product of history, current or upcoming activities (Franks et al., 2013). Franks et al., (2013) support the idea of getting read of the definition of cumulative impacts or effects ("what is or what not cumulative impacts are") and came up with the approach of focusing on the "cumulative dimensions of impacts" to manage cumulative impacts of mining.

Dimensions of impacts cover the aspects of understanding and managing impacts from a traditional cumulative viewpoint, as outlined by Franks et al., (2013). Dimensions of impacts in Figure 3 below, present the impact drivers, impacts areas and governance. The impact drivers refers to the sources of impacts or "actors" their decisions and actions towards the environmental or water resources (Franks et al., 2013). The impact arears refers to the receiving environment including the sufficient knowledge of the receiving environment and

receiving social classification or arrangements (Franks et al., 2013). Governance refers the interface of formal government legislation, policies, regulations and standards with the impact of society – their social characteristics and the resolutions endorsed and made by managers of the mining, industries and other operations in the impact areas (Franks et al., 2013). Then, impact drivers and impacts areas linked by the flows of energy, material and information that results from management decisions relating to existing and proposed developments in the region (Franks et al., 2013).

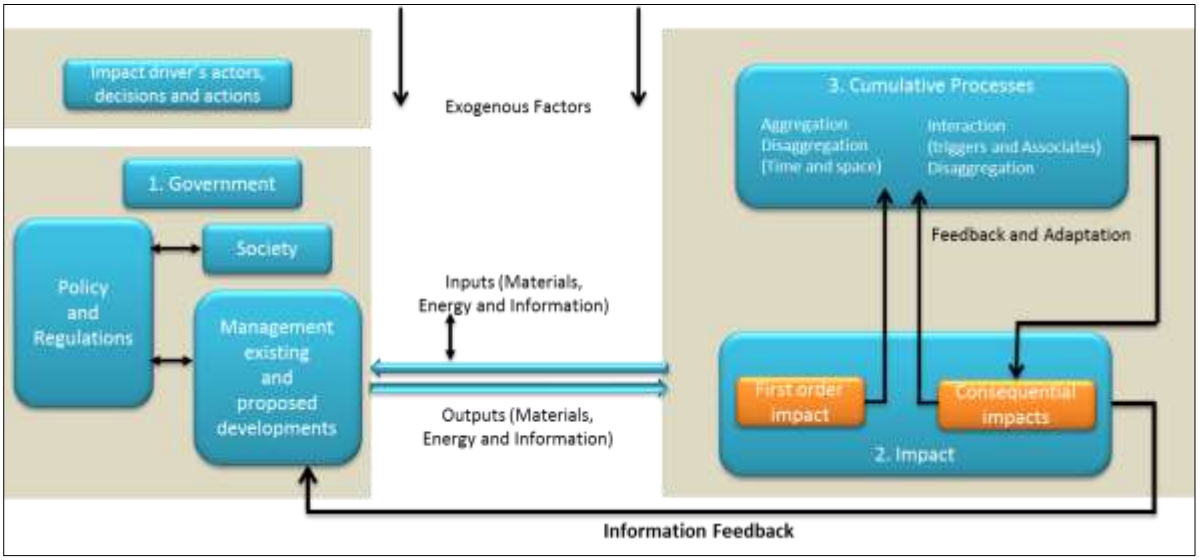


Figure 3: The cumulative dimensions of impacts (Franks et al., 2013)

According to Franks et al., (2013), cumulative dimensions of impacts illustrated in Figure 3, have an important role in how resource development (e.g. mining, industries and farming) and resources within the regions of Rustenburg can be regulated and managed going forward. Franks et al. (2013) argues that the traditional impact management paradigm in Figure 2 focuses only on identifying the impacts on the extent practical and quantifying the likely impacts that a particular development (such as KCM) will have on the receiving environment (such as the Hex River Catchment), for example, how much waste water or effluent is generated and discharge to the environment; how much dust is generated; how many jobs are created, biodiversity disturbance, emissions and others.

According to Franks et al., (2013), government will then makes a decision on whether the level of impact is acceptable, or desirable, and engages with developers or industries on mitigations and enhancement strategies for achieving the acceptable limits. For example, the exemption permit for waste water discharge into the Hex River and the return water dam issued to KCM by the Department of Water Affairs and Forestry by then in 2007, now Department of Water and Sanitation. According to Franks et al., (2013), the important tool for government or regulators is the set of operating conditions attached to the licence or exemption permits or permits, complemented by the requirements on developers to monitor

and report on compliance with various standards such as water quality discharge and others. Government or regulators also conduct periodic inspections to monitor and verify compliance by developers.

2.4 Addressing cumulative impacts in the shared water resource region

According to Franks et al ., (2013), there are number of established methods of addressing cumulative dimensions of impact, which differs from the traditional impact management paradigm in Figure 2 or the existing approach in several key respects. Below is the more mature approach to dealing with the cumulative dimensions of impacts in context of Hex River catchment and KCM, (Franks et al., 2013):

- The main emphasis of water quality analysis by all Hex River catchment stakeholders should be on the Hex River catchment, the receiving environment, instead of individual mines and other developments. This approach requires more work in understanding the surroundings of the impacted Hex River catchment and monitoring water quality trend over time. The lack of understanding the surroundings of the impacted Hex River water catchment or knowledge will render it impossible to make any informed decisions about the impacts of any development with potential to affect the Hex River catchment or to put appropriate mitigation strategies in place.

- Government, DWS in this regard, should contemplate the contribution of each particular development (e.g., volumes of waste water discharge in to the Hex River catchment) in assessing whether developments should proceed and under what conditions, as well as the disposable effect of all current and future developments that have the potential to impact the affected Hex River catchment.

- Additional broader approaches should be taken to the design and implementation of mitigation and enhancement strategies, with the focus being on the management of Hex River catchment, the receiving environment.

- Obligation for managing cumulative impacts at a regional scale should be imposed also to the established mines, famers, and industries already operating or may be working under less stringent water use licence conditions, e.g. exemption permits to discharge waste water issued to KCM, an established operating chrome mine within the Hex River catchment and water use licence issued to the newly developed mine with stringent conditions.

- Very low confidence anticipated on setting prescriptive conditions at the front end of the developments and more emphasis on adaptive regulatory and management processes. Receiving environment (groundwater, rivers and others) networks are very dynamic, generally are not well understood. Dealing with this uncertainty, government and developers must have sufficient capacity to modify existing response promptly as new information comes and as anticipated and unwanted changes are identified.

Working examples of cumulative impact management and assessment with the aim to guide and encourage future practice are outlined by Franks et al., (2012). Franks et al., (2012), argues that cumulative impacts in mining, in a context of three major Australian coal resource provinces and the challenges confronting each region, assessment and management practices adopted to respond to the diversity of cumulative impacts in those regions:

- The Hunter Valley in New South Wales, which is characterised by a mature high-density mining region,
- The Bowen Basin in Queensland, known as a relatively dispersed mining region, and
- The Gunnedah Basin in the New South Wales, which is characterised as a prospective region.

Franks et al.,(2012) augers that attentive consideration is required owing to the scale of cumulative impacts experienced by mining resource areas, a scope to improve impact assessments through careful analysis of the different ways by which impacts combined and cooperate, collection and anticipating of information on publicised and future developments, and collaborative research. According to Franks et al., (2012) government or regulators could also play a significant role through the provision of strategic assessments, and unambiguous relations between regional and land-use planning. The cumulative impact management can be attained through institutional forms from individual company initiatives and programmes, to cross-industry and multi-stakeholder partnerships and networking (Franks et al., 2012). According to Franks et al., (2012), cumulative impact management approaches – such as information exchange, networking and forums – are relatively straightforward and commonly practised, while more advanced approaches – such as coordination and planning, as well as multi-stakeholder monitoring – can be far more challenging to implement, but concurrently offer greater opportunities to manage cumulative impacts in the regional scale.

According to Weber et al., (2012), there are number subjects pertaining to the management of cumulative impacts in a regional scale similar to Rustenburg and Hex River catchment. According to Weber et al., (2012), science, social and governance dimensions of cumulative effects assessment and management are important on scenario analysis; the incorporation of social indicators in land-use decisions; understanding thresholds, adaptive capacity and resilience; and governance and decision-making in land use planning.

Scenario analysis applies in data-limited regions and how to incorporate social magnitudes of land-use change, especially in Indigenous communities (Weber et al., 2012). Identification and implementation of cumulative effects thresholds with local-to-global governance have its own challenges, (Weber et al., 2012). However there are different approaches for measuring social, economic, and ecological indicator responses to change (Weber et al., 2012).

Weber et al., (2012) argues the following important points regarding management of cumulative impacts in a regional scale such as Rustenburg region with different activities operating along the same water catchment:

- Organisation and presence of numerous shared procedures to inform cumulative effects assessment that highlights the exclusive role of Indigenous communities in identifying ethnical relevant indicators for cumulative effects assessments incorporated into various management decisions.

- Ongoing political support is essential to reinforce the collective scientific or public engagement process.

- Applying transparent and secured approaches is very significant for developing scenarios and applying this approach in data-limited regions,

- Placing value on the elusive and incommensurable ecological goods and services is very significant in cumulative impact management,

- Incorporating social values and indicators that explore reasonable outcomes while acknowledging that communities can indicate other courses of action in the managing cumulative impact in the shared water resource, and

- Simplified approach or methods to communicate combined displaying results with non-technical members will improve the flow of information in attaining cumulative impact management.

According to Bragagnolo et al. (2012), Spatial Planning and Strategic Environmental Assessment (SEA) currently address cumulative effects only to an insufficient magnitude. Bragagnolo et al. (2012) arguers that, the regional-scale or-level of SEA plays a significant role in potentially addressing cumulative impacts and/or environmental priorities in the impacted environment through the following aspects:

- Establishment of cumulative issues for the sub-regions,

- Resource-based targets and indicators (e.g. land-take threshold),

- Methods appropriate to scales (e.g. scenario analysis, SWOT, suitability analysis)

- Operational measures such as compensation mechanisms and responsive contracts.

Bragagnolo et al., (2012) identified areas for improvement to the assessment of cumulative effects in Strategic Environmental Assessment (SEA) of special plans. The main areas are as follows:

- Enhanced assessments of cumulative effects can provide for an early discussion of environmental and policy contexts concerning cumulative effects through stakeholders' consultation and participation. Enhanced assessments of cumulative effects may also play a significant role in detecting small-scale effects, defining shared priorities and addressing multi-level responsibilities.

- Supplementary operational spatial planning tiering by addressing cumulative assessment tasks for different levels of the spatial planning hierarchy, and inter-tier frameworks to improve management of cumulative effects across different levels of planning and decisions".

Case studies of tree farming in Victoria, groundwater protection in the Murray Darling Basin and farm dams by The Finlayson et al., (2008) proves that, cumulative impacts are widespread. However, the legislation, regulations, policies and standards if transformed into practice, managing cumulate impacts and effects could be more effective. Finlayson et al., (2008), argues that cumulative effects within the water resources industry must be taken much more seriously, as water is an important resource to human-beings and for our economic development. According to Finlayson et al., (2008) catchment management agencies should consider including at least five critical elements in the catchment management programmes in order to manage cumulative impacts of the shared water resources:

- Instituting of planned development of all practices of water abstractions and discharge on a catchment basis recognised in the water resource legislation, policies, regulations, standards and local government planning processes. Systems should be in place to implement all practices of water abstractions and discharge in consultation with all stakeholders.

- All practices of water abstractions and discharge must be comprehensive and inclusive, covering water extraction and discharge from surface and underground.

- Catchment Management Agencies to incorporate adaptive management principles thoroughly with catchment planning processes, in order to understand the drivers of change in the Hex River catchment, interest in stakeholders to address other water quality related issues, trade-offs between the ecological, social and economic perspectives and other .

- When developing all practices of water abstractions and discharge, concentration should be on the position where the water catchment faces water quality problems situation.

- Precautionary measures should be applied when setting practices of water abstractions and discharge.

According to Franks et al. (2013), a better response to cumulative impacts of mining and other industries can be achieved through collaborative and coordinated approaches across the range of environmental, economic and social concerns, geographical regions and different commodities. Most of the cumulative impacts management approaches, examined by different researchers reference in this report, emphasise the importance of various forms of collaboration for managing cumulative impacts, strategies for working together, networking, coordination, cooperation, collaborating, integrating and partnerships. These approaches – if well executed – can assist to achieve the cumulative problems in different regions of different receiving environments.

2.5 Pollution sources and pathways of contaminants in surface water

2.5.1 Chrome/Platinum Mining

Mining activities in Rustenburg negatively impact the water resources owing to poor management of mining waste, for example slimes, waste rock and overabundant exposure of mine over burdens or waste rock materials that contains sulphide-rich materials and sediments which are generated throughout the mine's lifespan with the potential to generate Acid Mine Drainage (AMD). The situation increases concern as the water run-off can transport to the environment the acidic and toxic contaminants. Polluted water from waste rocks may take a very long time to dilute, depending on the minerals or metals responsible for the pollution.

Product and water used in processing generates pollutants such hexavalent chromium (Cr (VI)) which can be formed from chrome/platinum mining waste rock in the study area. It is most usually associated with tailings, chromium ore processing residue and dust (Bialy and Layfield, 2012). According to Lenntech, (2011), Hexavalent chromium compounds are ranked as a water hazard class 3 and are regarded as very poisonous to plants and animals. In 2007, the Blacksmith Institute declared Orissa in India one of the top 10 most-polluted places in the world because it holds India's largest chromite deposits with a number of operational and abandoned mines in the area. The area is described as being heavily affected by leaching of hexavalent chromium and intestinal bleeding, asthma and birth defects have become common in communities surrounding the mines. The processing of chrome does not only affect the environment of the mine area and surroundings, it also has impact on the water resources used for domestic purposes by communities surrounding the mines.

Infiltration of polluted waters underground, contaminating the groundwater resources, depends on the geology and depth of the mining location and de-watering water from mine into rivers and particulate materials emitted during mining. For example, dust generated during extraction of the ore body getting into contact with water or settling on the water and increasing Total Dissolve Solids (TDS). Afterwards, the potential for precipitation of secondary minerals accelerates when water becomes saturated with emitted particulate matters or discharge pollutants. According to Hordijh and Kroeze, (1997), the release of

acidifying compounds into the atmosphere contributes to acid rain, same as the release of sulphur dioxide (SO_2) into the atmosphere is most commonly returned to the earth's surface as sulphuric acid (H_2SO_4) (Hordijh and Kroeze, 1997).

2.5.2 Agricultural run-off

Agricultural activities – such as ploughing, fertilising, planting, harvesting, grazing, and irrigation – are the sources of major agricultural pollutants. Rain fall water flushes agricultural pollutants from crops, pastures, and forest lands through farm drains and rivers, leaching pollutants from soils in to waterbodies such as Sandspruit and the Hex River. Rivers act as receptor and pathway of pollutants that originate from both point and non-point sources along their banks. Pollutants associated with agricultural activities – such as pesticides; other agricultural chemical, e.g., nutrients, salts, animal wastes/confined animal facilities; and sediment from eroded soils – is transported through the rivers and tributaries to the receptor.

2.5.3 Municipal sewage treatment plants and industrial facilities

The following waste water treatment works are situated within the Hex River Catchment; Jabula waste water treatment works; Thekwane waste water treatment works; Brakspruit waste water treatment works and Klipfontein waste water treatment works (Du Plessis, 2006). According to Van der Walt, (2006) as cited in Du Plessis (2006), Wastewater treatment works processes have been reported not to be able to remove all solvents, metals or chemicals from waste water. (MMSD, 2001), as sited in Du Plessis (2006) confirms that acidic saline conditions mobilisers dissolve metals and nutrients enrichment caused by blasting residues while eutrophication, pH fluctuations and decreased oxygen content are caused by sewage discharges. According Du Plessis (2006), pollutants from industries along the Hex River Catchment A22H include metallurgical industries – chrome plants; Scaw Metals; SA Breweries; Bokekeng Brick and Tile; Ceramic works; Alpha Ready Mix; Alpha Cement; Coca Cola; Epol; Rustenburg Abattoir; Rainbow Farms; Willard Batteries, storm water run-off as well as discharge from these waste water treatment works and industries can increase the pollution load and negatively impact the water quality of the Hex River.

2.5.4 Informal settlements

The Hex River catchment is surrounded by mining, industries, agriculture and informal settlement that are densely populated owing to the proximity of working areas (mining, industrial farm holdings) and Rustenburg town. This is indicated in Figure 1. Most of these settlements areas use the water from the Hex River and its tributaries for domestic purposes such as swimming, bathing and washing clothes. The surrounding community is currently supplied with drinking water from Rand Water and Magalies Water since the Bospoort Dam suffered a decline in water quality owing to the increase eutrophication, odour and taste problems. The current domestic use of the Hex River and its tributaries by informal settlements could increase the water quality problem in the catchment through the use of

detergents, discharge of informal domestic sewage, solid waste disposal and drainage run-offs and others.

2.6 Environmental geochemistry

Activities of KCM involved dewatering of underground water to the surface. Two surface water dams (Ericson Dam and Settlers Dam) within the mine contain underground water and some of the water is pumped from the two surface water dams and used in the process plant. According to Asklund and Eldvall (2005), the groundwater settings differ extensively and are a collective result of the arrangement of the water flowing in the groundwater basin and the reactions with minerals present in the rock that may transform the water quality. Some minerals – like carbonates – melt quickly and significantly change the water quality. According to Asklund and Eldvall (2005), other minerals, such as silicates, do not melt in water and have less influence on the water alignment. The mineral composition of the ore body of KCM blasting residues have an impact on the underground water intercepted during mining underground, this has been established by elevated physical and chemical constituents of the underground water quality brought to the surface by mine dewatering activities.

According to Appelo and Postma, (1999), the holding time of the water is another important element in determining the water quality or chemistry. Long holding times allow reactions of minerals to take place and these waters are likely to have higher concentrations of ions than water with short holding times (Appelo and Postma, 1999). The underground water in the Ericson and Settlers dams was always stored for a long time before the water could be used or the dam could be cleaned. The long storage of the underground water in the dams has influenced the physical and chemical constituents of the underground water quality because of exposure to different temperature on the surface ground and influence chemical reaction in the water dams.

Espeby and Gustafsson, (2001), argue that, in pollution-free environments, the concentration of most metals is very low and is commonly determined by the mineralogy and the weathering process. There are inadequate instances of local metal pollution through natural weathering, but usually metals become an environmental and health issue because of added-on anthropogenic activity like mining and smelting plants that release metals from the core or bedrock (Walker and Sibly, 2001). Soil concentration of adsorbing surfaces (oxide surfaces, clay mineral and humic substances) and the pH are very important parameters affecting the transportation of chemical parameters in the water-flowing pathway (Espeby and Gustafsson, 2001). This could be the case in the study area: different studies conducted in the Hex River Catchment have reported the concentration of most metal to be very low (Venter, 2004; Van der Walt et al*.,* 2006; Du Plessis, 2006; Clean Streams Environmental Services, 2003).

2.7 South African mine water quality control legal framework

According to Cochrane, (2002), formal mining in South Africa is more than 100 years old, early legislation focused on surface rehabilitation and the primary emphasis of mining was on economic gains excluding environmental management and rehabilitation. The Minerals Act (Act 50 of 1991) was the first South African piece of legislation that forced mining operations to include sustainable land management practices in mine closure (Cochrane, 2002). The responsibility to manage mining impact on the environment was according to The Minerals Act (Act 50 of 1991), consigned in the owner of a mine and regulated through an environmental management programme (EMP) (Hobbs et al., 2008). Mining companies therefore complied with the absolute minimum requirements and also followed a reactive approach (Swart, 2003). Mining does, in general, have a substantial impact on the environment, which has unfortunately left South Africa with an enormous economic, social and environmental legacy (Cochrane, 2002).

According to Swart, (2003), prior to the enactment of the Minerals Act (Act 50 of 1991), mining companies applied negligent mining methods, with no intention for protecting the environment and frequently avoided their obligations towards rehabilitating the environment, by leaving and area not rehabilitated prior to the company being liquidated or leaving the country. With regard to water quality legislation before 1994, the Water Act No. 54 of 1956 was introduced for the purpose of consolidating and amending the laws relating to the control, conservation and use of water for domestic, agriculture, urban and industrial purposes in certain areas and control of certain activities (Water Act No. 54 of 1956). Water Act No. 54 of 1956, failed to address the prevention of water pollution by all activities that have the potential to pollute or change the quality of the water resources.

Proper management of environmental impacts is required from the outset of mining operations. Internationally, principles of sustainable environmental management have developed rapidly in the past years. Locally, the Department of Water Affairs (DWAF, 2008) and the mining industry have made major strides together in developing principles and approaches for the effective management of water within the industry (DWAF, 2008). This has largely been achieved through the establishment of joint structures like Strategic Water Partnership Network (SWPN) South African Water Research Council, Catchment Management Agencies, Catchment Management Forums and Chamber of Mines, where problems have been discussed and addressed through cooperation (DWAF, 2008).

The coming to power of the new South African government in 1994 resulted in the adoption of a new Constitution (RSA, 1996) and the South African environmental framework underwent a major transformation to align with new Constitutional imperatives (Funke et al., 2007). Government became the custodian of South Africa's natural resources, which was the collective property of the people (Funke et al ., 2007). The National Water Act (NWA) (Act 36 of 1998) was promulgated. Three major pieces of legislation that emphasised the protection of the environment and natural resources came into being, namely: the National Water Act (NWA) (Act 36 of 1998), the National Environmental Management Act (NEMA)

(Act 107 of 1998) and the Minerals and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002).

Section 24 of the Bill of Rights in the Constitution of the Republic of South Africa (Act 108 of 1996) enshrines the concept of sustainability, specifying rights regarding the environment, water, access to information and just administrative action. These rights – and other requirements – are further legislated through the National Water Act (NWA) (Act 36 of 1998). The latter is the primary statute providing the legal basis for water management in South Africa and has to ensure ecological integrity, economic growth and social equity when managing and using water.

Under The National Water Act (NWA) (Act 36 of 1998), regulations (Regulation GN 704 of 1999) were passed on the use of water for mining and related activities, which were aimed at the protection of water resources. Use of water for mining and related activities is regulated through regulations updated after the promulgation of the NWA (Government Notice No. GN704 dated 4 June 1999).

The NWA, administered by the DWS, is the principal Act governing water resource management in South Africa, including the prevention of pollution of the water resources. The NWA also governs water abstractions and physical alterations for the purpose of protecting the water resources. The National Environmental Management Act No. 107 of 1998 (NEMA) is administered by the Department of Environmental Affairs (DEA), and addresses mining impacts through statutory requirements for Environmental Impact Assessments (EIAs) and Environmental Management Programmes (EMPs). The act further requires that pollution or degradation of the environment must be prevented or rectified. Section 2 of NEMA lists environmental principles such as the ‘Polluter Pays Principle’ that has direct implication for the mining industry (Hobbs et al., 2008). This principle requires that those responsible for producing, allowing or causing pollution should be held liable for the costs of clean-up and legal enforcement (DWAF, 1998; Taviv et al ., 1999). If the landowner or person responsible for the pollution fails to take the required action, the DEA may take actions and recover the costs from the responsible polluters. The MPRDA – administered by the DMR – regulates mining, including transformation of the minerals and mining industry, promotion of equitable access to the mineral resources of the country and environmental sustainability of the mining industry. Ownership of minerals rights was previously vested in the state or the private sector. The new objective of government is for all mineral rights to be vested in the state, with outstanding regard to constitutional ownership rights and security of freeholding (Mwape, et al., 2005).

The National Water Act, 1998 (Act No 36 of 1998) stipulates that water-use authorisation must be obtained before construction of a Mine Residue Deposit and/or return water dam may commence. Government Notice No 704, regulations of the National Water Act, 1998 (Act No 36 of 1998) regulating the use of water for mining and related activities aimed at the protection of water resources. The National Environmental Management Act, 1998 (Act No.

107 of 1998) requires that an environmental impact assessment (EIA) must be carried out before the construction of new infrastructure that is listed in the EIA regulations (mining and mining infrastructures) (NEMA 1998). The Mineral and Petroleum Resources Development Act (2002) and its regulations required that an environmental impact assessment be undertaken for a mine, which will include MRDs. However from December 2014, EIA requirements (section 39 to section 42) of the MPRDA were repealed and incorporated into NEMA. These changes gave birth to one environmental system and the DMR became the competent authority for mining permits, according to NEMA. The DEA was only involved in the appeal process for mining applications only. One environmental system is the integrated application for mining permits that includes environmental authorisation, water-use licences and other permits that may be required for the mine.

The National Water Act introduced the concept of Integrated Water Resource Management (IWRM), which consists of all aspects of water resources including water quality, water quantity and the aquatic ecosystem quality (quality of the aquatic biota and in-stream and riparian habitat). The integration of resource and source directed measures forms the basis of the hierarchy of decision aimed to protect the resource from waste impacts. This hierarchy is based on a preventative approach and the order of priority for mine and waste water management decisions and actions is applicable (Figure 4).

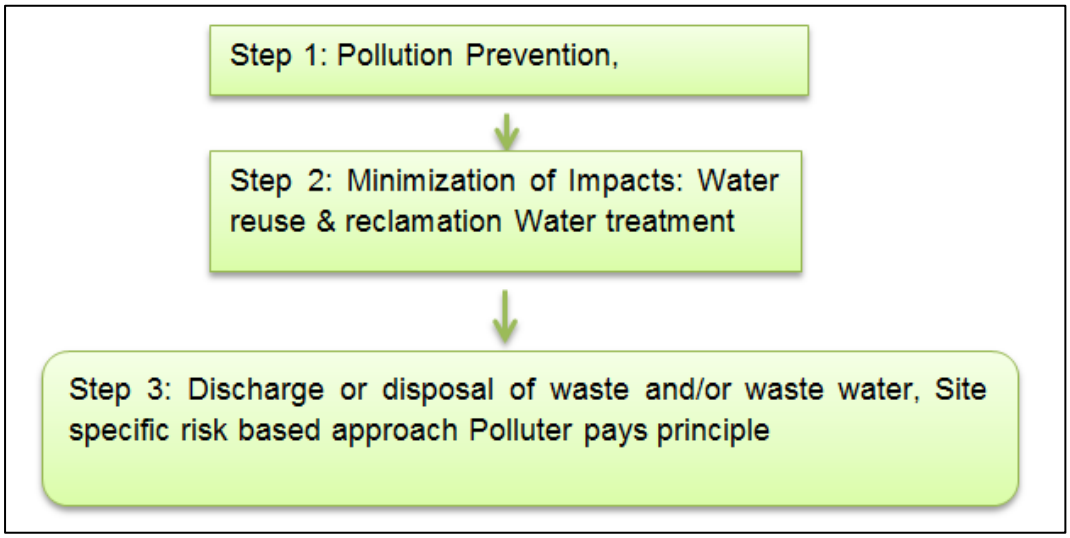


Figure 4: Resource protection and waste management hierarchy (DWAF, 2008)

Water Resource Protection and Waste Management in South Africa have developed at a number of different levels as described and illustrated in Figure 4. The general resource protection and waste management policy sets out the clarification of policy and legal principles as well as functional and organisational arrangements for resource protection and waste management in South Africa. Operational policies describe the rules applicable to different categories and aspects relating to waste discharge and disposal activities. Such

activities from the mining sector are categorised and classified based on their potential risks to the water environment. Operational guidelines contain the requirements for specific documents, e.g. water-use authorisation application reports. Best Practice Guidelines (BPGs) define and document best practices for water and waste management.

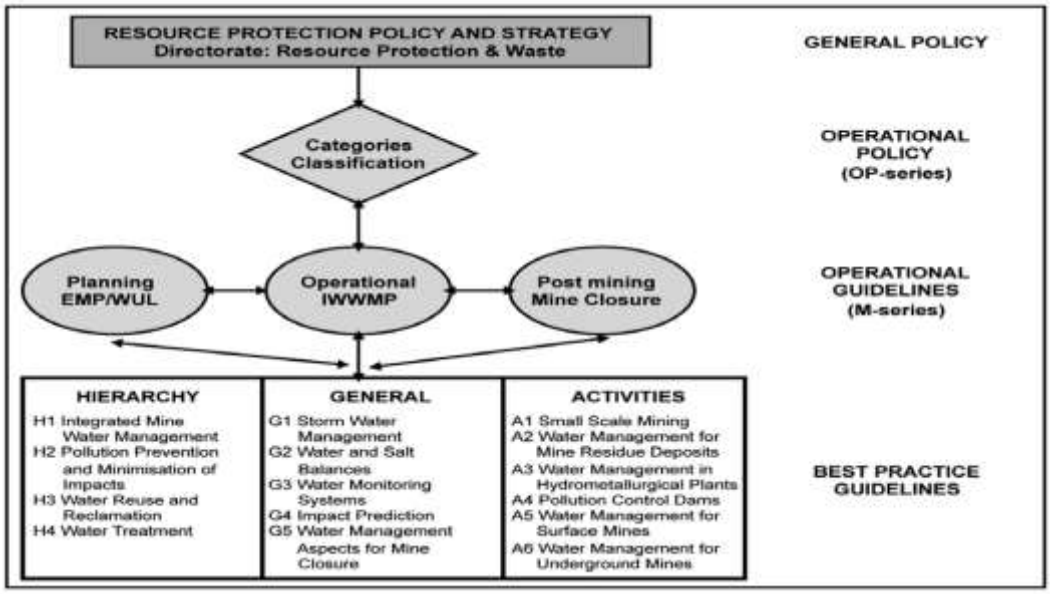


Figure 5: Schematic diagram of the mining sector resource protection and waste management strategy (DWAF, 2008)

South African Water Quality Guidelines and Target Water Quality Guideline Ranges (TWQGR) are currently used as the primary source of information for determining the water quality regulations of different water uses and for the protection and maintenance of the health of the aquatic ecosystem by the Department of Water Affairs. These guidelines form an integral part of the water quality management strategy to maintain South African's water resources as fit for use. The Department of Water and Sanitation described the acceptable levels of different constituents of water quality (physical, chemical and biological) in an effort to maintain the quality of water resources with no effect range (DWAF, 1996). According to Barnard, (1999) as cited in Du Plessis (2006), South African Target Water Quality Guidelines Ranges were determined with an assumption of the long-term continuous use of water.

South African Water Quality Guidelines and the Kroondal Exemption Permit or discharge limits have been used to set the target limit for concentration of the physical and chemical constituents analysed in this research report. For the purposes of this Study, the Water Quality Guidelines for domestic use class 0 = ideal. Agriculture (irrigation or livestock watering) and aquatic ecosystem were used to measure the concentration of physical and chemical constituents from Kroondal Mine to Kroondal tributary to Sandspruit to the Hex River. Water Quality Guidelines for domestic use class 0 = ideal. Agriculture/irrigation and aquatic ecosystem were selected based on the observations in the catchment, where

informal settlements utilised the water in the Sandspruit and the Hex River for domestic purposes, while agricultural activities (irrigation or livestock watering) also occur along the Hex River. According to Du Plessis (2006), the aquatic environment of the Hex River Catchment A22H has been severely affected in some areas and further economic and social development could result in the local extinction of certain species in the sections of the catchment.

Physical and chemical constituents could have effects on the Hex River Catchment A22H by influencing the water quality or suitability of the water for use for domestic and agricultural purposes as well as the aquatic environment (Du Plessis, 2006). The physical and chemical constituents listed in the exemption permit for KCM and those reported to be the problem in the Hex River Catchment will be discussed in Chapter 5 of the research report. (These are summarised in Table 1.) The TWQGR and the exemption permit for KCM by DWAF, currently DWS, set the limits from minimum to maximum as acceptable limits for monitoring measurement of water quality.

Table 1: Target Water Quality Guideline Ranges (DWAF, 1996) and Exemption permit for Kroondal Mine (DWAF, 2007)

Variable Limits	Irrigation	Livestock watering	Domestic (class 0 = ideal)	Aquatic ecosystem	Exemption permit for Kroondal mine
Physical water quality constituents					
pH	6.5 – 8.4	-	6.0 - 9.0	5% or 0.5 of a pH unit variation	Discharge in to the rivers: 6.0 – 8.5. Discharge in to the return water dam: 6.0 – 8.5
TDS mg/l	< 260	1000 diary, pigs and poultry; 2000	0 - 450	<15% variation	-
Electrical Conductivity (as EC) mS/m	< 40	500	0 -70	-	Discharge in to the rivers: ≤ 70 Discharge in to the return water dam: ≤ 150
Chemical water quality constituents					
Chloride (as Cl) mg/l	0 - 100	0 – 1500 non-rum; 0 - 3000 ruminants	0 – 1.00	400 max	Discharge in to the rivers: ≤ 100 Discharge in to the return water dam: ≤ 200
Sulphate (as SO_4) mg/l	200 max	0 - 1000	0 – 200	-	Discharge in to the rivers: ≤ 200 Discharge in to the return water dam: ≤ 400
Nitrate NO_3 as N mg/l	-	-	<6	-	Discharge in to the rivers: ≤ 6 Discharge in to the return water dam: ≤ 12
Ammonia mg/l	-	-	0 – 1.0	<0.007	-
Ortho phosphate-PO_4 mg/l	-	-	<2	<0.005	Discharge in to the rivers: ≤ 0.025
Hardness ($CaCO_3$) mg/l	-	-	0 - 200	-	-
Iron (as Fe) mg/l	0 – 5.0	0 -10	0 - 0.5	-	-
Aluminuim (as Al) mg/l	1 – 5.0	0 - 5	0 – 0.15	<0.005	-
Manganese (as Mn) mg/l	0 – 0.02	0 - 10	0 – 0.1	<0.18	-
Fluoride (as F) mg/l	0 – 2	0 - 2	<0.7	<0.75	Discharge in to the rivers: ≤ 1.5 Discharge in to the return water dam: ≤ 1.5
Sodium (as SAR) mg/l	70	0 - 2 000	0 - 100	-	Discharge in to the rivers: ≤ 1.5 Discharge in to the return water dam: ≤ 1
Chromium VI (Cr^6 mg/l	0 - 0.1	0 - 1	0 - 0.05	0.002	-

The following physical and chemical constituents – also listed in Table 1 – were analysed to determine the water quality of the Hex River (upstream and downstream of KCM) and mapping out the pathway of the pollutants from KCM to the Hex River Catchment AH22: pH, TDS (mg/l), electrical conductivity (as EC) (mS/m), chloride (as Cl) (mg/l), sulphate (as SO_4) (mg/l), NO_3 as N (mg/l), ammonia (mg/l), orthophosphate (as PO_4) (mg/l), hardness ($CaCO_3$) (mg/l), iron (as Fe) (mg/l), aluminium (as Al) (mg/l), manganese (as Mn) (mg/l), fluoride (as F) (mg/l), Sodium (as SAR) (mg/l) and chromium VI (Cr^6) (mg/l).

RESEARCH METHODOLOGY

3.1 Research techniques employed

3.1.1 Participant observation method

The research project is based primarily on the participant observation method. Participant observation is a method in which a researcher takes part in the daily activities, rituals, interactions, and events of a group of people as one of the means of learning the explicit and tacit aspects of their life routines and their culture (De Walt and De Walt, 2002). Participant observation methodology was used as the researcher was employed at KCM as an environmental officer from 2011 until 2014. The role of the researcher involved all environmental management aspects resulting from the mine operations and its activities, setting up the environmental management system in order to prevent and control environmental pollution and environmental legal compliance of the operation. The researcher's participation at KCM gave the advantage of entering the field, developing relationship with the other participants in the setting, and recording observations.

3.1.2 Case study method

The case study was used as the research strategy as it focuses on understanding a situation within the KCM natural setting when assessing the effects of chrome mines on the water quality of the Hex River. In this case study, attention was paid to the background and biophysical conditions of the mine, observed as highly relevant to the situation being investigated. The case study is the most common qualitative method used in information systems (Myers, 2003) and was particularly suited to the study of information systems in KCM as the focus was on KCM rather than other activities within the Hex River Catchment. Other chrome mines do exist along the Hex River Catchment AH22; however, the information regarding their specific impacts on the catchment was not part of this research.

3.1.3 Quantitative method

Quantitative research – according to Matveev (2002) and Smith (1988) – involves counting and measuring events and performing the statistical analysis of a numerical data (Phiri, 2011). It assumes that there is an objective truth existing in the world that can be measured and explained scientifically (Phiri, 2011). It can then be inferred that these methods ensure high-levels of reliability to gathered information (Phiri, 2011). Quantitative methods provide high-level of measurement precision and statistical power. The concept of quantitative research is taken from the physical sciences that are designed to ensure objectivity and reliability (Wenreich, 1996). Thus, it produces quantifiable, reliable data to some larger population. Qualitative research in this Study was complemented by quantitative data, which helped to provide a complete picture of the research issue.

The quantitative tools used in this research include raw water-quality data used to analyse the annual mean or annual average for a seven-year water-quality data, with an attempt to use water-quality concentration of all variables mentioned in chapter 2 to describe the fluctuations of the water-quality data over a certain period (2007 to 2013) in different locations (from the mine to catchment AH22). Box plots graphs – such as minimum, first quartile, mean, median, third quartile, and maximum – have been used to standardise way how the distribution of data is displayed based on the summaries. In the simplest box plot, the central rectangle spans the first quartile to the third quartile [the Inter Quartile Range or (IQR)]. A segment inside the rectangle shows the median/mean and "whiskers" above and below the box show the locations of the minimum and maximum. Another tool is the “The impact pathway analysis” (tables with annual average concentration of the variables analysed) used to determine the impacts of the point of discharge from KCM to the Hex River and its tributaries (Sandspruit and Kroondal tributary).

3.2 Limitations

Research work has challenges and this Study is no exception. The problems faced during the study included hostility and lack of updated detailed climatic data from the South African Weather Service. In this Study, updated detailed climatic data was going to be very crucial in understanding the water quality of the Hex River Catchment. There was no site-specific climatic data available for KCM. The climatic data Information was obtained from the mine (Xstrata Alloy, 2009) that was sourced from the Rustenburg weather station No. 05115234. It should be noted that this weather station is no longer available.

The available data used was an average climate data between 1992 and 2003. As such the data was not very useful as it was already outdated. Some missing values in the raw water-quality data were because of dry seasons or samples were not taken because of the water stagnancy and maintenance of the containment dams in the mine. However, the water-quality data available was sufficient to run the annual mean or average, minimum and maximum values of each sampling location. Missing values and some negative figures(recorded for variables such as Orthophosphate, Nitrate and Ammonium in the raw water quality data of some locations (KMS01,KMS12, KMS09) had a negative impact on the results of “the impact pathway analysis” conducted for the Hex River, Sandspruit, Kroondal tributary, Return Water Dam and the farmer’s dam. According to Aquatico (2012), the negative values presented in the spreadsheets (Appendix 2: KCM raw water quality data) relates to concentrations detected by the laboratory equipment as below detection limit. The negative signs as such recorded in the spread sheet, does not indicate negative concentrations but rather values that are below the detection limit of the laboratory equipment used.

Water pollution and mining are political in South Africa and as such the information was regarded as protected. In that regard, winning the hearts and minds of management of KCM was a challenge that needed to be overcome. This study was not funded and as such the

researcher had to bear the total costs of the whole research where the required as the data was already available from the mine.

3.3 Data and location of monitoring points

Water quality monitoring data was obtained from the mine and a KCM water-quality service provider that takes samples of surface and underground water every month and analyse the samples using standard methods. The chemical parameters for the assessment of surface and underground water quality characteristics is outlined in Chapter 2 The water-quality data available for the analysis in this Study belongs to the observed period from 2007 to 2013. The water-quality data was collected over seven years from the monitoring sampling locations as indicated in Figure 6.

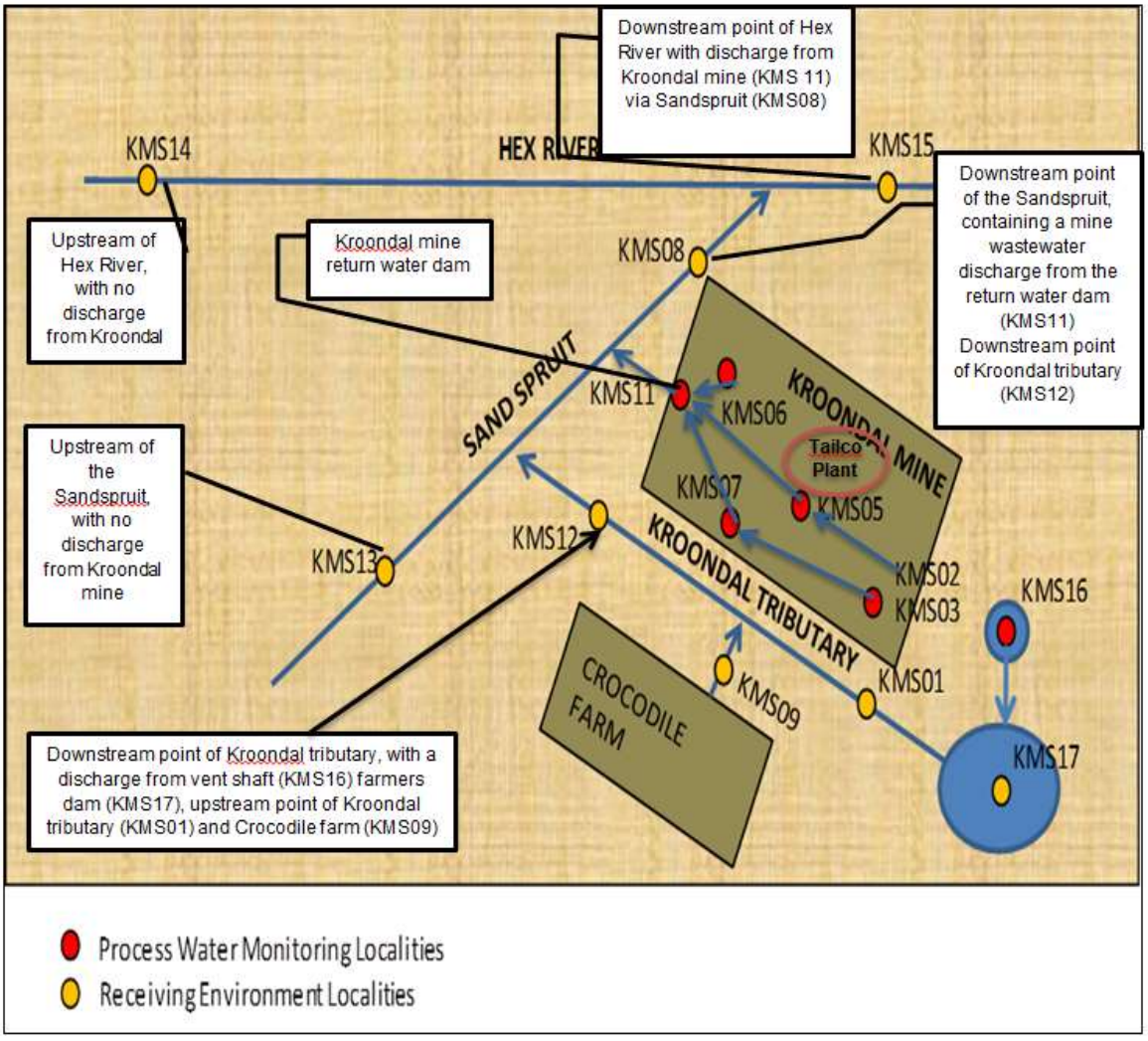


Figure 6: Geographical model on how the Hex River influenced by pollution from KCM

Red monitoring localities shown in Figure 6 within KCM – such as sewage effluent tank overflow within the mine (KMS02), Erickson Dam filled with underground water (KMS03), Settler Dam filled with underground water (KMS05), slimes dam seepage water (KMS06), fun-off from the plant in to the storm water canal (KMS07), collect into the return water dam (KMS11). KMS09 is the outlet discharge from Crocodile Farm discharging into Kroondal tributary and flowing to downstream of Kroondal tributary (KMS12). KMS16 is the mine vent shaft that discharges underground water into Farmer's Dam (KMS17). The water in Farmer's Dam (KMS17) is discharge into the upstream of Kroondal tributary (KMS01).

Water-quality monitoring points represented in Figure 6, and established in the KCM water-quality monitoring programme, adequately include most possible pollution sources from KCM, to Kroondal tributary, Sandspruit and up to the Hex Rive. These monitoring points were identified to represent the upstream and downstream conditions from the confluence of the primary tributary as well as the possible source of impacts.

3.4 Methodology or approach

In order to achieve the research objectives set out in chapter one, a geographical model was developed in order to map out the pathway from KCM, Farmer's Dam and Crocodile Farm to Kroondal tributary, Sandspruit and up to the Hex River (refer to Figure 6). KCM water quality geographical model showed two clusters of water-quality monitoring localities from Kroondal up to the impacted water catchment Hex River. The first cluster of water-quality monitoring localities is marked in red in Figure 6 and is referred to as "process water monitoring localities" within the mine boundaries. The second cluster of water-quality monitoring localities is marked in yellow in Figure 6 and is referred to as "receiving environment monitoring localities". Receiving environment simply means the water that is discharge from its original source to the rivers, water channels or canal and Farmer's Dam.

Cluster one "process water monitoring localities" comprises KMS02 sewage effluent tank overflow, KMS03 Erickson Dam with underground water, KMS05 Settler Dam with underground water, KMS06 slimes dam seepage water, KMS07 run-off plant water in to the canal, KMS11 return water dam and KMS16 vent shaft/underground water in dam.

Cluster two "receiving environment monitoring localities" comprises KMS01 upstream point of Kroondal tributary and KMS12 downstream point of Kroondal tributary, KMS13 upstream point of Sandspruit and KMS08 downstream point of Sandspruit, KMS14 upstream point of Hex River and KMS15 downstream point Hex River, KMS09 outlet discharge point from Crocodile Farm to Kroondal tributary and KMS17 Farmer's Dam receiving water from overflowing vent shaft underground water dam.

After developing the above geographical model, seven years' worth of water-quality data (from 2007 until 2013) of all monitoring localities in the geographical model was collected from the mine water-quality reports done by the external service provider. The data was arranged using a Windows Excel spreadsheet per monitoring locality in preparation to be

analysed for descriptive summary statistics and plotting of box plots. Data on Excel spreadsheets with 22 chemical water-quality parameters were generated as data records (Appendix 2 of this report). After arranging data to be analysed, a computer system or piece software called SAS enterprise 6.1 was used to analyse the 15 monitoring locality points in order to find annual mean/average for each variable in different localities and plotting the box plots of each variable in different locations (Hex River, Sandspruit, Kroondal tributary and KCM) with a water-quality data from 2007 until 2013.

According to SAS Institute Inc., (2009), SAS Enterprise streamlines the data analysis process to create highly accurate predictive and descriptive models based on analysis of vast amounts of data from across an enterprise. To analyse the 15 monitoring locality points and generate descriptive statistics, the following steps were undertaken:

- Seven years' worth of data from each monitoring locality point with the analysed physical and chemical constituents was exported from Excel to SAS Enterprise 6.1.

- After the export had taken place, descriptive and summary statistics were selected. All selected analysed chemical parameters data was attached to these statistics to analyse variables from left to right.

- In the exported Excel spreadsheet, the data was classified per year – from 2007 to 2013 – and it was referred to as time data in addition to being also classifies per location (KMS01 to KMS15).

- Time and location data was then attached to the classification variable from left to right.

- After attaching all variable data to analysis variables, and time and location data to classification variable, a box plot was selected under plots. Mean, standard deviation, maximum and minimum were selected under statistics and all data was run.

- After running data for descriptive statistics and box, SAS produced a summary descriptive statistics report for each monitoring locality (15). This data was analysed with statistics tables per year (2007 to 2013) and per location (KMS1 to KMS15) and box plots for each variable in different locations were generated. A summary descriptive statistics report was generated by SAS for each monitoring locality and this is referred to and attached to this report as Appendix 3.

3.4.1 Method for Question one

3.4.1.1 What is the biophysical environment of the study area that could have an influence on the water quality of the mine, Hex River and its tributaries?

The biophysical environment of the study area was described using the literature reviewed of the Kroondal Mine which was included in the Environmental Management Programme Report of 2009 by CHEMC, geohydrology report conducted in 2012 by GCS, water-quality reports from 2007 until 2013 by clean streams environmental services (Aquatico), Kroondal soil survey report conducted by the Institute of Soil, Climate and Water, 2007, Kroondal Mine site layout, Hex River land use map and other relevant studies conducted within the Hex River Catchment AH22. A site assessment was conducted to verify the detailed layout plan of the mine and other infrastructures around the Hex River Catchment.

3.4.2 Method for Question two

3.4.2.1 What is the Hex River's water quality status?

To answer the above question, summary descriptive statistics reports for KMS8 downstream of Sandspruit, KMS14 upstream of the Hex River and KMS15 downstream of the Hex River generated by SAS Enterprise 6.1 were used to check the maximum concentration on the statistics tables (2007 to 2013) and box plot of all variables analysed. Monthly water-quality monitoring data from 2007 to 2013 concentrations of all variables in Table 1 were compared with condition 3.1 (discharge into the rivers) and 3.2 (discharge in to the return water dam) of Kroondal exemption permit limits, TWQGR for irrigation, livestock watering, domestic use (class 0 = ideal) and Aquatic ecosystem. All physical and chemical variables that were found to be above the limits describe and stipulated in Table 1 at KMS15 downstream of Hex River, was considered a physical and chemical variable of concern in the Hex River Catchment A22H water quality that requires further investigation with regard to its sources and pathway.

3.4.3 Method for question three

3.4.3.1 How is the Hex River impacted by pollution from Kroondal?

To answer the above question, Figure 6, a geographical model on how the Hex River is influenced by water pollution from KCM was used to conduct an impact pathway analysis of physical and chemical variables of concern in the Hex River Catchment A22H. Water-quality variables analysed emphasised the variables of concern (variables above the Kroondal exemption permit and TWQGR) were identified at the downstream of Hex River (KMS15). The process was followed from Hex River (the receptor), Sandspruit, and Kroondal tributary and back to KCM. In order to trace the sources and pathway of all variables of concern in the Hex River, the assessments called "impact pathway analysis" were conducted using the annual mean/average extracted from the statistical water quality tables and variables box pots for different locations. The impacts or influences of the water quality were determined

by the higher concentration (concentration above the limits in Table 1) of the variable in a specific location. Below is the list of locations where “impact pathway analysis” was conducted:

- **Hex River:** an impact pathway analysis of Sandspruit tributary (KMS08) and Hex River upstream pollution sources (KMS14) to downstream of Hex River (KMS15) 2007 to 2013.

- **Sandspruit:** an impact pathway analysis of the return water dam (KMS11) downstream of Kroondal tributary (KMS12) and pollutants from the upstream of Sandspruit (KMS13) to downstream of Sandspruit (KMS08) from 2007 to 2013.

- **Kroondal tributary:** an impact pathway analysis of discharge from Crocodile Farm to Kroondal tributary (KMS09), pollutants from the upstream of Kroondal tributary (KMS01) and impacts of Farmer’s Dam (KMS17) receiving water from overflowing vent shaft (KMS16) to downstream of Kroondal tributary (KMS12) from 2007 to 2013.

- **KCM:** an impact pathway analysis of seepage from the slimes dam (KMS06), plant run-off to the storm water canals (KMS07), Ericson Dam (KMS03) that receives water from underground, Settlers Dam (KMS05) also receiving water from underground, sewage effluent tank (KMS02) to the return water/catchment dam (KMS11) from 2007 to 2013.

3.4.4 Method for Question four

3.4.4.1 What are the possible pollution sources from KCM and other land uses?

To answer this question the following process was conducted:

Firstly, Figure 6 – geographical model on how the Hex River was influenced by the pollution from KCM and the impact pathway analysis – were used to trace pollution sources of all variable of concern in the Hex River from Hex River back to KCM(KMS15).

Secondly, KCM site survey or site layout and Hex River catchment land-use map were used in order to identify possible water pollution sources from KCM physically and other land uses within the catchment.

The site survey and the catchment land-use map information include aerial photos of the site and the site layout plan, for site layout and the catchment land-use map refer to Appendix 4 of this report. The site layout assessment includes the high-level detail of site infrastructure and storm water infrastructure, verification by site inspection in order to obtain a lower-level detail layout. This was conducted during 2013. Topographical features such as the slope of the area as well as the longest flow path of the Hex River catchment area was considered. The development influences, or land use within the catchment area, was taken into account

in the process of determining the pollution sources of the area in order to compare and differentiate pollution sources from Kroondal Mine and other land uses within the catchment. The process flow of the mine and the quality of the inputs materials that are put into the mining process was the primary instruments used on the identification of pollution sources with regard to the water quality of KCM to the Hex River catchment.

3.4.5 Method for Question five

3.4.5.1 What are the possible pollution pathways from the mine to the Hex River?

The following process was followed to determine the water pollution pathways from Kroondal Mine to the Hex River:

In Figure 6, the geographical model on how the Hex River is influenced by pollution from KCM and the impact pathway analysis, were used to trace the pathways of all variable of concern in the Hex River from Hex River back to KCM.

The hydrogeological data review, site topographic maps and site geohydrology maps of KCM was used to follow the pollution pathways. According to Ritter et al (2002) moving water can dissolve and mobilise physical and chemical parameters in its path. These can include contaminants on the surface or in the subsurface of the earth. Storage of some waste material or tailings from mine operations can result in the formation of polluted leachate. This type of mining effluent generates high concentrations of pollutants that could potentially compromise the Hex River water quality.

3.4.6 Method for Question six

3.4.6.1 What can be done to manage the pollution sources and pathways of Kroondal Mine?

To answer question six, the reviewed findings and research result of question one to question five, was used to come up with different improved ways of managing waste water for KCM as recommendations of this research report. KCM water-monitoring programme and environmental management system was also reviewed by collecting relevant information and data analysis. Documents such as annual water-quality reports and legal and other requirements were review before setting up the recommendation to the mine.

RESULTS

Section 4.1 and 4.2 of the research report answers research Question one: what is the biophysical environment of the study area that could have an influence on the water quality of the mine, the Hex River and its tributaries? Chapter 4 Section 4.1 and 4.2 outlines the Hex River Catchment location and the Kroondal Chrome Mine,

4.1 Description of the study area

4.1.1 Hex River Catchment

The study area (Hex River Sub-Catchment A22H and KCM) is located in the North West Province within the Bojanala District Municipality, which falls under the Rustenburg Local Municipality. The area of Rustenburg is regarded as an arid region with a high water demand owing to the rapid development of the area.

The hydrographic basin of the area is almost entirely formed by the northern slopes of the Magaliesberg. Four main streams and their tributaries drain the area northwards to the low-lying areas where the whole drainage system enters the Crocodile River. These four streams are the Crocodile River (across the area of Brits), the Elandspruit and Sterkstroom rivers (across the area of Mooinooi/Marikana) and the Hex River. This whole drainage system cuts across, perpendicularly, the narrow and elongated strips of the geological, edaphic and vegetation formations of the area. The existing topography is flat, resulting in minimal run-off of water. The case study KCM falls under the primary drainage region A and in quaternary sub-catchment A22H (WRC Report No 298/1.2/94). The affected catchment includes one non-perennial stream Sandspruit and a tributary of the Sandspruit (Kroondal tributary) which flows from east to west towards the Sandspruit and is directly adjacent to the mine. The Sandspruit then flows north – west towards the Hex River. The clear layout of the sub-catchment A22H is well presented in Figure 7**,** which shows an aerial view of the monitoring locality points used for surface water quality monitoring outside the KCM lease area.

4.1.2 KCM

The KCM operation consists of underground (current) and open-cast mining that has been rehabilitated. KCM is located approximately 2km from the Kroondal Township in the Rustenburg Local Municipality. The mine is situated within the Hex River Catchment, approximately 2 km from the Hex River and in close proximity to the Sandspruit River, Hex River tributary passing next to the return water dam and the Kroondal tributary of the Sandspruit River, as shown in Figure 7. The case study area is also situated closer to agricultural activities, which can be seen in Figure 7. The Hex River Catchment area, in total, covers an area of 1,080 km² and conveys water to the Bospoort Dam, east of Rustenburg (Figure 1).



Figure 7: KCM locality map or aerial image, showing the mine location, surrounding land use and part of the Hex Catchment AH22 in close proximity to the mine (Clean streams, 2008)

4.2 Factors that could have an influence on the water quality of the Hex River Catchment

4.2.1 KCM process description

KCM has been in operation since 1989 with an estimated 25 years of chrome mining remaining. The estimated average production rate is 993,280 tonnes of ore per annum (Xstrata Alloys, 2009). Ferrochrome is manufactured for both the local and export markets. Mining activities are situated on a total of 48.7 ha in total, of which 19 ha is utilised for infrastructure and mining. Only underground mining remains. The room and pillar method is used to mine various chrome products which includes lumpy ore, chrome chips, metallurgical grade ore, and foundry grade ore. The mining depth of Kroondal Mine ranges between 60 to 400 m. KCM is just one of several mining operations in the Hex River vicinity, and there are three main land uses surrounding Kroondal Mine: human settlement, mining and agricultural activities as indicated in Figure 5.

Chrome ore is extracted underground using drilling and blasting methods, machinery is used to collect ore from the panel which is loaded to the surge bin. A conveyor network is used to transport ore to the surface via a surge bin. From the surge bin, ore is extracted by means of a vibrating feeder onto a conveyor belt, feeding a crushing plant operating in close circuit with a scalping screen. The product from the crusher plant (-115 mm) reports to a double deck screen, which separates the ore into three fractions. Waste rock is stored on an unlined waste stockpile and slimes tailings are pumped via a thickener to the unlined tailings dam. This process flow has the potential to influence the mine water quality by using explosive for blasting, hydrocarbons from the machine, pumping of slimes tailings to unlined tailings dam and poor management of ore and production stockpiles that were without proper water pollution controls from the mine surface to the return water dam.

The Kroondal Mine infrastructure comprises transport, power and water supply networks; telephone lines; an explosives magazine (permit 28/1/21/19356); beneficiation plant (crushing, screening circuit, HMS, spiral and stockpile sections); stockpile areas for product; slimes dam and associated unlined return water dam as well as two unlined surface waste rock dumps. Cumulatively, these dumps have a volume of 125,526 m^3 and contain approximately 1,000,000 t of norite and pyroxenite. The approximate dimensions of the larger, more recent dump – to the east of the Kroondal administration block – are 60,000 m^2 and 42 m high. It was noted that the dump is expected to decrease from 42 m as there was an external contractor – called Tailco – mining waste rock dump and processing to recover more chrome during the study period (2013 to 2015).

The unlined tailings dam is 5 m high and covers 4ha. The return water dam is unlined and is 0.75 ha. The dam was designed and constructed with clay material. A total of 60% of water is lost through evaporation and seepage from the return water dam excluding the mine surface area. No chemical processes were used in the mineral processing plant, thus the water discharged into the tailings dam is expected to contain no – or a reduced amount – of

chemicals. Approximately 34 000 t of tailings is being pumped (per month) to the Kroondal platinum mine adjacent to KCM. The purpose of this activity is to recover PGMs and it helps the mine to extend the life spend of the tailings dams. Tailings left over after the recovery process are sent back to Kroondal Mine's tailings facilities. It was noted that process water is also reclaimed from Kroondal old, rehabilitated tailings dam area (previously Mabot tailings) for use in mining activities. This can have a negative influence on the mine process water quality and return water dam (that discharges mine surface water to Sandspruit via a channel as outlined in Figure 10) owing to the old water chemical reaction in the old tailings dam.

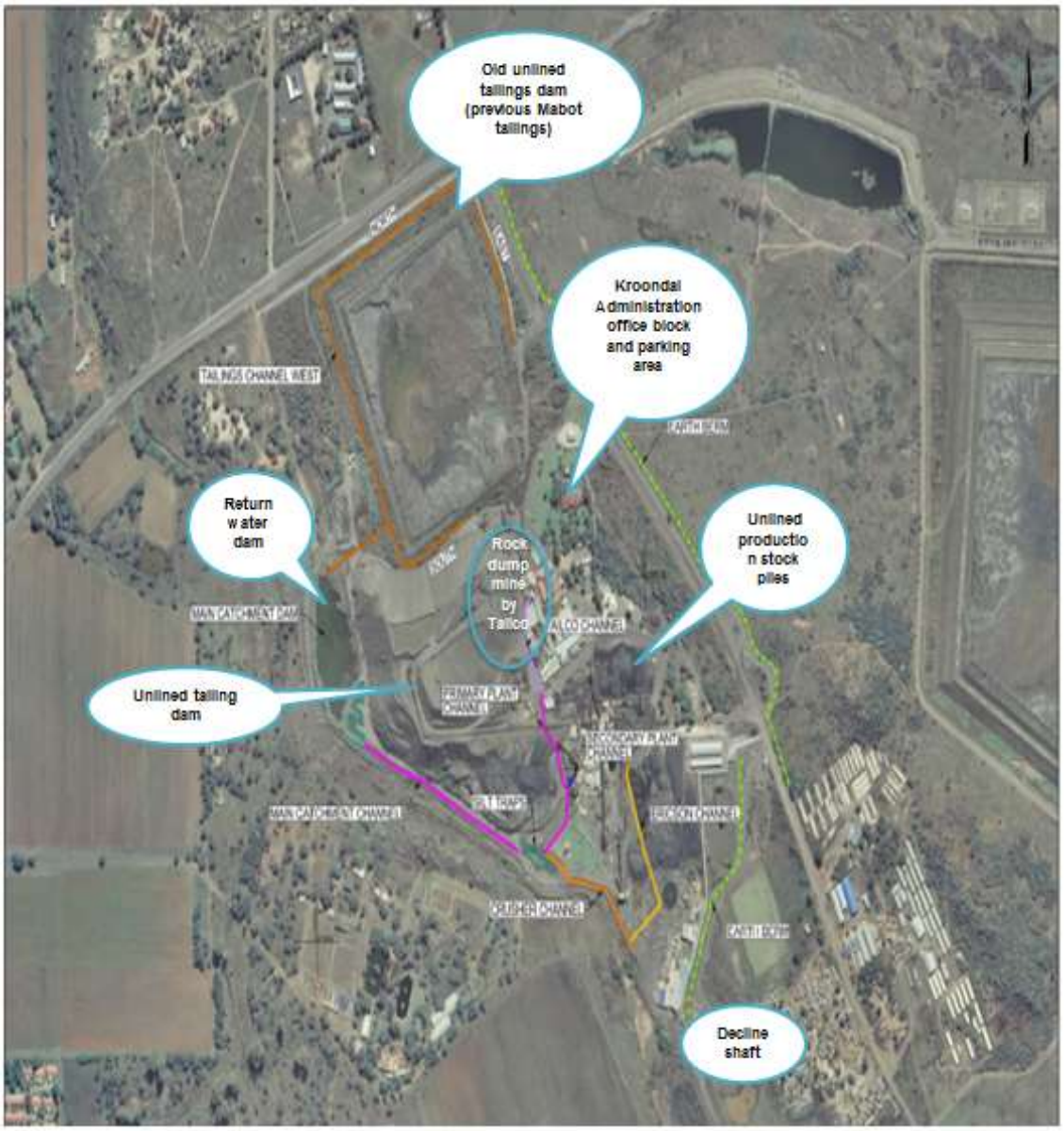


Figure 8: KCM water infrastructure layout

4.2.2 Drainage and water management infrastructure

KCM water management infrastructure consists of storm water infrastructure such as canals/channel, a process water dam (capacity 222 kilolitres), Erickson Dam (capacity 1,089 kilolitres), a silt trap (capacity 800 kilolitres), slimes dam, pump station that pumps the slimes to and from Aquarius via a pipeline, and the main containment dam/or return water dam (capacity 20,000 kilolitres).10 water-quality-monitoring boreholes and 11 water-flow metres. See Figure 9 and Figure 10, a model for KCM water infrastructure, process flow and KCM water infrastructure layout in order to gain an understanding of KCM water management and the water is transported from KMC to the Sandspruit, Hex River tributary.

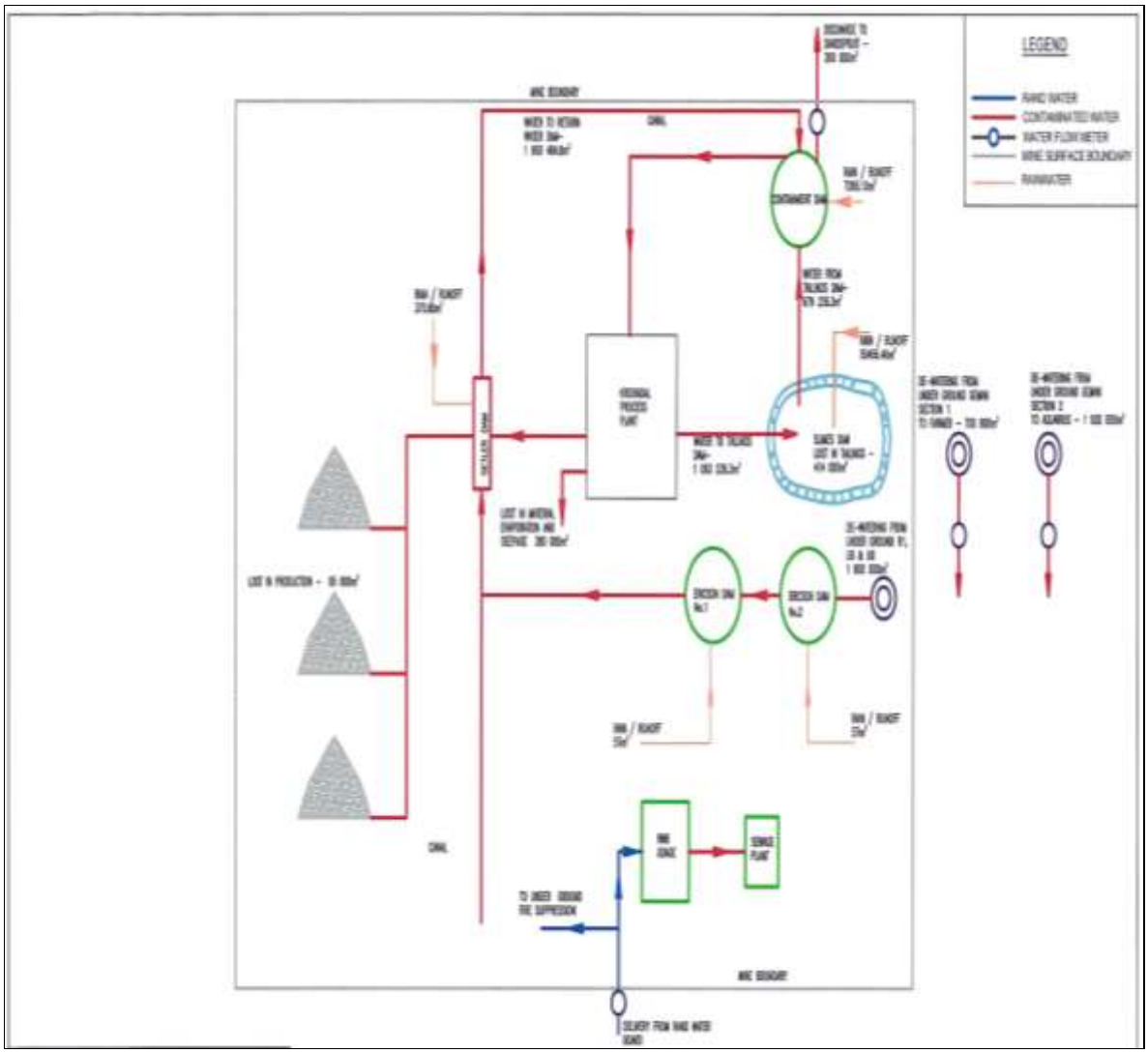


Figure 9: Model for Kroondal Mine water infrastructures and process flow (Kroondal Chrome Mine, 2012), which shows the mine contaminated and clean water process flow from the sewage plant, processing plant to the containment dam or return water dam and then discharge via a channel to Sandspruit River

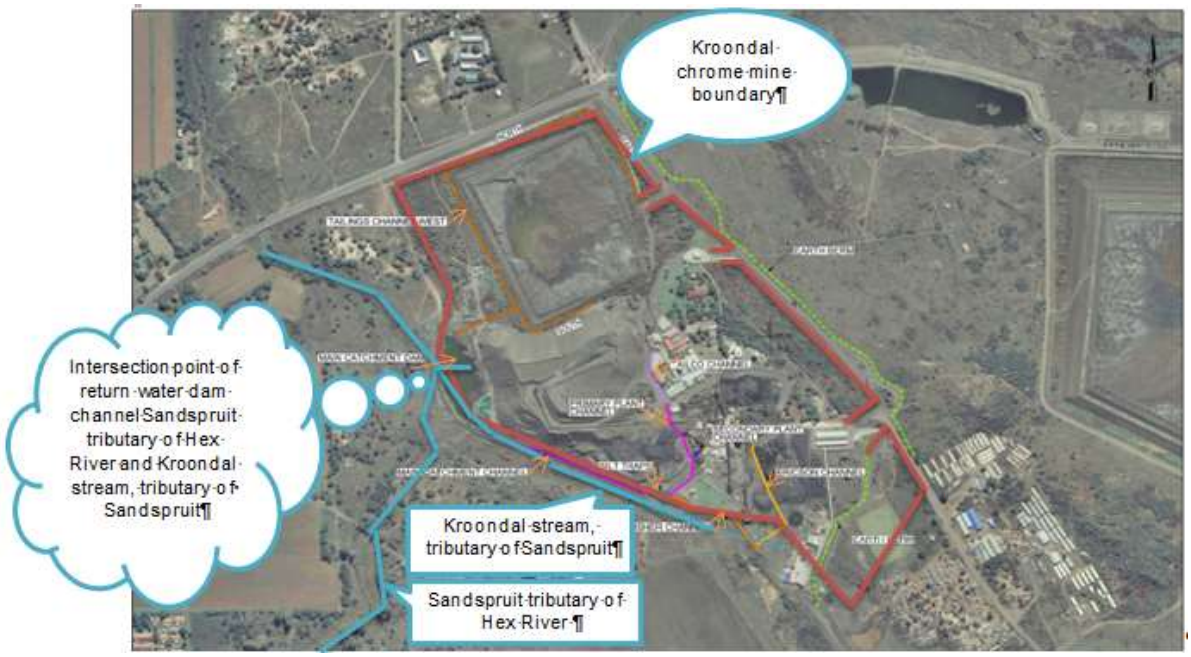


Figure 10: KCM surface water infrastructure layout showing the intersection point of the main catchment dam or return water dam channel, Sandspruit tributary of the Hex River and Kroondal stream tributary of Sandspruit; KCM boundary and all surface drainage channels that drain into the main catchment dam or return water dam (KCM – Storm water Management and Implementation Report, 2012)

4.2.3 Waste management

The mine general waste management follows good practice by disposing domestic waste (after it has been separated for recycling) at the designated Rustenburg Local Municipality landfill site. A waste management company is employed in order to look after recycling and the safe disposal of hazardous waste that is generated on site. Plans are in place to upgrade existing salvage yards so that it will be possible to increase waste separation on site. All working areas – including underground – have designated waste bins to encourage waste separation from site. In terms of mineral waste, there are two unlined waste rock dumps identified on site, two old unlined tailing dams and currently used tailing and production stock piles in the concreate slab. There are also some in the bare surface area around the production plant.

4.2.4 Climate

Currently, site-specific data is unavailable for KCM. The closest weather station information was used (Rustenburg weather station No 05115234). Rustenburg is 3km North West of Kroondal. Information was obtained from the South African Weather Service. Rustenburg falls within the Summer Rainfall Climatic Zone. The area is characteristically warm to hot with rainfall that is erratic and extremely variable, ranging from 450 to 750 mm per year. Temperatures range from approximately 21.1 to 30.1^{o}C and mean minimum temperatures

range from 3.2 to 17.3°C. There are 76 average annual rainfall days with a total annual average rainfall – for the period 1993 to 2003 – of 589.7mm. Winds are heavily influenced by the underlying topography of the region. Rustenburg town is to the south of the Pilanesberg and experiences moderate northerly winds. Other weather stations in the vicinity experience south-westerly winds, and occasionally strong north-easterly winds influenced by the Magaliesberg mountain range.

January is typically the hottest month with July being the coldest. The mean temperature ranges from approximately 21.1 to 30.1°C. The minimum temperatures range from 3.2 to 17.3°C. High temperatures have the major influence on the water chemistry of a river and other process and storm water. High temperatures are regarded to attract attention as a medium for organic chemistry (Akiya and Savage, 2002).

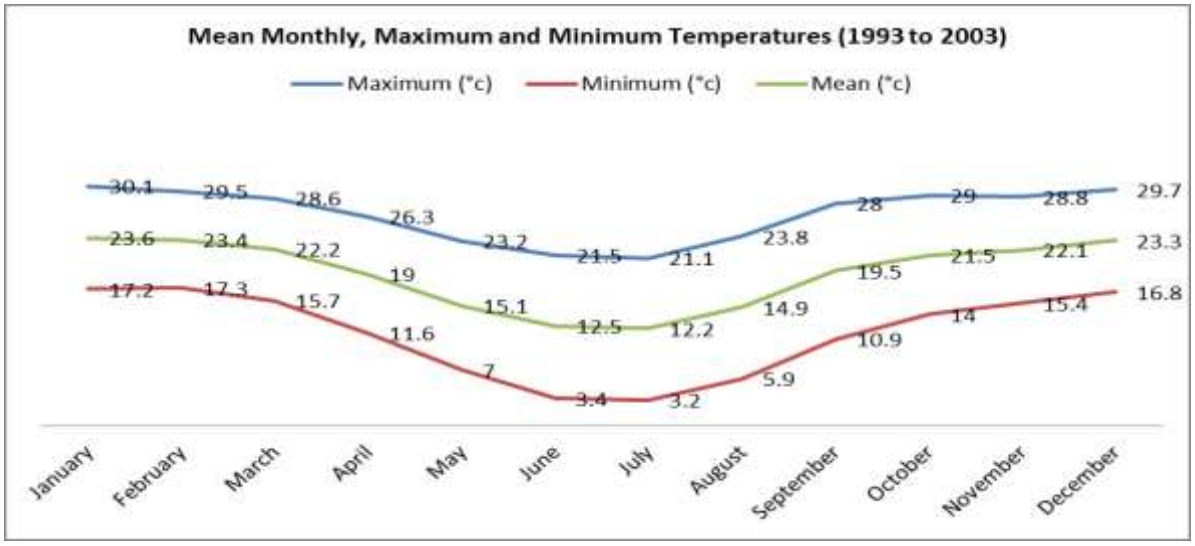


Figure 11: Mean monthly, maximum and minimum temperatures: 1993 to 2003 (Xstrata Alloys, 2009)

A review of Kroondal water-quality data – from 2007 until 2013 – showed physical and chemical constituents decreasing in concentration during peak rainy seasons (during the summer months) and increasing during dry seasons. These figures were recorded for the Hex River, Sandspruit, Kroondal tributary and KCM monitoring locality point in Figure 7. This means that rainfall impacts the water quality of the Hex River and KCM because of the dilution effect that took place during rainy season and the higher concentrations of physical and chemical constituents during dry season. The seasonal effect on the water quality of KCM monitoring programme is evident in the annual (2007 to 2013) average water quality variation assessment presented in Chapter 4 of this report.

4.2.5 Geology

An understanding of the geology of the study area is of importance because of the types of rocks and its mineralogy over which the mine run-off or surface water flows will influence the water quality of the mine and the Hex River catchment via the pathways from the mine (Du Plessis, 2006). The Rustenburg Layered Suite of the Bushveld Igneous Complex (CHEMC 2009) lies under the study area. The Rustenburg Layered Suite is a mafic to ultra-mafic sequence, subdivided into five zones, i.e. Upper, Main, Critical, Lower and Marginal zones. KCM is situated in the critical zone of the western lobe of the Bushveld Complex grouped from the bottom upwards (Dube, 2010). The Bushveld Complex is the world's largest layered igneous intrusion. It hosts over half the world's platinum, chromium, vanadium and refractory minerals, and arguably has ore reserves capable of lasting for a hundred to a thousand years (Vermaak, 1995). Du Plessis (2006) confirms that the base-metal sulphide is found in the Hex River Catchment area within the UG2 and that below Merensky reef and the most the Platinum Group Metals (PGM) are closely associated with base-metal sulphide.

The geology of the study area has a direct influence on the water quality of the Hex River Catchment. The chrome and platinum mining activities along the catchment contribute to the mobilisation of some constituents from the mineral deposits (Du Plessis, 2006). The minerals within the extracted ore react in different ways when exposed to the surface and comes into contact with air and water so affecting the water quality within the mine. The same water is washed out or transported through run-offs and mine drainage canals collecting in the return water dam, from the dam to the nearest Sandspruit tributary of the Hex River through a natural canal. The mining methods used in KCM processes could influence the water quality from the mine waste rock and blasting residues brought to the surface by mine de-watering from underground to the mine surface dams, for example Ericson Dam.

4.2.6 Topography

The topography of the region is generally flat with little or no undulations, apart from scattered norite rock outcrops (CHEMC, 2009). The topography of the study area is relatively flat, with a gentle even slope from southwest to northeast. The site topography is relatively flat, with elevations in the site area varying between 1,000 and 1,250 m above mean sea level. Locally, there are rises in topography known as "wonderkoppies", mainly in the eastern section of the site (Clean stream, 2012a). To the south of the site the Magaliesberg ridge rises to elevations between 1,625 and 1,800 m above mean sea level (Clean stream, 2012a). The general flow direction of surface water across the site is from the southeast to northwest, with the perennial Hex River being the main drainage feature for the site. The affected catchment includes the Hex River's non-perennial Sandspruit tributary and the Kroondal tributary, which flows into the Sandspruit (Clean stream, 2012a).

4.2.7 Soil

Two soil surveys have been conducted for KCM in March 2003 by Mr. Albie Gotze – of Environment Research Technology CC (Xstrata Alloys, 2009). The soil was investigated with an auger and then the soil form was determined in 200 x 200m grids throughout the study area. A more recent study was compiled by the Institute of Soil, Climate and Water (2007). The area predominantly has black top soils with strong structure and heavy texture (>35% clay). The soils in this unit belong to the Arcadia (Ar) soil form. The analysis results show the clayey nature of the soils (many of the Arcadia soils in this area show much higher clay contents) and associated high CEC levels, mainly because of the calcium and magnesium present in the soil (Institute of Soil, Climate and Water, 2007). The soil is alkaline, but shows no signs of previous fertilisation, with low phosphate levels. The mainly smectitic nature, with consequent shrinking and swelling properties, of the arcadia (turf) soil means that there is a narrower moisture range for cultivation than most other agricultural soils. Black clay soil is naturally fertile, with high cation exchange capacities and moderately high organic carbon contents.

According to the Rustenburg weather station No. 05115234, Rustenburg receives a low amount of rainfall, ranging from 450 to 750 mm per year. This makes the soil in the area slightly leached with a high evaporation rate. This causes high upward movement of moisture in the soil and result in a high concentration of salts in the soil (Du Plessis, 2006). As a result of a high salinity concentration in the soil, these become more alkaline which subsequently affects the water-quality profile of the catchment.

4.2.8 Land use

The study area is dominated by mining activities, informal and formal settlements, industrial areas and agricultural activities. The driving forces behind the settlements patterns of informal settlements are economic activities and industrial employment opportunities resulting in increasing urbanisation. According to Du Plessis (2006) the rapid rate of population growth is consistent with the trends in environmental degradation and rapid depletion of natural resources. Environmental impacts in the Rustenburg area include land transformation through industrial, agricultural and urban development (NWPSoER, 2002). Du Plessis (2006) alludes to the fact that general municipal waste and storm water from informal settlements are the major contributors to non-point sources of pollution entering the Hex River and its associate tributaries, however, water-quality impacts are associated with the impact of a variety of undesirable contaminants from the mining activities. There are number of mines along the Hex River Catchment Figure 5as can be seen in figure 5) which is mined by different mining companies. These companies exploit the platinum and chrome ore deposits in the Western Igneous Bushveld Complex. The extensive mining activities in the area are considered to be placing negative pressures on the water quality of the catchment as mines discharge or drain effluents or waste water into the rivers and surface water pond.

4.2.9 Conclusion

The study area in Figure 7 and Figure 1 is situated in environment where number of development activities such as mining, agriculture, informal and formal settlement and other industries. Such development has already proven to have an effect on the water quality of the Hex River by Du Plessis (2006). The biophysical environment of the study area has an influence to the water quality of the Hex River in different ways. The KCM processes and its water infrastructure layout appear to directly discharging mine process water into the Hex River sub-catchment via Sandspruit and Kroondal tributary. Climate of the area can influence the water quality of the Hex River catchment due to seasonal changes of very dry and wet seasons. The geology of the study area also can influence the water quality of the Hex River catchment through mining activities that expose the ore to reacts when exposed to surface and mobilised minerals and other constituents to the downstream of the Hex River catchment. Lastly, the soil composition was found to be very alkaline and causing the increase on the salinity of the water quality of Hex River Catchment.

4.3 Water quality of the Hex River and influence of the mine (KCM) on the Hex River

This section answers research question two – what is the Hex River's water quality status – and research question three: how is Hex River impacted by pollution from Kroondal?

Tables and box plot graphs have been used to present the annual mean or average as well as the minimum and maximum concentration of the constituents of concern in the Hex River Catchment. The annual mean or average water quality has been compared with the TWQGR (DWAF, 1996) for irrigation, livestock watering, domestic use class 0 = ideal, aquatic ecosystem and KCM exemption permit for waste water discharge to the Hex River and waste water discharge to the return water dam as tabulated in Table 1. The comparison of annual mean or average water quality and TWQGR was conducted to establish the level of water-quality decline in the Hex River Catchment downstream of KCM over seven years, identify the pollution sources and pathways, and establish the impacts emanating from KCM and other sources of the Hex River Catchment.

The physical and chemical water-quality constituents of concern – investigated for the 15 water-quality monitoring points within KCM and Hex River catchment (as indicated in figure 10) – are as follows: pH, TDS (mg/l), electrical conductivity (as EC) (mS/m), chloride (as Cl) (mg/l), sulphate (as SO_4) (mg/l), NO_3 as N (mg/l), ammonia (mg/l), orthophosphate (as PO_4) (mg/l), and hardness ($CaCO_3$) (mg/l). These were the selected constituents of concern that exceed the TWQGR and KCM exemption permit limits outlined in Table 1 at the downstream point of Hex River (KMS15) monitoring locality. The tables and figures to follow in the next sections indicate the mean, annual and monthly concentration over a seven-year period of water-quality monitoring points on the Hex River, Sandspruit, Kroondal tributary and KCM.

The box plot graphs indicate each of the Target Water Quality Guideline Ranges (DWAF, 1996) and KCM exemption permit as follows:

- Blue line indicating the TWQGR for domestic use class 0 = ideal limits
- Green line indicating the TWQGR for irrigation limits
- Purple line indicating the TWQGR for livestock watering limits
- Blue light line indicating the TWQGR for aquatic ecosystem limits
- Red line indicating the KCM exemption permit for waste water discharge to the Hex River and/or to the KCM return water dam

According to DWAF (1996): “South African water quality guidelines are used as a primary source of information and decision-support to judge the fitness of water for use and for other water quality management purposes.” DWAF (1996) explains the TWQGR as an instrument used to maintain the quality of water resources to remain within the “No Effect Range”. According to DWAF (1996), is included, and highlighted as such, in the water-quality criteria provided for each of the constituents in the guidelines. DWAF (1996) water-quality guideline document emphasises that “it should be noted that an important implication of setting the TWQGR equal to the No Effect Range is that it specifies good or ideal water quality instead of water quality that is merely acceptable”. That is why the study area water-quality data has been presented from annual average, minimum and maximum in the tables and box plots to follow in the next section of this report.

It should be noted that, graphs (box plots) of the same variables in the figures did not have the same Y- axis scale, because the water quality data set used to plot the graphs of the same variables was taken from different location. The X-axis shows the different location or sampling point where the water quality data was collected per month over seven years (2007 – 2013). Different concentration of the same variable was recoded in different locations, hence the graphs Y- axis scale of the same variables are different.

Descriptive statistics results on the mean/average values presented in table format were affected. Variables such as Orthophosphate (PO_4) on Table 9 and Ammonium (NH_4) have negative values, due to the missing values within the raw water quality data (used to run the descriptive statistics results (Appendix 2)) for some locations (KMS 01, KMS12, KMS09) and very low concentration recoded in various sampling points during 2007 to 2013. According to Aquatico (2012), the negative values (presented in the spreadsheets Appendix 2: KCM raw water quality data) relates to concentrations detected by the laboratory equipment as below detection limit. The negative signs as such recorded in the spread sheet, does not indicate negative concentrations but rather values that are below the detection limit of the laboratory equipment used

4.4 Physical and chemical water-quality constituents of concern at the downstream point of the Hex River (KMS15)

The water quality at the downstream point of the Hex River (KMS15) was compared with the TWQGR and KCM exemption permits for waste water discharge into the Hex River and return water dam for all physical and chemical constituents listed in Table 1. The following physical and chemical constituents were found to be above the all limits tabled in Table 1: pH, TDS (mg/l), electrical conductivity (as EC) (mS/m), chloride (as Cl) (mg/l), sulphate (as SO4) (mg/l), NO_3 as N (mg/l), ammonia (mg/l), orthophosphate (as PO_4) (mg/l), and hardness (CaCO3) (mg/l). This means that the downstream of the Hex River (KMS15) was found to be polluted with the above mentioned constituents, and the water was found to be unfit for irrigation, livestock watering, domestic use and aquatic ecosystems. The next section analyses all the constituents of concern from the downstream point of Hex River (KMS15) and traces it back to KCM in order to find out how KCM impacts the downstream of the Hex River (KMS15).

4.4.1 pH Level

Table 2 below illustrates the annual average pH level of the Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points over a seven-year period from 2007 until 2013.

Table 2: Annual mean or average pH levels recorded for the Hex River, Sandspruit, Kroondal tributary and KCM from 2007 to 2013

Physical variable Annual average pH							
Monitoring Locality	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Hex River							
KMS 15	8.1	8.2	7.9	8.1	8.2	8.3	8.2
KMS 14	8.3	8.1	7.9	8.0	8.0	8.1	8.2
Sandspruit							
KMS 08	7.7	8.1	7.9	8.2	8.1	8.1	8.1
KMS 11	7.7	8.0	8.0	8.3	8.3	8.1	8.1
KMS 13	No data	8.4	8.1	8.3	8.2	8.5	8.4
Kroondal tributary							
KMS 12	8.1	8.2	7.6	8.3	8.3	8.2	8.3
KMS 09	8.1	7.7	7.7	8.1	8.1	8.2	8.8
KMS 01	8.7	9.4	8.3	7.5	8.3	8.9	8.7
KMS 17	8.5	9.0	8.1	8.0	8.6	8.7	8.7
KMS 16	8.4	8.4	8.3	8.5	8.4	8.6	No data
KCM							
KMS 02	8.0	7.9	7.9	8.3	8.5	8.7	8.7
KMS 03	8.4	8.2	8.0	8.7	9.0	8.8	8.7
KMS 05	7.6	7.8	7.8	8.3	8.7	No data	No data
KMS 06	7.2	7.4	7.4	7.7	8.2	8.1	8.0
KMS 07	7.6	7.9	8.0	8.1	8.4	8.3	8.2

According to Table 1, the pH for the irrigation ranges between 6.5 and 8.4. For the domestic-use class 0 = ideal, the range is between 6.0 and 9.0, and the exemption permit for the

waste water discharge range is between 6.0 and 8.5. TWQGR does not indicate specific pH limits set for livestock watering and only states the 5% or 0.5 of a pH unit variation on aquatic ecosystem. Hence these limits are not presented in the graphs.

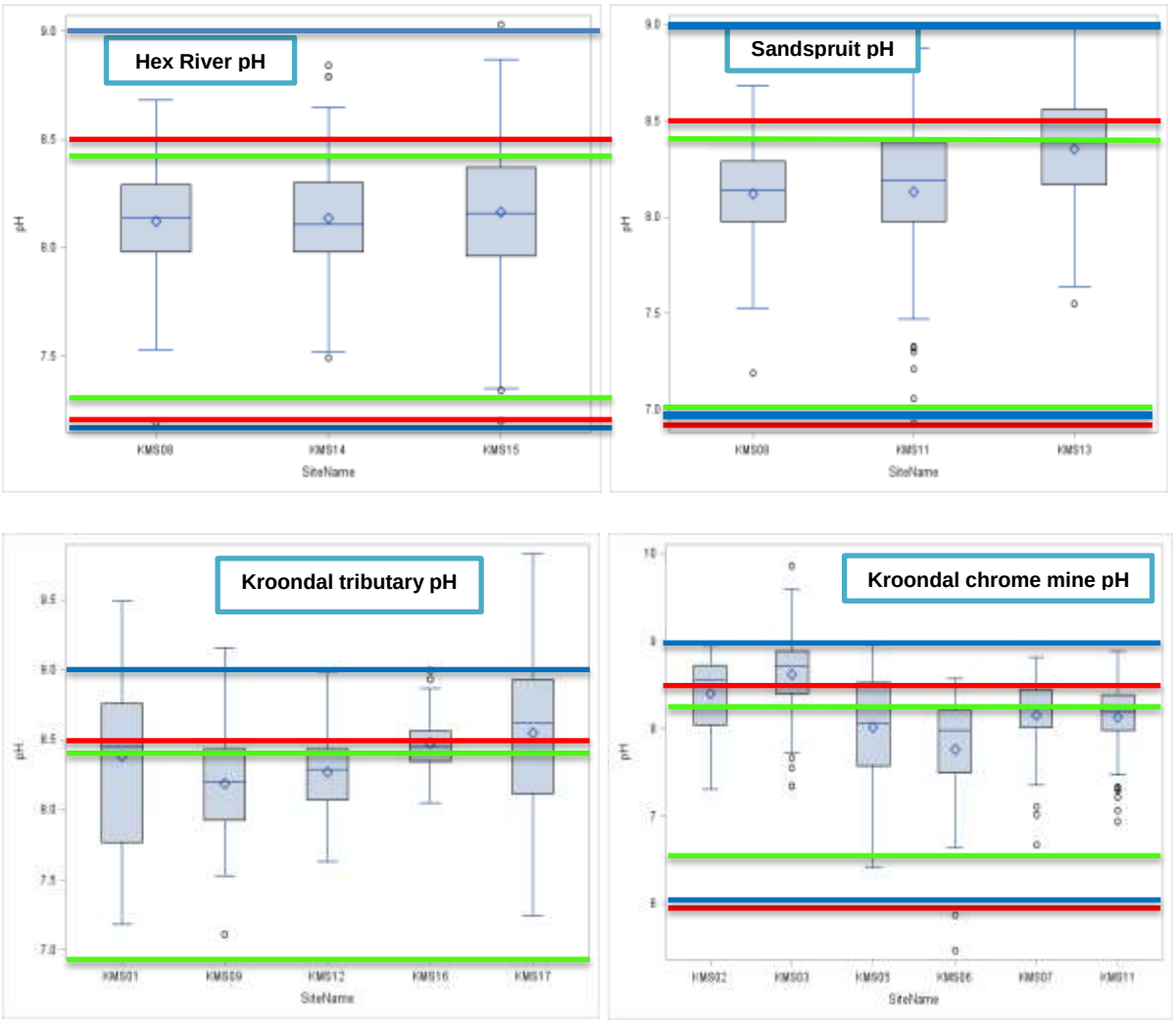


Figure 12: Boxplots presenting the distribution of monthly pH recorded for Hex River, Sandspruit, Kroondal tributary and KCM water quality monitoring points during 2007 to 2013

Hex River: According to Figure 6 and 12, pH recorded at KMS08 downstream of Sandspruit (which discharges waste water to the Hex River as indicated in Figure 12), KMS14 the upstream of the Hex River and KMS15 downstream of the Hex River were above TWQGR for irrigation by 8.4 and Kroondal exemption permit for waste water discharge to the rivers by above 8.5. The pH levels were within the TWQGR limits for domestic use class 0 = ideal by 9.0 for pH levels recorded at KMS08 downstream of Sandspruit, which discharges waste water into the Hex River and KMS14 the upstream of the Hex River. KMS15 downstream of the Hex River was above the TWQGR limits for domestic use class 0 = ideal by 9.1

Sandspruit: According to Figure 6 and 12, pH recorded at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS11 Kroondal Mine return water dam (that discharges waste water to Sandspruit as indicated in figure 14) and KMS13 upstream of the Sandspruit were above TWQGR for irrigation by above 8.4 and Kroondal exemption permit for waste water discharge to the rivers by above 8.5. However, the pH levels were within the TWQGR limits for domestic use class 0 = ideal by 9.0 at all three Sandspruit water-quality monitoring points.

Kroondal tributary: According to Figure 6 and 12, pH recorded at KMS012 downstream of Kroondal tributary, KMS09 discharge from Crocodile Farm to Kroondal tributary, KMS01 upstream of Kroondal tributary and KMS17 Farmer's Dam (which receives water from KMS16 overflowing vent shaft with water from underground) were above TWQGR for irrigation by above 8.4, domestic use class 0 = ideal by 9.0 and Kroondal exemption permit for waste water discharge to the rivers by above 8.5. The highest pH level recorded at KMS01 upstream of Kroondal tributary and KMS17 Farmer's Dam was from 9.5 and 10.

KCM: According to Figure 6 and 12, pH recorded at the following sampling points were above TWQGR for irrigation by above 8.4 and Kroondal exemption permit for waste water discharge to the return water dam (KMS11) by above 8.5: KMS02 sewage effluent tank, KMS03 Ericson Dam that receives water from underground, KMS05 Settlers Dam also receiving water from underground, KMS06 seepage from the slimes dam, KMS07 plant run-off to the storm water canals, and KMS11 return water/catchment dam.

The pH levels were below 9.0 limits for domestic use class 0 = ideal for pH levels recorded at the five KCM water-quality monitoring points except for KMS03 Ericson Dam that receives water from underground. KMS03 Ericson Dam recorded pH levels of about 9.8, which is above 9.0 for domestic use class 0 = ideal.

4.4.2 Electric conductivity (EC mS/m)

Table 3 below Illustrates the annual average of electric conductivity (EC mS/m) of the Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points over a seven-year period from 2007 until 2013.

Table 3: Annual mean or average electric conductivity (EC mS/m) recorded for the Hex River, Sandspruit, Kroondal tributary and KCM from 2007 to 2013

Physical variable Annual average EC mS/m **Monitoring Locality**	2007	2008	2009	2010	2011	2012	2013
Hex River							
KMS 15	120.0	61.8	61.9	40.6	35.1	81.0	66.6
KMS 14	96.1	42.5	53.0	35.20	30.0	40.89	49.0
Sandspruit							
KMS 08	151.6	99.9	87.8	45.9	44.2	103.0	149.0
KMS 11	174.2	152.8	139.9	159.6	153.5	178.1	218.8
KMS 13	No data	60.0	71.1	48.8	34.1	60.6	61.5
Kroondal tributary							
KMS 12	191.0	133.0	13.9	92.2	95.1	95.7	131.4
KMS 09	220.6	216.0	74.7	146.9	141.67	129.7	108.4
KMS 01	126.0	21.0	64.9	8.1	67.94	69.9	126.0
KMS 17	93.0	77.8	63.1	45.6	72.4	96.5	41.1
KMS 16	123.3	126.6	120.4	128.1	122.1	112.2	No data
KCM							
KMS 02	118.8	130.4	130.4	151.5	131.5	93.5	105.1
KMS 03	94.2	116.6	131.1	134.9	115.0	88.0	99.9
KMS 05	187.3	157.9	140.7	173.3	113.6	187.3	157.9
KMS 06	165.5	234.3	183.4	154.0	205.0	180.5	226.0
KMS 07	193.6	145.8	142.1	163.3	146.1	171.5	210.8

According to Table 1, Target Water Quality Guideline Ranges (DWAF, 1996) and the exemption permit for Kroondal Mine (DWAF, 2007) the electric conductivity (EC mS/m) limits for irrigation are < 40, livestock watering limit is 500, domestic used class 0 = ideal limit range between 0 -70, and exemption permit for waste water discharge into the rivers limit is ≤ 70, while waste water discharge into the Kroondal return water dam limit is ≤ 150. TWQGR does not indicate specific electric conductivity (EC mS/m) limits set for aquatic ecosystem.

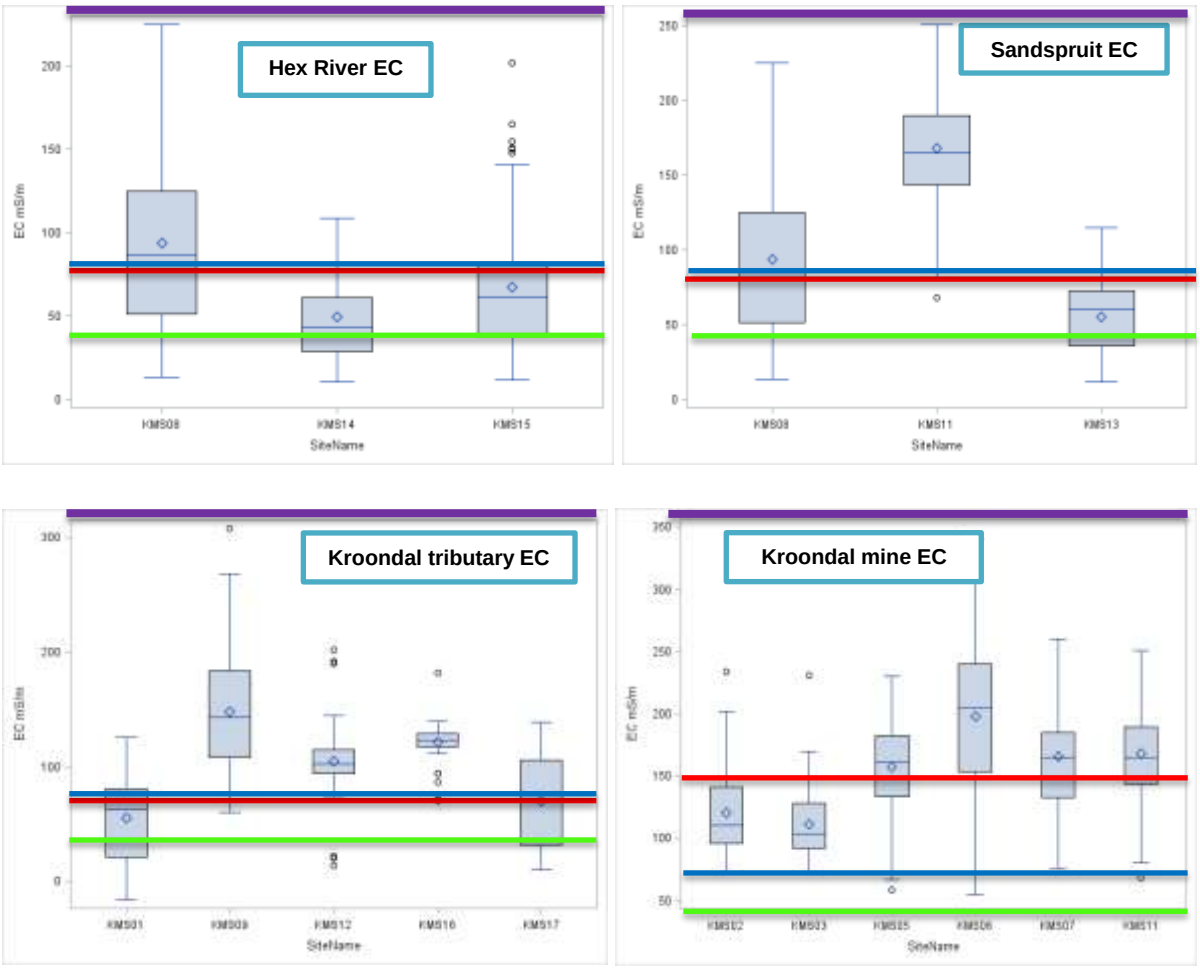


Figure 13: Box plots presenting the distribution of monthly electric conductivity (EC mS/m) recorded for the Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points during 2007 to 2013

Hex River: According to Figure 6 and 13, electric conductivity (EC mS/m) recorded at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS14 upstream of the Hex River and KMS15 downstream of the Hex River were above TWQGR for irrigation 40 limit, domestic use class 0 = ideal 70 limit, and Kroondal exemption permit for waste water discharge to the rivers' 70 limit. The electric conductivity (EC mS/m) recorded at the Hex River sampling locations was above 200 mS/m at KMS8 downstream of Sandspruit that discharges waste water to the Hex River. TWQGR for livestock watering was below the 500 limit at all three sampling location for Hex River.

Sandspruit: According to Figure 6 and 13, electric conductivity (EC mS/m) recorded at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS11 Kroondal Mine return water dam (that discharges waste water to Sandspruit), KMS13 upstream of the Sandspruit were above TWQGR for irrigation 40 limit, domestic use (class 0 = ideal) 70 limit, and Kroondal exemption permit for waste water discharge to the rivers' 70

limit. The electric conductivity (EC mS/m) recorded at Sandspruit sampling locations was above 250 mS/m at KMS11 Kroondal Mine return water dam that discharges waste water to Sandspruit. TWQGR for livestock watering was below the 500 limit at all three sampling location for Sandspruit.

Kroondal tributary: According to Figure 6 and 13, electric conductivity (EC mS/m) recorded at KMS012 downstream of Kroondal tributary, KMS09 discharge from Crocodile Farm to Kroondal tributary, KMS01 upstream of Kroondal tributary and KMS17 Farmer's Dam (receiving water from KMS16 overflowing vent shaft with water from underground) were above TWQGR for irrigation 40 limit, domestic use (class 0 = ideal) 70 limit, and Kroondal exemption permit for waste water discharge to the rivers' 70 limit. The electric conductivity (EC mS/m) recorded at Kroondal tributary was 300 mS/m indicated by a graph at the top of KMS09 discharge from Crocodile Farm to Kroondal tributary. TWQGR for livestock watering was below the 500 limit at all three sampling location for Kroondal tributary.

KCM: According to Figure 6 and 13, electric conductivity (EC mS/m) was recorded at the following sampling points: KMS02 sewage effluent tank, KMS03 Ericson Dam that receives water from underground, KMS05 Settlers Dam which also receives water from underground, KMS06 seepage from the slimes dam, KMS07 plant run-off to the storm water canals and KMS11 return water/catchment dam. Electric conductivity was recorded to be above TWQGR for irrigation 40 limit, domestic use (class 0 = ideal) 70 limit, and Kroondal exemption permit for waste water discharge to the KCM return water dam 150 limit. The highest electric conductivity (EC mS/m) recorded at KCM was approximately 330 mS/m at KMS06 seepage from the slimes dam. TWQGR for livestock watering was below the 500 limit at all three sampling location for Kroondal.

4.4.3 Total Dissolve Solids (TDS mg/l)

Table 4 illustrates the annual average of Total Dissolve Solids (TDS mg/l) of the Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points over a seven-year period from 2007 until 2013.

Table 4: Annual mean or average Total Dissolve Solids (TDS mg/l) recorded for Hex River, Sandspruit, Kroondal tributary and KCM from 2007 to 2013

Physical variable Annual average TDS mg/l **Monitoring Locality**	2007	2008	2009	2010	2011	2012	2013
Hex River							
KMS 15	715.5	350.8	315.0	178.4	170.0	365.2	359.6
KMS 14	574.0	219.5	269.0	157.6	169.9	217.0	270.6
Sandspruit							
KMS 08	902.0	544.5	448.8	220.4	213.3	532.0	797.1
KMS 11	1008.1	888.9	639.8	628.8	656.3	937.9	1126.0
KMS 13	No data	315.7	388.8	227.4	184.6	354.3	348.2
Kroondal tributary							
KMS 12	1091.0	688.0	96.0	422.5	479.7	563.1	718.4
KMS 09	966.6	825.0	650.0	656.3	719.8	725.9	645.5
KMS 01	836.0	601.0	304.0	32.3	339.0	399.5	No data
KMS 17	540.0	474.9	328.2	209.0	375.4	583.8	216.2
KMS 16	724.6	786.2	641.7	573.5	602.6	629.8	No data
KCM							
KMS 02	693.0	644.2	644.2	698.3	649.4	540.2	612.9
KMS 03	578.1	668.3	643.7	598.3	573.9	530.8	593.8
KMS 05	1037.3	866.5	649.2	672.7	496.3	No data	No data
KMS 06	976.4	1456.0	817.1	660.5	875.5	928.6	1201.5
KMS 07	1015.6	828.7	647.6	663.1	641.6	826.0	1098.8

According to Table 1, Target Water Quality Guideline Ranges (DWAF, 1996) and exemption permit for Kroondal Mine (DWAF, 2007), Total Dissolved Solids (TDS mg/l) TWQGR limits, which were used, are: Irrigation is < 260; livestock watering limit is 1 000 diary, pigs and poultry 2 000 cattle and 3 000 sheep. Domestic use class 0 = ideal limit range is between 0 and 450. TWQGR does not indicate specific limits set for Total Dissolve Solids (TDS mg/l) aquatic ecosystem. The exemption permit for waste water discharge into the rivers and waste water discharge into the Kroondal return water dam does not specify the limits for Total Dissolve Solids (TDS mg/l) concentration.

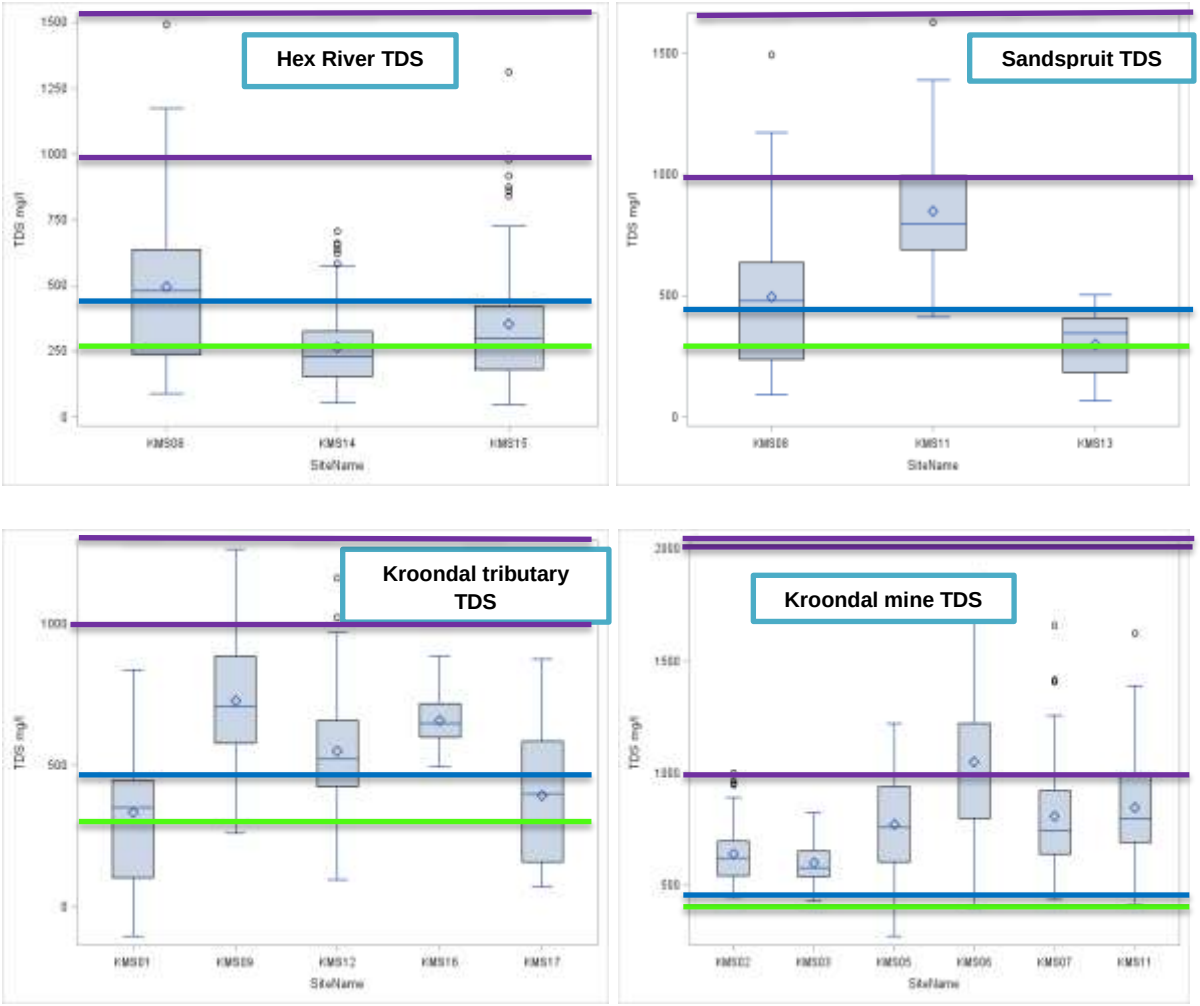


Figure 14: Box plots presenting the distribution of monthly Total Dissolved Solids (TDS mg/l) recorded for Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points during the period 2007 to 2013

Hex River: According to Figure 6 and 14, Total Dissolved Solids (TDS mg/l) recorded at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS14 upstream of the Hex River and KMS15 downstream of the Hex River were above TWQGR for irrigation < 260 limit, and domestic use (class 0 = ideal) 0 – 450 limit. TWQGR for livestock watering was within the limit of 1 000 for dairy at KMS14 and KMS15, KMS08 was above the1 000 limit for dairy by about 1500 mg/l. However, it was below the limit of 2 000 for pigs, poultry and cattle and 3 000 for sheep at all three Hex River water monitoring points. The highest Total Dissolved Solids (TDS mg/l) recorded at the Hex River sampling locations was 1 500 mg/l indicated by a graphh at the top of KMS8 downstream of Sandspruit that discharges waste water to the Hex River.

Sandspruit: According to Figure 6 and 14, Total Dissolved Solids (TDS mg/l) recorded at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS11

Kroondal Mine return water dam (that discharges waste water to Sandspruit) and KMS13 upstream of the Sandspruit were above the TWQGR for irrigation < 260 limit, and domestic use (class 0 = ideal) 0 to 450 limit. TWQGR for livestock watering was below the limit of 1,000 – by 500 mg/l for dairy – at KMS13. KMS11 was above the 1 000 limit for dairy by more than 1500 mg/l. However, TWQGR for livestock watering was below the limit of 2 000 for pigs, poultry and cattle and 3 000 for sheep at all three Sandspruit water-quality monitoring points. The highest Total Dissolved Solids (TDS mg/l) recorded at Sandspruit sampling locations was approximately 1,700 mg/l indicated by a graph at the top of KMS11 Kroondal return water dam.

Kroondal tributary: According to Figure 6 and 14, Total Dissolved Solids (TDS mg/l) recorded at KMS012 downstream of Kroondal tributary, KMS09 discharge from Crocodile Farm to Kroondal tributary, KMS01 upstream of Kroondal tributary and KMS17 Farmer's Dam (which receives water from KMS16 overflowing vent shaft with water from underground) were above the TWQGR for irrigation < 260 limit, and domestic use (class 0 = ideal) 0 – 450 limit. TWQGR for livestock watering was below the limit of 1 000 mg/l for dairy at KMS1, KMS16 and KMS17. KMS09 and KMS12 recorded the TWQGR for livestock watering limit above1,000 mg/l for dairy. However, TWQGR for livestock watering was below the limit of 2 000 for pigs, poultry and cattle and 3,000 for sheep at all five Kroondal tributary water-quality monitoring points. The highest Total Dissolved Solids (TDS mg/l) recorded at Kroondal tributary sampling locations was approximately 1,300 mg/l at KMS09 the outlet discharge from Crocodile Farm.

KCM: According to Figure 6 and 14, Total Dissolved Solids (TDS mg/l) at the following sampling points recorded TWQGR above the limit for irrigation < 260, and domestic use (class 0 = ideal) 0 – 450 limit: KMS02 sewage effluent tank; KMS03 Ericson Dam that receives water from underground; KMS05 Settlers Dam which also receives water from underground; KMS06 seepage from the slimes dam; KMS07plant run-off to the storm water canals and KMS11 return water/catchment dam. TWQGR for livestock watering was below the limit of 1 000 mg/l for dairy at KMS02 and KMS03, KMS05, KMS06, KMS07 and KMS11 recorded the TWQGR for livestock watering limit above1 000 mg/l for dairy. However, TWQGR for livestock watering was below the limit of 2 000 for pigs, poultry and cattle, and 3000 for sheep at all six KCM water-quality monitoring points. The highest Total Dissolved Solids (TDS mg/l) concentration recorded at KCM sampling locations was approximately 1 800 mg/l at KMS06 seepage from the slimes dam.

4.4.4 Chloride (Cl mg/l)

Table 5 illustrates the annual average of chloride (Cl mg/l) concentration of the Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points over a seven-year period from 2007 until 2013.

Table 5: Annual mean or average chloride (Cl mg/l) concentration recorded for the Hex River, Sandspruit, Kroondal tributary and KCM from 2007 to 2013

Chemical variable Annual average Cl mg/l							
Monitoring Locality	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Hex River							
KMS 15	77.2	27.6	26.0	11.6	11.4	38.4	34.8
KMS 14	38.2	11.2	17.2	9.6	18.1	14.7	14.0
Sandspruit							
KMS 08	99.7	51.1	40.9	13.7	16.9	69.6	161.5
KMS 11	112.2	88.2	93.7	92.8	95.0	181.0	249.8
KMS 13	No data	8.7	11.7	6.1	8.8	11.3	9.6
Kroondal tributary							
KMS 12	124.0	75.4	5.52	28.2	40.8	33.8	142.6
KMS 09	84.3	54.5	44.9	71.3	72.2	65.9	85.7
KMS 01	48.7	-154.6	23.6	-1.7	23.6	27.1	No data
KMS 17	35.1	33.3	22.3	11.8	28.3	35.6	6.8
KMS 16	46.2	43.4	47.1	39.1	39.3	35.8	No data
KCM							
KMS 02	70.5	115.7	115.7	124.2	116.	37.3	53.7
KMS 03	41.7	66.5	119.0	99.3	78.3	36.4	51.4
KMS 05	116.9	90.25	91.5	97.6	77.4	No data	No data
KMS 06	91.7	104.2	95.0	79.7	112.5	191.8	277.5
KMS 07	130.8	84.5	90.8	94.1	84.7	142.0	237.2

According to Table 1, the chloride (Cl mg/l) concentration limits for irrigation range between 0 and 100, livestock watering limits range between 0 and, while the limit for non-ruminants is 1500 and between 0 and 3 000 for ruminants. TWQGR for domestic used (class 0 = ideal) limits range between 0 and 1.00. The aquatic ecosystem limit is 400. The limit for waste water discharge into the rivers – as set out in the Kroondal Mine exemption permit – is ≤ 100, while the limit for waste water discharge into the Kroondal return water dam is ≤200.

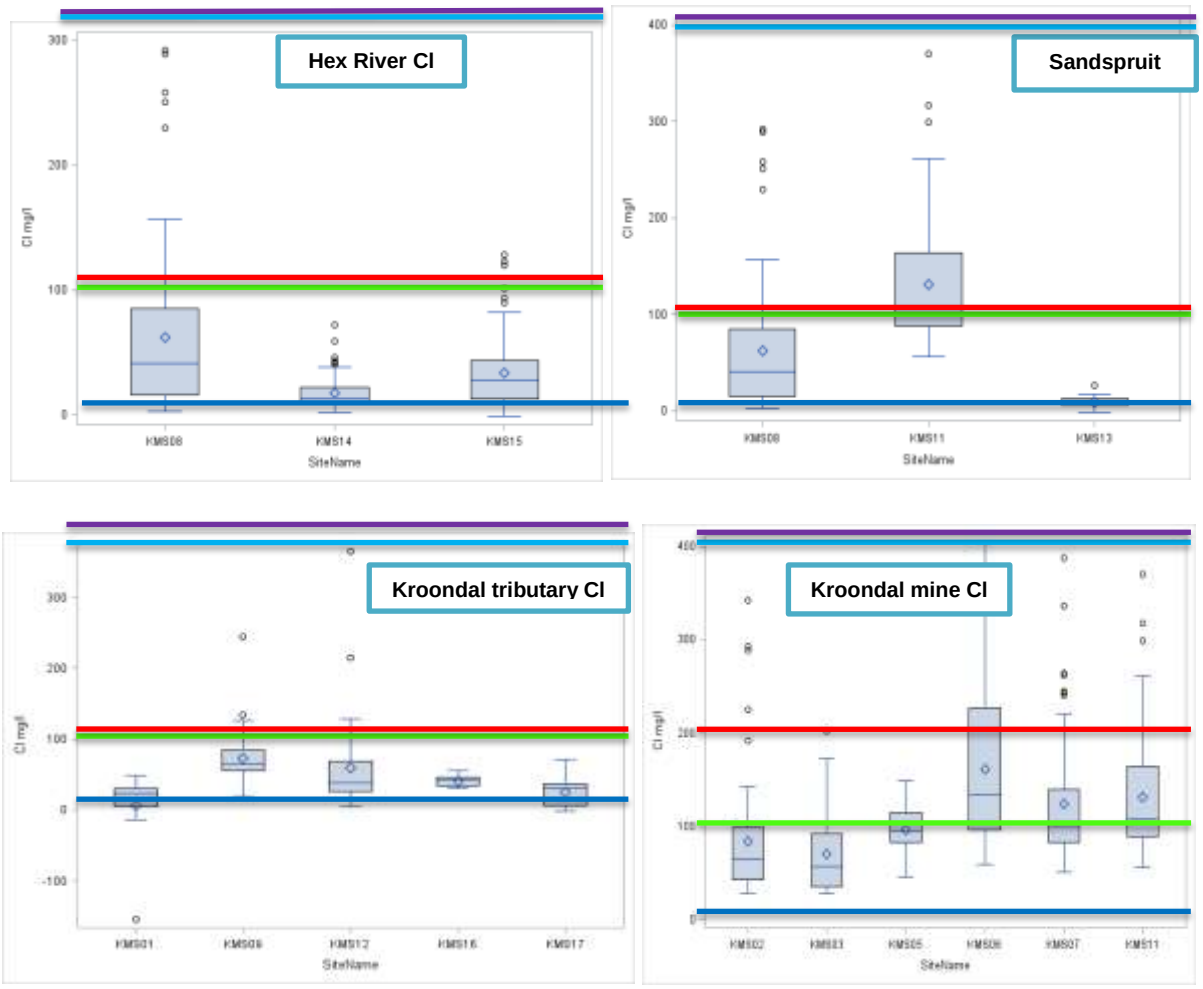


Figure 15: Box plots presenting the distribution of monthly chloride (Cl mg/l) concentrations recorded for the Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points during 2007 to 2013

Hex River: According to Figure 6 and 15, chloride (Cl mg/l) concentration recorded at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River) and KMS15 downstream of the Hex River were above TWQGR for the irrigation 0 – 100 limit, domestic use (class 0 = ideal) 0 – 1.00 limit and Kroondal exemption permit for water discharge in to the rivers limit of ≤ 100. KMS14 (the upstream of the Hex River) was only above the TWQGR limits for domestic use (class 0 = ideal) 0 – 1.00, and below on TWQGR for the irrigation 0 – 100 limit, Kroondal exemption permit for water discharge into the rivers, aquatic ecosystem and livestock watering. TWQGR for livestock watering was below the limit of 0 – 1 500 for non-ruminants as well as 0 – 3 000 for ruminants and the aquatic ecosystem limit of 400 at KMS08 and KMS15. The highest chloride (Cl mg/l) concentration recorded at the Hex River sampling locations was about 290 mg/l indicated by a graphh at the top of KMS8 downstream of Sandspruit that discharges waste water to the Hex River.

Sandspruit: According to Figure 6 and 15, chloride (Cl mg/l) concentration recorded at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River) and KMS11 Kroondal Mine return water dam (that discharges waste water to Sandspruit) were above the TWQGR for irrigation 0 – 100limit, domestic use (class 0 = ideal) 0 – 1.00 limit and Kroondal exemption permit for water discharge into the rivers limit of ≤ 100. KMS13 upstream of the Sandspruit was only above the TWQGR limits for domestic use (class 0 = ideal) 0 – 1.00, and below on TWQGR for irrigation 0 – 100 limit, Kroondal exemption permit for water discharge into the rivers, aquatic ecosystem and livestock watering. TWQGR for livestock watering was below the limit of 0 – 1 500 for non-ruminants and 0 – 3 000 for ruminants and aquatic ecosystem limit of 400 at all three Sandspruit water-quality monitoring points (KMS08, KMS11 and KMS13). The highest chloride (Cl mg/l) concentration recorded at the Sandspruit sampling locations was about 380 mg/l indicated by a graphh at the top of KMS11 Kroondal return water dam.

Kroondal tributary: According to Figure 6 and 15, chloride (Cl mg/l) concentration recorded at KMS01 upstream of Kroondal tributary was above the TWQGR for domestic use (class 0 = ideal) 0 – 1.00 limit; below the TWQGR for the irrigation 0 – 100 limit, livestock watering limit of 0 – 1 500 for non-ruminants and 0 – 3 000 limit for ruminants, aquatic ecosystem limit of 400 and Kroondal exemption permit for water discharge into the rivers limit of ≤ 100. Chloride (Cl mg/l) concentration recorded at KMS012 downstream of the Kroondal tributary and KMS09 discharge from Crocodile Farm to Kroondal tributary was above the TWQGR for irrigation 0 – 100 limit, domestic use (class 0 = ideal) 0 – 1.00 limit and Kroondal exemption permit for water discharge into the rivers limit of ≤ 100. KMS12 chlorine concentration was within the TWQGR for aquatic ecosystem limit of 400 max and below the limit of TWQGR for livestock watering limit of 0 – 1 500 for non-ruminants and 0 – 3 000 for ruminants. KMS09 chlorine concentration was below the TWQGR for aquatic ecosystem limit of 400 max and livestock watering limit of 0 – 1500 for non-ruminants and 0 – 3000 for ruminants. KMS17 Farmer's – which receives water from KMS16 overflowing vent shaft with water from underground – were above the TWQGR for domestic use (class 0 = ideal) 0 – 1.00 limit and below the TWQGR for irrigation 0 – 100 limit, livestock watering 0 – 1 500 limit for non-ruminants and 0 – 3 000 limit for ruminants, aquatic ecosystem limit of 400 and Kroondal exemption permit for water discharge in to the rivers limit of ≤ 100

KCM: According to Figure 6 and 15, chloride (Cl mg/l) concentration at the following sampling points recorded a TWQGR above the 0 – 100 limit for irrigation and domestic use (class 0 = ideal) 0 – 1.00 limit: KMS02 sewage effluent tank, KMS03 Ericson Dam that receives water from underground, KMS05 Settlers Dam which also receives water from underground, KMS06 seepage from the slimes dam, KMS07 plant run-off to the storm water canals and KMS11 return water/catchment dam. KMS02 and KMS03 also recorded the chloride concentration above the Kroondal exemption permit for water discharge into the Kroondal return water dam limit of 200 mg/l and below the TWQGR limit for livestock watering, 0 – 1 500 for non-ruminants, 0 – 3000 for ruminants and aquatic ecosystem limit of

400. KMS05 chloride concentration was below the TWQGR limit for livestock watering, 0 – 1 500 for non-ruminants, 0 – 3 000 for ruminants and aquatic ecosystem limit of 400.

Chloride (Cl mg/l) concentration at KMS06 seepage from the slimes dam was above the TWQGR limit for irrigation 0 – 100, domestic use (class 0 = ideal) 0 – 1.00 limit, aquatic ecosystem limit of 400 and Kroondal exemption permit for water discharge into the Kroondal return water dam limit of 200 mg/l and below the limits for livestock watering of 0 – 1 500 for non-ruminants and 0 – 3000 for ruminants. KMS07 and KMS11 recorded the TWQGR above the limit for irrigation 0 – 100, domestic use (class 0 = ideal) 0 – 1.00 limit and Kroondal exemption permit for water discharge into the Kroondal return water dam limit of 200 mg/l. At KMS07 and KMS11, chloride (Cl mg/l) concentration was below the limits for livestock watering, 0 – 1 500 for non-ruminants. 0 – 3 000 for ruminants and aquatic ecosystem limit of 400.

4.4.5 Sulphate (SO_4 mg/l)

Table 6 illustrates the annual average of sulphate (SO_4 mg/l) concentration of Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points over a seven-year period from 2007 until 2013.

Table 6: Annual mean or average Sulphate (SO_4 mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM from 2007 to 2013

Chemical variable Annual average SO_4 mg/l							
Monitoring Locality	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Hex River							
KMS 15	147.9	54.3	59.9	33.4	22.3	61.0	61.2
KMS 14	114.0	36.5	49.6	31.3	28.2	36.6	46.5
Sandspruit							
KMS 08	152.3	86.2	72.8	35.5	29.9	94.4	127.3
KMS 11	167.4	133.8	124.7	131.6	128.8	207.4	150.1
KMS 13	44.6	56.1	32.6	24.2	46.3	35.1	44.6
Kroondal tributary							
KMS 12	178.5	167.0	6.4	86.4	90.1	103.8	161.0
KMS 09	157.6	82.4	177.0	110.5	116.1	81.5	59.7
KMS 01	155.0	105.0	49.2	17.7	82.0	92.85	No data
KMS 17	102.1	117.8	75.8	56.9	85.0	145.4	50.9
KMS 16	137.6	140.6	159.3	148.3	136.1	149.9	No data
KCM							
KMS 02	112.3	120.8	120.8	141.7	116.8	101.1	89.0
KMS 03	105.2	115.8	117.0	116.8	111.1	111.7	96.9
KMS 05	168.7	130.5	127.4	145.7	70.5	No data	No data
KMS 06	209.7	270.6	237.5	165.0	183.5	186.8	180.4
KMS 07	148.5	120.1	125.5	137.4	124.3	158.2	150.2

According to Table 1, Target Water Quality Guideline Ranges (DWAF, 1996) and exemption permit for Kroondal Mine (DWAF, 2007), sulphate (SO_4 mg/l) concentration limits for

irrigation is 200 max, livestock watering limit range between 0 – 1000, domestic use (class 0 = ideal) limit range between 0 to 200. Kroondal Mine exemption permit for waste water discharge into the rivers limit is ≤200 while waste water discharge into Kroondal return water dam limit is ≤ 400.TWQGR (DWAF,1996) for aquatic ecosystems does not specify the limit for sulphate (SO_4 mg/l) concentration, hence it is not presented in Figure 16.

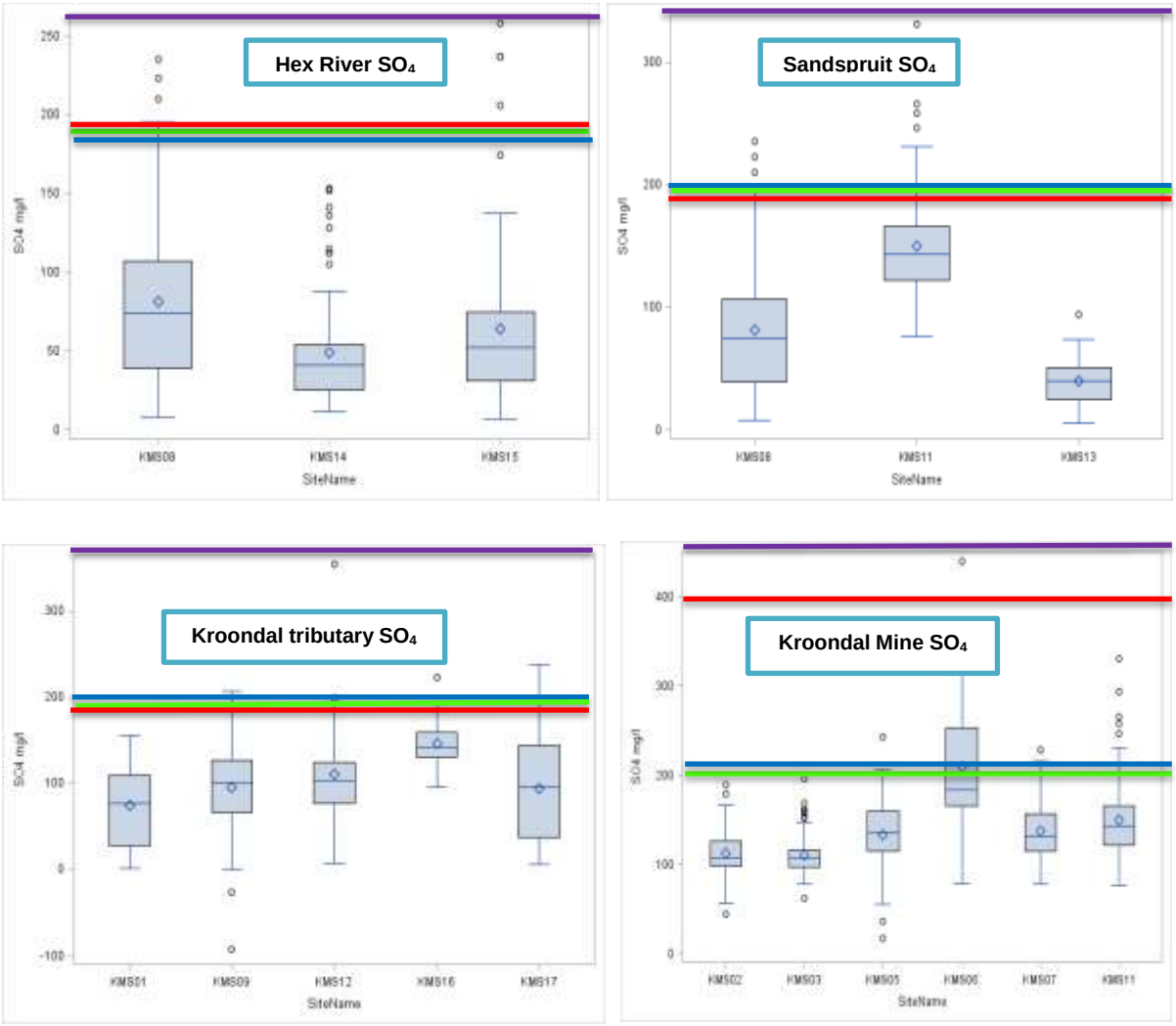


Figure 16: Box plots presenting the distribution of monthly sulphate (SO_4 mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points during the period 2007 to 2013

Rex River: According to Figure 6 and 16, sulphate (SO_4 mg/l) concentration at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), and KMS15 downstream of the Hex River were above TWQGR for irrigation 200 max limit, domestic use (class 0 = ideal) 0 – 200 limit and Kroondal exemption permit for water discharge into the rivers limit of ≤200 and below the limit for livestock watering limit range of 0 – 1 000.

Sulphate (SO4 mg/l) concentration at KMS14 upstream of the Hex River was below the TWQGR for irrigation 200 max limit, domestic use (class 0 = ideal) 0 – 200 limit, livestock watering limit range of 0 – 1 000 and Kroondal exemption permit for water discharge into the rivers limit of ≤200. The highest sulphate (SO_4 mg/l) concentration recorded at the Hex River sampling locations was about 260 mg/l indicated by a graph at KMS15 downstream of the Hex River.

Sandspruit: According to Figure 6 and 16, sulphate (SO_4 mg/l) concentration recorded at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River) and KMS11 Kroondal Mine return water dam (that discharges waste water to Sandspruit) were above TWQGR for irrigation 200 max limit, domestic use (class 0 = ideal) 0 – 200 limit and Kroondal exemption permit for water discharge into the rivers limit of ≤200 and below the limit for livestock watering limit range of 0 – 1 000. Sulphate (SO4 mg/l) concentration at KMS13 upstream of the Sandspruit was below the TWQGR for irrigation 200 max limit, domestic use (class 0 = ideal) 0 – 200 limit, livestock watering limit range of 0 – 1000 and Kroondal exemption permit for water discharge in to the rivers limit of ≤200. The highest sulphate (SO_4 mg/l) concentration recorded at Sandspruit sampling locations was about 310 mg/l indicated by a graphh at KMS11 Kroondal Mine return water dam that discharges waste water to Sandspruit.

Kroondal tributary: According to Figure 6 and 16, sulphate (SO_4 mg/l) concentration at KMS012 downstream of Kroondal tributary, KMS09 discharge from Crocodile Farm to Kroondal tributary and KMS17 Farmer's Dam that receives water from KMS16 overflowing vent shaft with water from underground were above TWQGR for irrigation 200 max limit, domestic use (class 0 = ideal) 0 – 200 limit and Kroondal exemption permit for water discharge into the rivers limit of ≤200 and below the limit for livestock watering limit range of 0 – 1000. Sulphate (SO4 mg/l) concentration at KMS01 upstream of Kroondal tributary was below the TWQGR for irrigation 200 max limit, domestic use (class 0 = ideal) 0 – 200 limit, livestock watering limit range of 0 – 1000 and Kroondal exemption permit for water discharge in to the rivers limit of ≤200. The highest sulphate (SO_4 mg/l) concentration recorded at Kroondal tributary sampling locations was about 380 mg/l indicated by a graph at KMS012 downstream of Kroondal tributary.

KCM: According to Figure 6 and 16, sulphate (SO_4 mg/l) concentration at the following sampling points at KMS02 sewage effluent tank was below the TWQGR for irrigation 200 max limit, domestic use (class 0 = ideal) 0 – 200 limit, livestock watering limit range of 0 – 1 000 and Kroondal exemption permit for water discharge into Kroondal return water dam limit of ≤400. KMS03 Ericson Dam – which receives water from underground – was within the TWQGR limit for irrigation 200 max and domestic use (class 0 = ideal) 0 – 200 limit and below the limit for livestock watering limit range of 0 – 1 000 and Kroondal exemption permit for water discharge into Kroondal return water dam limit of ≤400. Sulphate (SO4 mg/l) concentration at KMS05 Settlers Dam (which also receives water from underground), KMS07 plant run-off to the storm water canals and KMS11 return water/catchment dam were

above TWQGR limits for irrigation 200 max and domestic use (class 0 = ideal) 0 – 200 limit and below the limit for livestock watering limit range of 0 – 1 000 and Kroondal exemption permit for water discharge into Kroondal return water dam limit of ≤ 400. Sulphate (SO_4 mg/l) concentration at KMS06 seepage from the slimes dam was above the TWQGR limit for irrigation 200 max, domestic use (class 0 = ideal) 0 – 200 limit and Kroondal exemption permit for water discharge into Kroondal return water dam limit of ≤400 and only below the limit for livestock watering limit range of 0 – 1 000. The highest sulphate (SO_4 mg/l) concentration recorded at KCM sampling locations was about 380 mg/l at KMS06 seepage from the slimes dam.

4.4.6 Nitrate (NO_3 mg/l)

Table 7 illustrates the annual average nitrate (NO_3 mg/l) concentration of Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points over a seven-year period from 2007 until 2013.

Table 7: Annual mean or average nitrate (NO_3 mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM from 2007 to 2013

Chemical variable Annual average NO_3 mg/l							
Monitoring Locality	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Hex River							
KMS 15	19.9	7.2	8.4	1.6	3.5	24.5	10.8
KMS 14	7.5	1.8	5.3	2.3	1.8	2.1	2.2
Sandspruit							
KMS 08	64.3	23.5	14.1	0.7	7.6	42.0	66.9
KMS 11	64.2	57.2	57.9	54.4	74.2	120.2	140.0
KMS 13	0.0	0.7	0.0	0.7	0.2	0.4	0.0
Kroondal tributary							
KMS 12	469.9	19.1	0.86	2.3	14.6	6.0	54.4
KMS 09	-1.7	-0.0	0.0	0.7	4.3	2.0	18.3
KMS 01	-25.8	-77.4	0.4	3.3	15.7	2.7	No data
KMS 17	2.4	6.7	5.2	3.4	9.6	5.0	0.3
KMS 16	17.3	22.0	31.2	25.8	36.9	31.7	No data
KCM							
KMS 02	27.7	35.8	35.8	29.8	30.5	13.9	16.4
KMS 03	14.4	22.4	36.1	21.2	25.7	12.1	15.2
KMS 05	81.0	57.3	57.8	64.5	92.6	No data	No data
KMS 06	83.0	122.1	104.1	57.5	136.5	119.2	138.9
KMS 07	63.7	44.4	60.5	51.7	65.3	111.0	132.0

Note: Negative values relates to concentrations detected by the laboratory equipment as below detection limit. The negative signs as such recorded in table 7 and Appendix 2, does not indicate negative concentrations but rather values that are below the detection limit of the laboratory equipment used.

According to Table 7, Target Water Quality Guideline Ranges (DWAF, 1996) and exemption permit for Kroondal Mine (DWAF, 2007), Nitrate (NO_3 mg/l) concentration for domestic used

(class 0 = ideal) limit is < 6. The Kroondal Mine exemption permit for waste water discharge into the rivers limit is ≤ 6 while the limit for waste water discharge into Kroondal return water dam is ≤ 12.TWQGR (DWAF,1996) for irrigation, livestock watering and aquatic ecosystem does not specify the limit for nitrate (NO_3 mg/l), hence it is not presented in figure 18.

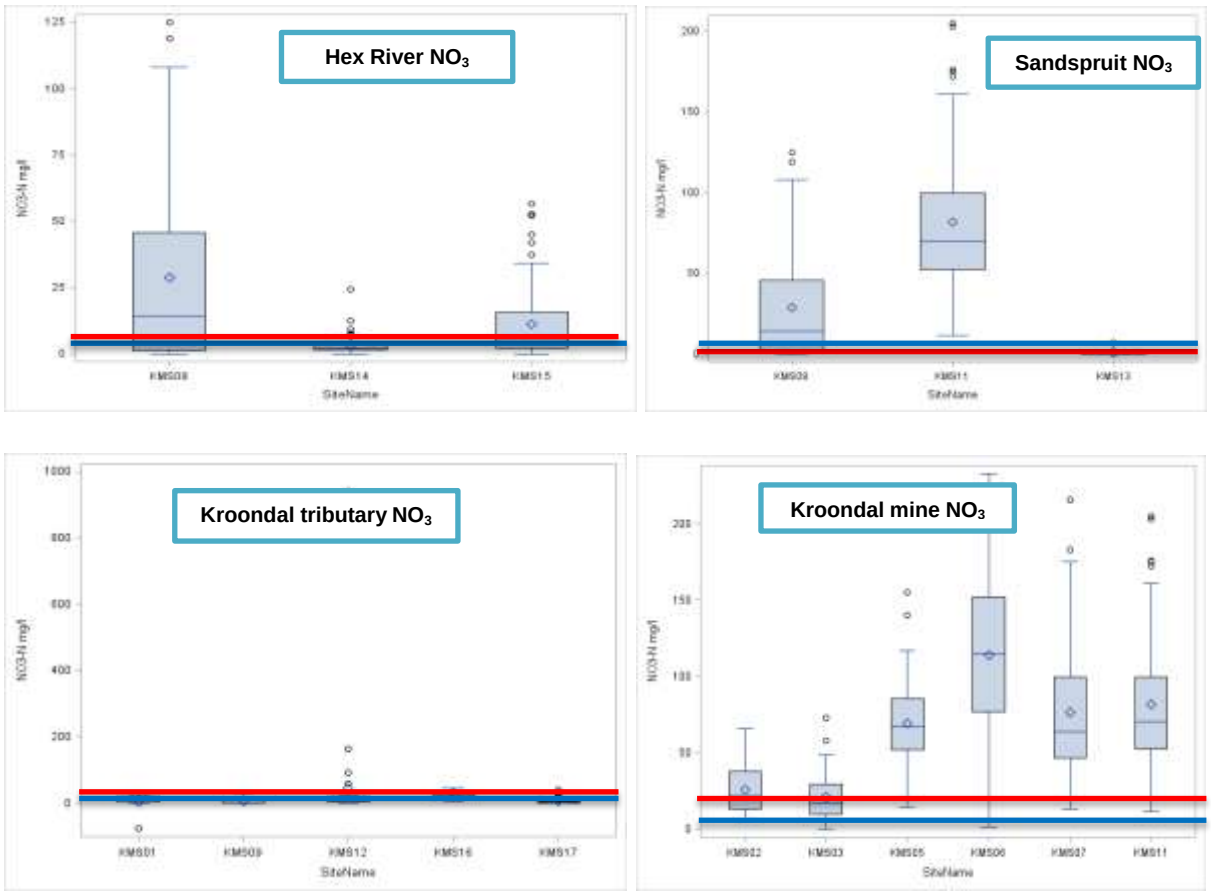


Figure 17: Box plots presenting the distribution of monthly nitrate (NO_3 mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points during the period2007 to 2013

Hex River: According to Figure 6 and 17**,** nitrate (NO_3 mg/l) concentration at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS14 upstream of the Hex River and KMS15 downstream of the Hex River were above the TWQGR for domestic use (class 0 = ideal) limit of < 6 and Kroondal Mine exemption permit for waste water discharge into the rivers limit of ≤ 6. The highest nitrate (NO_3 mg/l) concentration recorded at the Hex River sampling locations was 125 mg/l indicated by a graphh at the top of KMS8 downstream of Sandspruit that discharges waste water to the Hex River.

Sandspruit: According to Figure 6 and 17**,** nitrate (NO_3 mg/l) concentration at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS11 Kroondal Mine return water dam (that discharges waste water to Sandspruit) and KMS13 upstream of

the Sandspruit were above the TWQGR for domestic use (class 0 = ideal) limit of <6 and Kroondal Mine exemption permit for waste water discharge into the rivers limit of ≤6. The highest nitrate (NO_3 mg/l) concentration recorded at the Hex River sampling locations was 200 mg/l indicated by a graphh at the top of KMS11 Kroondal Mine return water dam that discharges waste water to Sandspruit.

Kroondal tributary: According to Figure 6 and 17**,** nitrate (NO_3 mg/l) concentration recorded at KMS012 downstream of Kroondal tributary and KMS17 (Farmer's Dam receiving water from KMS16 overflowing vent shaft with water from underground) were above the TWQGR for domestic use (class 0 = ideal) limit of <6 and Kroondal Mine exemption permit for waste water discharge into the rivers limit of ≤6. KMS09 discharge from Crocodile Farm to Kroondal tributary and KMS01 upstream of Kroondal tributary were below the TWQGR for domestic use (class 0 = ideal) limit of <6 and Kroondal Mine exemption permit for waste water discharge into the rivers limit of ≤6. The highest nitrate (NO_3 mg/l) concentration recorded at Kroondal tributary sampling locations was about 200 mg/l at KMS012 downstream of Kroondal tributary.

KCM: According to Figure 6 and 17**,** nitrate (NO_3 mg/l) concentration at the following sampling points were above the TWQGR for domestic use (class 0 = ideal) limit of <6 and Kroondal Mine exemption permit for waste water discharge into the rivers limit of ≤6: KMS02 sewage effluent tank, KMS03 Ericson Dam (that receives water from underground), KMS05 Settlers Dam (which also receives water from underground), KMS06 seepage from the slimes dam, KMS07plant run-off to the storm water canals and KMS11 return water/catchment dam. The highest nitrate (NO_3 mg/l) concentration recorded at KCM sampling locations was about 300 mg/l at KMS06 seepage from the slimes dam.

4.4.7 Ammonia (NH_3 mg/l)

Table 8 illustrates the annual average ammonia (NH_3 mg/l) concentration of Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points over a seven-year period from 2007 until 2013.

Table 8: Annual mean or average ammonia (NH_3 mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KMS from 2007 to 2013

Chemical variable Annual average Ammonia (NH_3 mg/l) Monitoring Locality	2007	2008	2009	2010	2011	2012	2013
Hex River							
KMS 15	1.4	0.2	0.1	0.0	0.1	1.6	0.4
KMS 14	0.1	0.1	0.0	0.1	0.1	0.1	0.1
Sandspruit							
KMS 08	3.3	0.7	0.2	0.0	0.7	2.5	7.7
KMS 11	12.8	5.0	5.7	6.3	7.9	10.3	32.9
KMS 13	0.1	0.0	0.0	0.0	0.1	0.5	0.1
Kroondal tributary							
KMS 12	18.0	4.9	-0.0	0.4	2.2	1.2	0.1
KMS 09	77.6	88.6	13.7	14.6	13.6	19.7	0.6
KMS 01	-0.0	-0.0	-0.0	0.0	0.1	0.2	No data
KMS 17	0.3	0.2	0.1	0.1	0.1	0.1	0.1
KMS 16	-0.0	0.1	0.0	0.3	0.1	0.0	No data
KCM							
KMS 02	1.6	2.1	2.1	0.6	0.6	0.0	0.0
KMS 03	0.5	1.5	1.6	0.2	0.1	0.2	0.1
KMS 05	19.1	6.6	4.9	9.3	3.1	No data	No data
KMS 06	17.3	24.1	17.9	6.1	23.9	16.3	24.7
KMS 07	19.6	4.6	6.9	8.0	9.0	22.6	34.2

Note: Negative values relates to concentrations detected by the laboratory equipment as below detection limit. The negative signs as such recorded in the spread sheet, does not indicate negative concentrations but rather values that are below the detection limit of the laboratory equipment used.

According to Table 1, Target Water Quality Guideline Ranges (DWAF, 1996) and exemption permit for Kroondal Mine (DWAF, 2007), ammonia (NH_3 mg/l) concentration for domestic use (class 0 = ideal) limit range is between 0 to 1.0 and the TWQGR for aquatic ecosystem limit is <0.007. TWQGR (DWAF, 1996) for irrigation and livestock watering does not specify the limit for ammonia (NH_3 mg/l) concentration; hence this is not presented Figure 18. Kroondal Mine exemption permit for waste water discharge into the rivers and waste water discharge into Kroondal return water dam also does not specify the limit for ammonia (NH_3 mg/l) concentration. Hence, it is also not presented in Figure 18

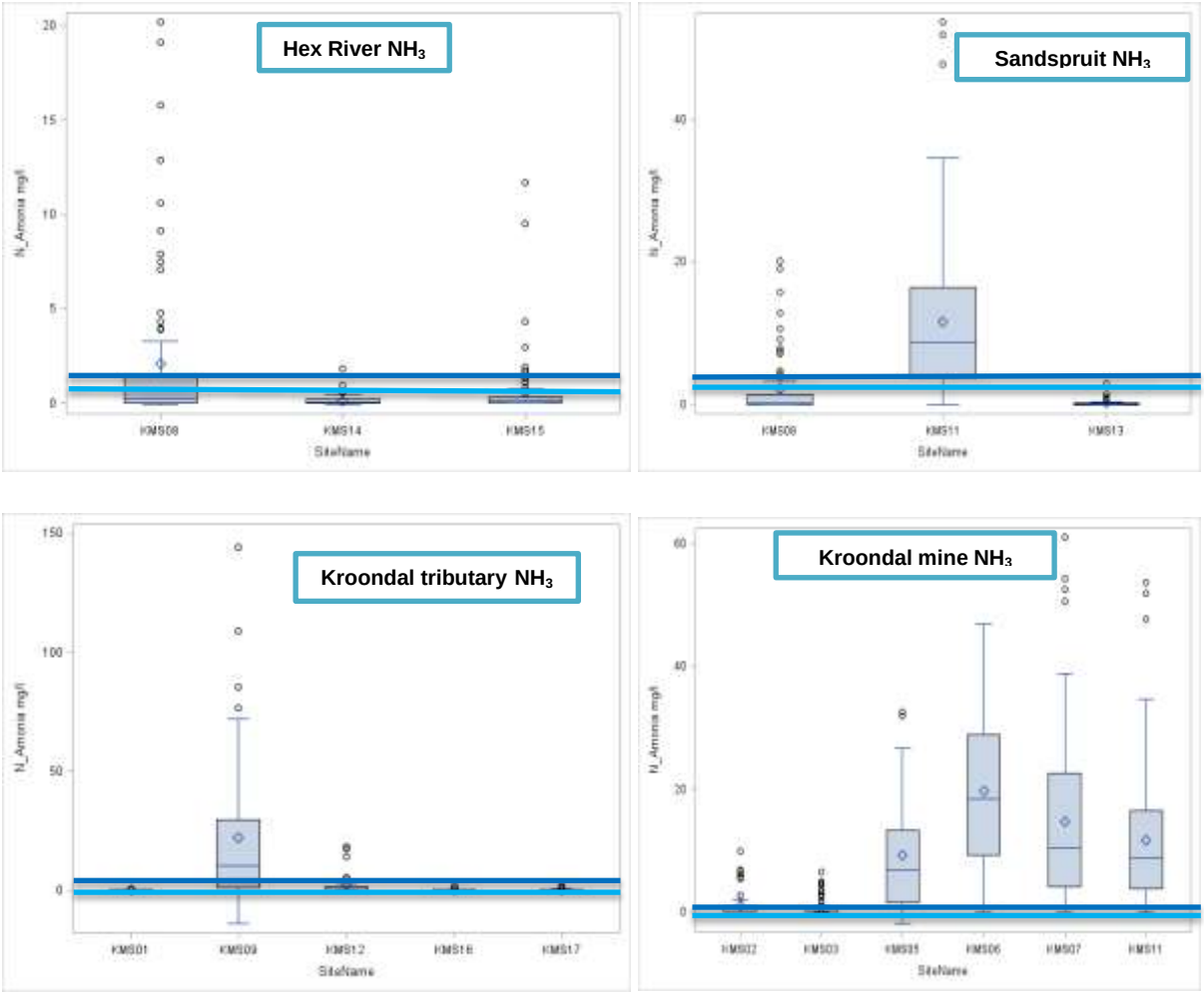


Figure 18: Box plots presenting the distribution of monthly ammonia (NH_3 mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points during 2007 to 2013

Hex River: According to Figure 6 and 18, ammonia (NH_3 mg/l) concentration at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS14 upstream of the Hex River and KMS15 downstream of the Hex River were above the TWQGR for domestic use (class 0 = ideal) range between 0 to 1.0 and TWQGR for aquatic ecosystem limit of <0.007. The highest ammonia (NH_3 mg/l) concentration recorded at the Hex River sampling locations was 21 mg/l, which was indicated in the graph at KMS8 downstream of Sandspruit that discharges waste water to the Hex River.

Sandspruit: According to Figure 6 and 18, ammonia (NH_3 mg/l) concentration at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River) and KMS11 Kroondal Mine return water dam (that discharges waste water to Sandspruit) were above the TWQGR for domestic use (class 0 = ideal) range between 0 – 1.0 and TWQGR for aquatic ecosystem limit of <0.007. KMS13 upstream of the Sandspruit was below the TWQGR for

domestic use (class 0 = ideal) range between 0 – 1.0 and above the TWQGR for aquatic ecosystem limit of <0.007 The highest ammonia (NH_3 mg/l) concentration recorded at Sandspruit sampling locations was about 50 mg/l indicated by a graph at the top of KMS11 Kroondal Mine return water dam that discharges waste water to Sandspruit.

Kroondal tributary: According to Figure 6 and 18, ammonia (NH_3 mg/l) concentration recorded at KMS012 downstream of Kroondal tributary and KMS09 discharge from Crocodile Farm to Kroondal tributary were above the TWQGR for domestic use (class 0 = ideal) range between 0 – 1.0 and TWQGR for aquatic ecosystem limit of <0.007. KMS01 upstream of the Kroondal tributary and KMS17 Farmer's Dam receiving water from KMS16 overflowing vent shaft with water from underground were below the TWQGR for domestic use (class 0 = ideal) range between 0 – 1.0 and TWQGR for aquatic ecosystem limit of <0.007. The highest ammonia (NH_3 mg/l) concentration recorded at Kroondal tributary sampling locations was about 140 mg/l, which was indicated by a graph at KMS09 discharge from Crocodile Farm to Kroondal tributary.

KCM: According to Figure 6 and 18, ammonia (NH_3 mg/l) concentration at the following sampling points were above the TWQGR for domestic use (class 0 = ideal) range between 0 – 1.0 and TWQGR for aquatic ecosystem limit of <0.007: KMS02 sewage effluent tank, KMS03 Ericson Dam that receives water from underground, KMS05 Settlers Dam that also receives water from underground, KMS06 seepage from the slimes dam, KMS07plant run-off to the storm water canals and KMS11 return water/catchment dam. The highest ammonia (NH_3 mg/l) concentration recorded at KMS sampling locations was about 62 mg/l indicated by a graph at KMS07plant run-off to the storm water canals.

4.4.8 Orthophosphate (PO_4 mg/l)

Table 9 illustrates the annual average orthophosphate (PO_4 mg/l) concentration of Hex River, Sandspruit, Kroondal tributary and KCM water quality monitoring points over a seven-year period from 2007 until 2013.

Table 9: Annual mean or average orthophosphate (PO_4 mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM from 2007 to 2013

Chemical variable Annual average Ortho phosphate (PO_4 mg/l) Monitoring Locality	2007	2008	2009	2010	2011	2012	2013
Hex River							
KMS 15	0.1	0.0	0.1	0.0	0.0	0.0	-0.0
KMS 14	0.1	-0.0	0.0	0.0	0.0	-0.0	-0.0
Sandspruit							
KMS 08	0.0	0.0	0.1	0.0	0.0	0.2	0.0
KMS 11	0.0	-0.0	-0.0	0.0	0.0	0.1	0.1
KMS 13	No data	0.0	0.1	0.0	0.0	0.0	0.1
Kroondal tributary							
KMS 12	0.0	1.1	1.5	1.1	0.8	1.5	0.9
KMS 09	12.3	19.2	3.0	3.0	3.0	5.4	-0.1
KMS 01	-0.0	-0.0	-0.0	0.1	0.0	-0.0	No data
KMS 17	0.2	0.0	0.0	0.0	0.0	0.0	0.2
KMS 16	-0.0	-0.0	0.0	0.0	0.0	0.0	No data
KCM							
KMS 02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KMS 03	-0.0	0.0	-0.0	0.0	0.0	0.1	-0.0
KMS 05	-0.0	-0.0	0.0	-0.0	-0.0	No data	No data
KMS 06	0.0	0.0	0.0	-0.0	0.0	0.0	-0.0
KMS 07	-0.0	0.0	0.0	0.0	0.0	0.1	0.2

Note: Negative values relates to concentrations detected by the laboratory equipment as below detection limit. The negative signs as such recorded in the spread sheet, does not indicate negative concentrations but rather values that are below the detection limit of the laboratory equipment used.

According to Table 1, Target Water Quality Guideline Ranges (DWAF, 1996) and exemption permit for Kroondal Mine (DWAF, 2007), orthophosphate (PO_4 mg/l) concentration for domestic used (class 0 = ideal) limit is <2 and TWQGR for aquatic ecosystem limit is <0.005. Kroondal Mine exemption permit for waste water discharge limit into the rivers is ≤0.025. TWQGR (DWAF, 1996) for irrigation and livestock watering does not specify the limit for orthophosphate (PO_4 mg/l) concentration. Hence, this figure is not presented in Figure 19. Kroondal Mine exemption permit for waste water discharge into Kroondal return water dam also does not specify the limit for orthophosphate (PO_4 mg/l) concentration which means that this is not presented in Figure 19.

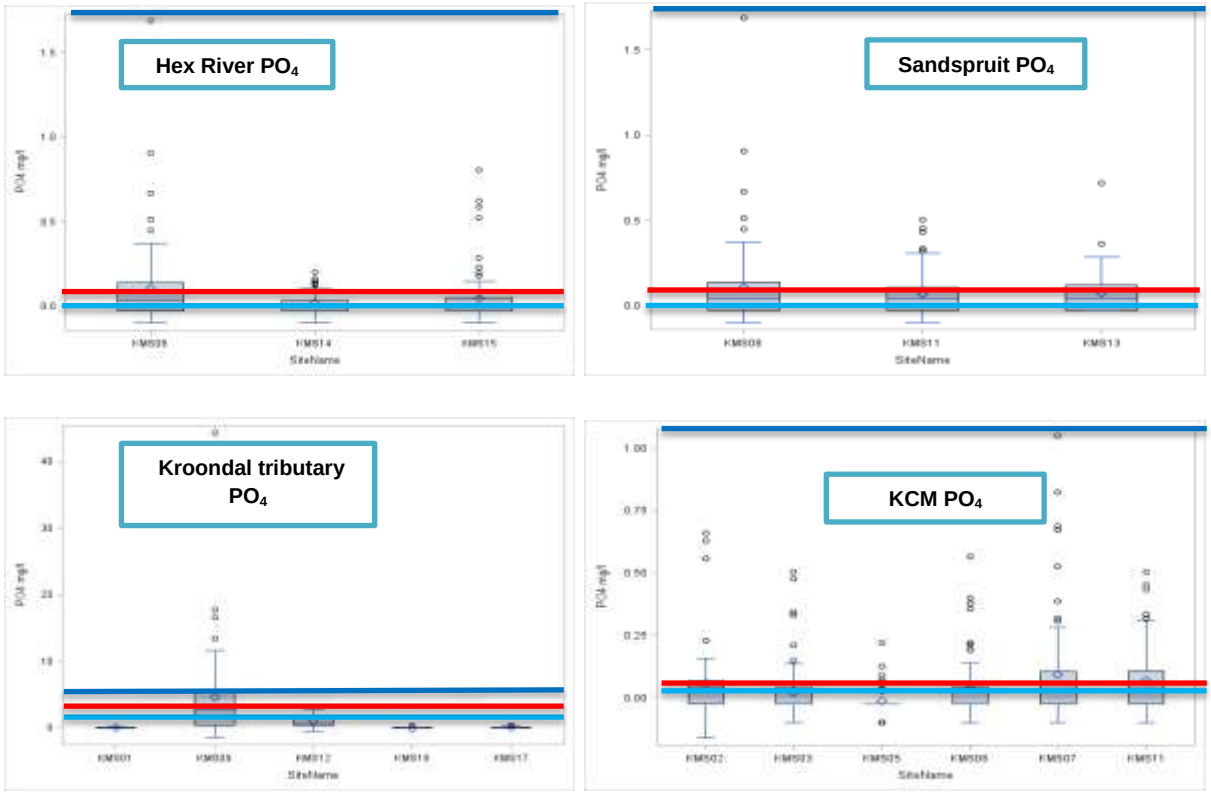


Figure 19: Box plots presenting the distribution of monthly orthophosphate (PO_4 mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM water quality-monitoring points between 2007 and 2013

Hex River: According to Figure 6 and Figure 19, orthophosphate (PO_4 mg/l) concentration at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS14 the upstream of the Hex River and KMS15 downstream of the Hex River were above the TWQGR for aquatic ecosystem limit of <0.005 and Kroondal Mine exemption permit for waste water discharge into the rivers limit of ≤0.025. The orthophosphate concentration was below the limit for domestic use (class 0 = ideal) limit of <2. The highest orthophosphate (PO_4 mg/l) concentration recorded at the Hex River sampling locations was approximately 1.6 mg/l which was indicated by a graph at the top of KMS8 downstream of Sandspruit that discharges waste water to the Hex River.

Sandspruit: According to Figure 6 and Figure 19, orthophosphate (PO_4 mg/l) concentration at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS11 Kroondal Mine return water dam that discharges waste water to Sandspruit and KMS13 upstream of the Sandspruit were above the TWQGR for aquatic ecosystem limit of <0.005 and Kroondal Mine exemption permit for waste water discharge into the rivers' limit of ≤0.025. Orthophosphate concentration was below the limit for domestic use (class 0 = ideal) limit of <2.The highest orthophosphate (PO_4 mg/l) concentration recorded at the Hex River

sampling locations was1.6 mg/l, indicated by a graph at the top of KMS8 downstream of Sandspruit that discharges waste water to the Hex River.

Kroondal tributary: According to Figure 6 and Figure 19, orthophosphate (PO_4 mg/l) concentration recorded at KMS09 discharge from Crocodile Farm to Kroondal tributary were above the TWQGR for domestic use (class 0 = ideal) limit of <2, aquatic ecosystem limit of <0.005 and Kroondal Mine exemption permit for waste water discharge into the rivers limit of ≤0.025. KMS012 downstream of Kroondal tributary was above the TWQGR for aquatic ecosystem limit of <0.005 and Kroondal Mine exemption permit for waste water discharge into the rivers' limit of ≤ 0.025 and below TWQGR limit for domestic use (class 0 = ideal) of <2. Orthophosphate (PO_4 mg/l) concentration at KMS01 upstream of the Kroondal tributary and KMS17 Farmer's Dam receiving water from KMS16 overflowing vent shaft with water from underground were below the TWQGR for domestic use (class 0 = ideal) limit of <2, aquatic ecosystem limit of <0.005 and Kroondal Mine exemption permit for waste water discharge into the rivers' limit of ≤0.025 The highest orthophosphate (PO_4 mg/l) concentration recorded at Kroondal tributary sampling locations was about 43 mg/l, a fact indicated by a graph at KMS09 discharge from Crocodile Farm to Kroondal tributary.

KCM: According to Figure 6 and Figure 19, orthophosphate (PO_4 mg/l) concentration at the following sampling points were above the above the TWQGR for aquatic ecosystem limit of <0.005 and Kroondal Mine exemption permit for waste water discharge into the rivers' limit of ≤0.025 but below the limit for domestic use (class 0 = ideal) limit of <2: KMS02 sewage effluent tank, KMS03 Ericson Dam that receives water from underground, KMS05 Settlers Dam that also receives water from underground, KMS06 seepage from the slimes dam, KMS07plant run-off to the storm water canals and KMS11 return water/catchment dam. The highest orthophosphate (PO_4 mg/l) concentration recorded at KCM sampling locations was about 1.05 mg/l, which was indicated by a graph at KMS07plant run-off to the storm water canals.

4.4.9 Hardness (CaCO3) mg/l

Table 10 illustrates the annual average hardness (CaC03) mg/l concentration of the Hex River, Sandspruit, Kroondal tributary and KCM water quality monitoring points over a seven-year period from 2007 until 2013.

Table 10: Annual mean or average hardness ($CaCO_3$) mg/l concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM from 2007 to 2013

Chemical variable Annual average Hardness ($CaCO_3$) mg/l **Monitoring Locality**	**2007**	2008	2009	2010	2011	2012	2013
Hex River							
KMS 15	336.0	168.7	196.2	124.5	127.8	195.3	217.0
KMS 14	351.0	154.8	185.8	108.5	112.0	162.5	203.0
Sandspruit							
KMS 08	199.3	193.2	281.4	165.7	146.1	231.9	198.3

Chemical variable Annual average Hardness ($CaCO_3$) mg/l							
Monitoring Locality	**2007**	2008	2009	2010	2011	2012	2013
KMS 11	190.1	195.6	206.2	201.4	196.2	129.6	142.2
KMS 13	271.9	326.4	192.9	152	308.2	319.6	271.9
Kroondal tributary							
KMS 12	177.5	400	73.9	286.25	299.0	407	304.5
KMS 09	849	902	378	447.25	523.4	578.5	381.6
KMS 01	348	567	222	-2.5	183.4	255.5	348
KMS 17	298.6	222.1	199.2	116.7	218.0	375.6	148.2
KMS 16	316.3	339.3	322.6	288.8	315.9	354.7	No data
KCM							
KMS 02	241.5	245	245	273.7	275.8	368.3	415.0
KMS 03	313	253.5	241.4	268.8	275.7	343.2	383.2
KMS 05	188.1	192.5	216.8	196.1	85.1	No data	No data
KMS 06	122.5	86.5	111.1	190	175.5	142.4	130.9
KMS 07	189.8	207	219.6	232	227.6	178.4	158.1

According to Table 1, Target Water Quality Guideline Ranges (DWAF, 1996) and exemption permit for Kroondal Mine (DWAF, 2007), hardness ($CaCO_3$) mg/l concentration for domestic used (class 0 = ideal) limit ranges between 0 – 200. TWQGR (DWAF, 1996) for irrigation, livestock watering and aquatic ecosystem does not specify the limit for hardness ($CaCO_3$) concentration. Hence, these figures are not presented in figure 21. Kroondal Mine exemption permit for waste water discharge into the rivers discharge also does not specify the limit for hardness (CaCO3) concentration. Hence, these figures are also not presented in Figure 20.

Figure 20: Box plots presenting the distribution of monthly hardness ($CaCO_3$ mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points during 2007 to 2013

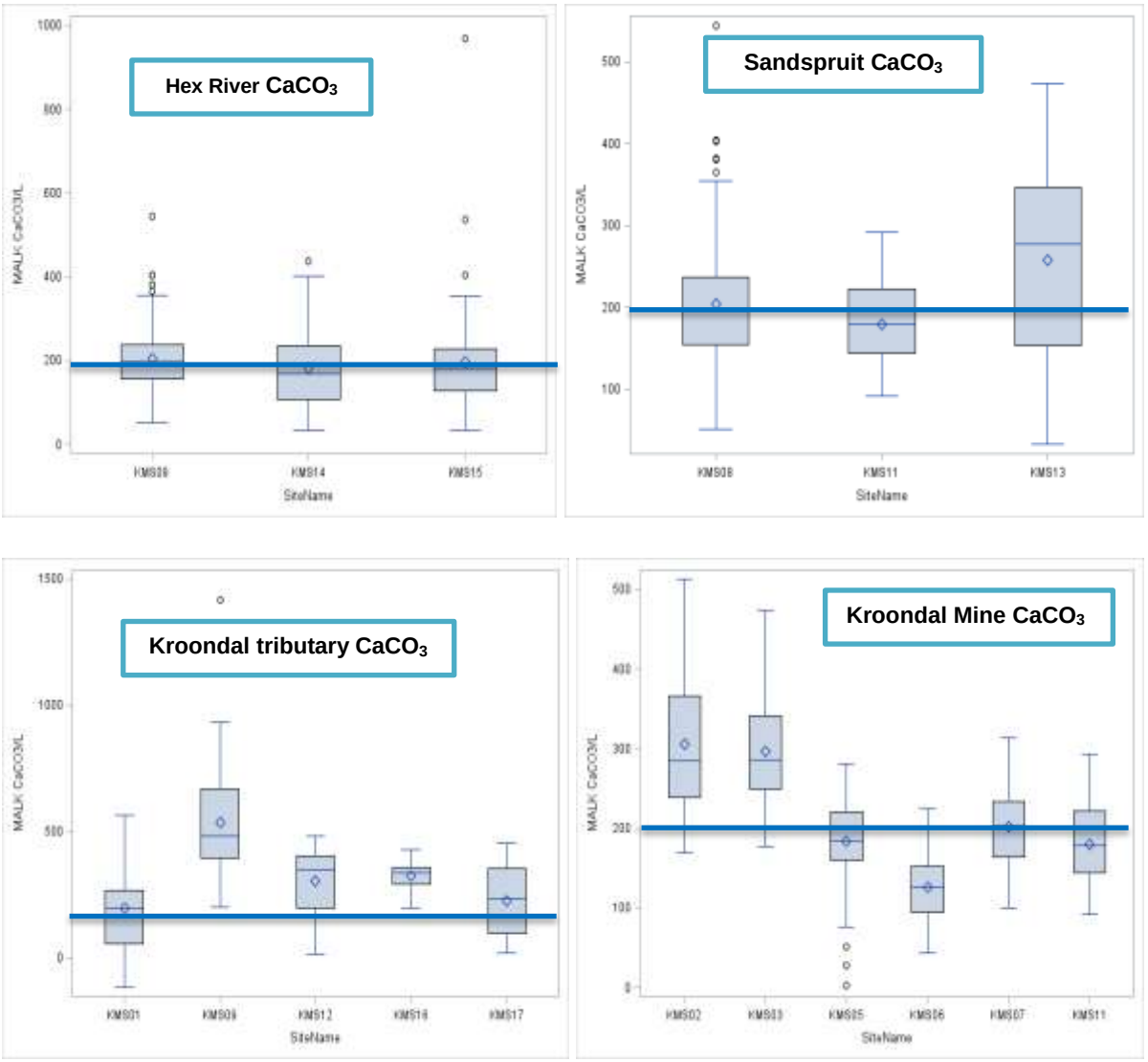


Figure 21: Box plots presenting the distribution of monthly hardness ($CaCO_3$ mg/l) concentration recorded for Hex River, Sandspruit, Kroondal tributary and KCM water-quality monitoring points during 2007 to 2013

Hex River: According to Figure 6 and Figure 21, hardness ($CaCO_3$ mg/l) concentration at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS14 upstream of the Hex River and KMS15 downstream of the Hex River were above the TWQGR for domestic use (class 0 = ideal) range between 0 – 200. The highest hardness ($CaCO_3$ mg/l) concentration recorded at the Hex River sampling locations was 900 mg/l, which is shown on the graph at KMS15 downstream of the Hex River.

Sandspruit: According to Figure 6 and

Figure 20, hardness ($CaCO_3$ mg/l) concentration at KMS08 downstream of Sandspruit (that discharges waste water to the Hex River), KMS13 upstream of the Sandspruit and KMS11 Kroondal Mine return water dam (that discharges waste water to Sandspruit) were above the TWQGR for domestic use (class 0 = ideal) range between 0 – 200. The highest hardness ($CaCO_3$ mg/l) concentration recorded at the Sandspruit sampling locations was about 550 mg/l indicated by a graph at the top of KMS08 downstream of Sandspruit that discharges waste water to the Hex River.

Kroondal tributary: According to Figure 6 and

Figure 20, hardness ($CaCO_3$ mg/l) concentration recorded at KMS012 downstream of Kroondal tributary, KMS09 discharge from Crocodile Farm to Kroondal tributary, KMS01 upstream of the Kroondal tributary and KMS17 Farmer's Dam receiving water from KMS16 overflowing vent shaft with water from underground were above the TWQGR for domestic use (class 0 = ideal) range between 0 – 200. The highest hardness ($CaCO_3$ mg/l) concentration recorded at Kroondal tributary sampling locations was about 1 400 mg/l indicated by a graph at KMS09 discharge from Crocodile Farm to Kroondal tributary.

KCM: According to Figure 6 and

Figure 20, hardness ($CaCO_3$ mg/l) concentration at the following sampling points were above the TWQGR for domestic use (class 0 = ideal) range between 0 – 200: KMS02 sewage effluent tank, KMS03 Ericson Dam that receive water from underground, KMS05 Settlers Dam that also receives water from underground, KMS06 seepage from the slimes dam, KMS07plant run-off to the storm water canals and KMS11 return water/catchment dam. The highest hardness ($CaCO_3$ mg/l) concentration recorded at KCM sampling locations was about 510 mg/l, which was indicated by at KMS02 sewage effluent tank.

4.5 Summary and conclusion remarks of the Hex River catchment water quality status from KCM.

Table 11 below, presents a summary of the water-quality monitoring points of the study area not suitable for ideal domestic purpose, irrigation, livestock watering, aquatic ecosystems and/or compliance to KCM exemption permit for waste water discharge to the Hex River and return water dam. Physical and chemical constituents – such as pH, EC, TDS, Cl, SO_4 – exceeded the TWQGR limits for irrigation (not fit for irrigation purposes) at KCM water quality monitoring points (KM05,KM6,KM7), Crocodile Farm (KMS09), downstream of Kroondal tributary (KMS12), KCM Return water dam (KMS11), downstream Sandspruit (KMS08) and downstream of Hex River (KMS15).

Table 11: physical and chemical water quality constituents above the TWQGR for irrigation, livestock watering, domestic (class 0 = ideal), aquatic ecosystem and exemption permit for KCM

Monitoring Locality	Monitoring Locality Description	Water quality constituents of concern in the Hex River catchment				
		Irrigation	Livestock watering	Domestic (class 0 = ideal)	Aquatic ecosystem	Exemption permit for Kroondal mine
Hex River						
KMS 15	Downstream of Hex River	pH, EC, TDS, Cl, SO_4	TDS (Dairy)	pH, EC, TDS, Cl, SO_4 NO_3, NH_3, $CaCO_3$	NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, SO_4, NO_3, and PO_4
KMS 14	Upstream of Hex River	pH, EC, TDS		,EC, TDS, Cl, SO4 NO_3 NH_3, $CaCO_3$	NH_3, $CaCO_3$ and PO_4	pH, EC, NO_3, and PO_4
Sand Spruit						
KMS 08	Downstream Sandspruit	pH, EC, TDS, Cl, SO_4	TDS (Dairy)	EC, TDS, Cl, SO_4, NO_3 NH_3, $CaCO_3$	NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, SO_4, NO_3, and PO_4
KMS 11	Kroondal chrome mine Return water dam	pH, EC, TDS, Cl, SO_4	TDS (Dairy)	EC, TDS, Cl, SO_4, NO_3 NH_3, $CaCO_3$	NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, SO_4, NO_3, and PO_4
KMS 13	Upstream of Sandspruit	pH, EC, TDS		pH, EC, TDS, Cl, $CaCO_3$	$CaCO_3$ and PO_4	pH, EC, and PO_4
Kroondal Tributary						
KMS 12	Downstream of Kroondal Tributary	pH, EC, TDS, Cl, SO_4	TDS (Dairy)	EC, TDS, Cl, SO_4, NO_3 NH_3, $CaCO_3$	NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, SO_4, NO_3, and PO_4
KMS 09	Discharge outlet from crocodile farm	pH, EC, TDS, Cl, SO_4	TDS (Dairy)	pH, EC, TDS, Cl, SO_4 NO_3, NH_3, $CaCO_3$ and PO_4	NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, SO_4, and PO_4
KMS 01	Upstream of the Kroondal Tributary	pH, EC, TDS		pH, EC, TDS, Cl, NO_3 $CaCO_3$	$CaCO_3$	pH, EC
KMS 17	Farmers dam receiving water from the vent shaft	pH, EC, TDS, SO_4		pH, EC, TDS, Cl, SO_4 NO_3, $CaCO_3$	$CaCO_3$	pH, EC, SO_4, NO_3
KMS 16	Overflowing vent shaft from underground	pH, EC, TDS, SO_4		EC, TDS, Cl, SO_4, NO_3 $CaCO_3$	$CaCO_3$	pH, EC, SO_4, NO_3
Kroondal chrome mine						
KMS 02	Sewage effluent tank	pH, EC, TDS, Cl	TDS (Dairy)	EC, TDS, Cl, NO_3, NH_3 $CaCO_3$	NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, NO_3, and PO_4
KMS 03	Erickson dam receiving water from underground	pH, EC, TDS, Cl		pH, EC, TDS, Cl, NO_3 NH_3, $CaCO_3$	NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, NO_3, and PO_4
KMS 05	Settlers dam receiving water from underground	pH, EC, TDS, Cl, SO_4	TDS (Dairy)	EC, TDS, Cl, SO_4, NO_3 NH_3, $CaCO_3$	NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, NO_3, and PO_4
KMS 06	Seepage from the slimes dam	pH, EC, TDS, Cl, SO_4	TDS (Dairy)	EC, TDS, Cl, SO_4, NO_3 NH_3, $CaCO_3$	Cl, NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, SO_4, NO_3, and PO_4
KMS 07	Run-off from the plant to the storm water canal	pH, EC, TDS, Cl, SO_4	TDS (Dairy)	EC, TDS, Cl, SO_4, NO_3 NH_3, $CaCO_3$	NH_3, $CaCO_3$ and PO_4	pH, EC, Cl, NO_3, and PO_4

According to Figure 7 and Table 11, pH, EC, TDS, Cl, and SO4 were transported from KCM slimes dam, plant run-off, overflow of Settlers Dam and discharged into the return water dam as well as the downstream point Sandspruit. These settled in the downstream of the Hex River. The readings for pH, EC, TDS, Cl, and SO4 were also transported from Crocodile Farm via an outlet, discharged into the downstream of the Kroondal tributary and the Sandspruit, and accumulated in the downstream of the Hex River.

TDS exceeded the TWQGR limits for livestock watering (dairy 1,000) (not fit for dairy livestock watering purposes) at KCM water-quality monitoring points (KMS02, KM05, KM6, KM7), Crocodile Farm (KMS09), downstream of Kroondal tributary (KMS12), KCM Return water dam (KMS11), downstream Sandspruit (KMS08) and downstream of Hex River (KMS15). According to Figure 6, Figure 7 and Table 11, the results indicate that TDS was transported from KCM slimes dam, plant run-off, overflow of Settlers' Dam, sewage effluent tank and discharged into the return water dam and downstream point Sandspruit. It settled in the downstream of the Hex River. TDS were also transported from the Crocodile Farm via an

outlet, discharged into the downstream of the Kroondal tributary and the Sandspruit, and accumulated in the downstream of the Hex River.

Physical and chemical constituents – such as EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$ – exceeded the TWQGR limits for domestic use (class 0 = ideal) (not fit for ideal domestic water use purposes) at KCM quality monitoring points (KMS03, KM05, KM6, KM7), Crocodile Farm (KMS09), downstream of Kroondal tributary (KMS12), KCM return water dam (KMS11), downstream Sandspruit (KMS08) and downstream of Hex River (KMS15). According to Figure 6, Figure 7, and Table 11, the results indicate that EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$ were transported from the KCM slimes dam, plant run-off, overflow of Settlers Dam and Erickson Dam that receives water from underground. These substances were discharged into the return water dam and the downstream point Sandspruit and settled in the downstream of the Hex River. EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$ were also transported from Crocodile Farm via an outlet, discharged into the downstream of the Kroondal tributary and the Sandspruit, and accumulated in the downstream of the Hex River. EC, TDS, Cl, $CaCO_3$ were also discharged from the upstream of Sandspruit and the Hex River. PO_4 exceeded the TWQGR limits for domestic used (class 0 = ideal) (not fit for ideal domestic water use purposes) at Crocodile Farm only. This indicates that PO_4 was discharged from Crocodile Farm as the TWQGR for domestic used (class 0 = ideal) on PO_4 is the highest (<2) as compared to TWQGR limit for aquatic ecosystem on PO_4 (<0.005).

Chemical constituents – such as NH_3, $CaCO_3$ and PO_4 _ exceeded the TWQGR limits for aquatic ecosystem (not fit for the well-being of the aquatic ecosystem) at KCM quality monitoring points (KMS02, KMS03, KM05, KM6, KM7), Crocodile Farm (KMS09), downstream of Kroondal tributary (KMS12), KCM Return water dam (KMS11), downstream Sandspruit (KMS08), upstream of Hex River (KMS14) and downstream of Hex River (KMS15). According to Figure 6, Figure 7 and Table 11, NH_3, $CaCO_3$ and PO_4 were transported from KCM slimes dam, plant run-off, overflow of Settlers Dam, Erickson Dam that receives water from underground and sewage effluent dam. These were discharged into the return water dam and the downstream point Sandspruit, and settled in the downstream of the Hex River. NH_3, $CaCO_3$ and PO_4 were also transported from the upstream of Hex River and accumulated in the downstream of said river. $CaCO_3$ and PO_4 were also discharged from upstream Sandspruit to downstream Sandspruit. These accumulate in the downstream of Hex River.

Physical and chemical constituents – such as pH, EC, Cl, SO_4, NO_3 and PO_4 – exceeded the limits for KCM exemption permit for discharge of waste water into the Hex River and return water dam at KCM quality monitoring point, KMS06 seepage from the slimes dam, downstream of Kroondal tributary (KMS12), KCM Return water dam (KMS11), downstream Sandspruit (KMS08), and downstream of Hex River (KMS15). According to Figure 6, Figure 7 and Table 11, pH, EC, Cl, SO_4, NO_3, and PO_4 were transported from KCM slimes dam and discharged into the return water dam and the downstream point Sandspruit. These accumulate in the downstream of the Hex River.
Therefore, the above results concludes that physical and chemical constituents – such as pH, EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$ and PO_4 were mobilised from the KCM activities, Crocodile

farm, Farmers dam, Hex River upstream activities such as other mines, agriculture, Municipal Sewage works, informal settlements and other industries and other downstream development activities near KCM. The next section outline in detail the results on pollution sources and pathway from KCM or/and other land uses to the Hex River.

4.6 Pollution sources and pathways from KCM or/and other land uses to the Hex River

This section present the answers of research question four: what are the possible pollution sources from KCM – and other land use – into the Hex River, and question five: what are the possible pollution pathways from KCM and other land use into the Hex River, using the study area site layout plan assessment, impact pathway analysis and available geohydrological data for KCM.

4.6.1 Site layout plan assessment

According to Appendix 4 as well as figures 7, 9 and 10, potential sources of contamination on the site – which were related to the mine operation – include the tailings storage facilities, return water dam that captures/collects all the mine surface water run-offs, waste rock dumps, Tailco spiral plant, Kroondal Mine spiral plant area and dewatering of underground water that contains explosive residue (stored at KMS03 and KMS05) as well as underground excess water. The following channels were identified in Figure 8 as the main waste water pathways within KCM boundaries:

- Unlined Tailco channel responsible for transporting contaminated run-off from Tailco spiral plant where they are processing the waste rock dump material to recover chrome in different grades from the main catchment dam, return water dam or containment dam (KMS11).

- Unlined secondary plant channel, responsible for transporting contaminated run-off from the processing or spiral plant where different grades of chrome products (met grade, lumpy grade and foundry grade) is produced from the main catchment dam, return water dam or containment dam (KMS11).

- Unlined Ericson channel, responsible for transporting contaminated water from the overflow of Ericson Dam – owing to excessive dewatering or dam maintenance (KMS03 storing waste water from underground) – to the main catchment dam or return water dam or containment dam (KMS11).

- Unlined tailings channel responsible for transporting tailing seepage or leachate from the tailing dam to the main catchment dam, return water dam or containment dam (KMS11).

- Unlined mine catchment channel or canal lined with concrete, responsible for transporting contaminated run-off from the mine storm water to the return water dam,

containment dam (KMS11), and unlined return water dam. Alternatively the containment dam natural channel discharges the cumulative waste water from the return water dam to the downstream point of Sandspruit (KMS08) tributary of the Hex River.

- Overflowing vent shaft with waste water from underground dam (KMS16) responsible for transporting contaminated water from underground straight to the Farm's Dam (KMS17) that discharges to the upstream of Kroondal tributary (KMS01).

- Unlined Crocodile Farm channel responsible for transporting pollutants from the Crocodile Farm to downstream of Kroondal tributary of Sandspruit (KMS12). Platinum and/or chrome mines, municipal sewage plant and industries upstream of the Hex River sampling point (KMS14) discharge to downstream of the Hex River (KMS15), unnamed activities upstream of Kroondal tributary (KMS12) and Sandspruit (KMS13), chrome mine tailings and return water dam opposite KCM and human settlement downstream of Hex River monitoring point (KMS15).

The non-perennial rivers, Kroondal tributary (KMS01 and KMS12) and Sandspruit (KMS08 and KMS13) to the south of the mine – as well as the Hex River (KMS14) to the west of the mine – are likely to act as pathways for surface water contamination and possible non-point sources of contamination to the surface water and the upper aquifer. According to the hydrogeological investigation conducted on site by Ground Water Consulting Services (GCS) during 2012, contaminant pathways for the underground mine – including fracture zones within the aquifer zones, fault zones and dyke structures identified within the area – in the mine structural geology data, a series of east-west striking faults were identified to the north of the site. Joint sets were identified striking north south in the tailing storage areas north of the mine, which may act as pathways to both aquifer systems on the site (Ground Water Consulting Services, 2012).

4.6.2 Impact pathway analysis

According to the results presented in Chapter 4 of this report, physical and chemical constituents from different pollution sources and pathways responsible for the Hex River water quality problem were examined and identified as follows:

4.6.2.1 Hex River (KMS15) Pollution Sources or pathways

When determining the impacts of downstream Sandspruit tributary (KMS08) and upstream Hex River pollution sources (KMS14) on the downstream of Hex River (KMS15), it was found that KMS08 and KMS14 were responsible for the pollution problem in the Hex River. Table 12 presents the constituents that were found to be highly concentrated in the downstream of the Hex River water-quality monitoring points over time (2007 to 2013).

Table 12: Hex River concentrated constituents for the identified pollution sources or pathways over time (2007 to 2013)

Pollution sources or pathways	Highly concentrated pollutants
Downstream Sandspruit (KMS08)	EC, TDS, Cl, SO_4, NO_3, NH_3, PO_4 and $CaCO_3$
Upstream of Hex River (KMS14)	NH_3, PO_4, NO_3, and TDS

4.6.2.2 Sandspruit tributary of Hex River Pollution (KMS08) Sources or pathways and its pollutants

When determining the impacts of return water/catchment/containment dam of KCM (KMS11), downstream of Kroondal tributary (KMS12) and upstream of Sandspruit tributary (KMS13), on the downstream of Sandspruit (KMS08) it was found that KMS11, KMS12 and KMS13 were responsible for the pollution problem in the downstream of Sandspruit (KMS08). Table 13 presents the constituents that were found to be highly concentrated in the downstream of Sandspruit (KMS08) water-quality monitoring points over time (2007 to 2013).

Table 13: Sandspruit tributary of Hex River concentrated constituents for the identified pollution sources or pathways over time (2007 to 2013)

Pollution sources or pathways	Highly concentrated pollutants
Return water/catchment/containment dam of KCM (KMS11)	EC, TDS, Cl, SO_4, NO_3, NH_3, PO_4 and $CaCO_3$
Downstream of Kroondal tributary (KMS12)	PO_4. EC, Cl, TDS, SO_4, NO_3, NH_3 and $CaCO_3$
Upstream of Sandspruit tributary (KMS13) pollution sources	NH_3, PO_4, NO_3, and TDS

4.6.2.3 Kroondal tributary of Sandspruit (KMS12) pollution sources or pathways and its pollutants

When determining the impacts of discharge from Crocodile Farm (KMS09), impacts of upstream of Kroondal tributary (KMS01) and impacts of Farmer's Dam (KMS17) receiving water from overflowing vent shaft (KMS16) on the downstream of Kroondal tributary (KMS12) it was found that KMS09, KMS0, and KMS17 were responsible for the pollution problem in the downstream of Kroondal tributary (KMS12). Table 13 presents the constituents that were found to be highly concentrated in the downstream of Kroondal tributary (KMS12) water-quality monitoring points over time (2007 to 2013).

Table14: Kroondal tributary of Sandspruit concentrated constituents for the identified pollution sources or pathways over time (2007 to 2013)

Pollution sources or pathways	Pollutants
Discharge from Crocodile Farm (KMS09)	EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$ and PO_4
Upstream of Kroondal tributary (KMS01)	EC, TDS, Cl, and SO_4
Farmer's Dam (KMS17) receiving water from overflowing vent (KMS16)	EC,TDS, Cl, SO_4, NH_3 and NO_3

4.6.2.4 KCM return water dam/main catchment dam/containment dam (KMS11) pollution sources or pathways and its pollutants

When determining the impacts of slimes dam (KMS06), run-off from the plant (KMS07), Settlers Dam receiving water from underground (KMS05), impacts of the underground water stored in the Erickson Dam (KMS03) and sewage effluent tanks (KMS02), it was found that KMS07, KMS06, KMS05,KMS03 and KMS02 were somehow responsible for the pollution problem in the return water dam (KMS011).Table 15 presents the constituents that were found to be highly concentrated in the KCM return water dam (KMS11) water-quality monitoring points over time (2007 to 2013).

Table 15: Kroondal Chrome Mine return water dam/main catchment/containment dam pollutants loadings for each pollution source or pathway over time (2007 to 2013)

Pollution sources or pathways	Pollutants
Seepage from the slimes dam (KMS06)	EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$
Run-off from the plant to the storm water canal (KMS07).	EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$ and PO_4
Settlers dam receiving water from underground (KMS05)	EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$
Erickson Dam receiving water from underground (KMS03).	EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$
Sewage effluent tank (KMS02)	EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$

4.6.2.5 Farmer's Dam (KMS17) receiving water from vent shaft underground water dam (KMS16) pollution sources or pathways and its pollutants

When determining the impacts of an overflowing vent shaft (KMS16) on the Farmer's Dam (KMS17), it was found that KMS16 was responsible for the pollution problem in the Farmer's Dam (KMS17). The physical and chemical parameters (related to mining activities) found to be highly concentrated at overflowing vent shaft (KMS16), was also found in the Farmers

dam (KMS 17) Table 16 presents the constituents that were found to be highly concentrated in Farmer's Dam (KMS17) water quality monitoring point over time (2007 to 2013).

Table 16: Farmer's Dam (KMS17) receiving water from vent shaft underground water dam pollutants loadings for kms16 pollution source over time (2007 to 2013)

Pollution sources (water quality monitoring locality)	Pollutants
Overflowing vent shaft underground water dam (KMS16)	EC,TDS, Cl, SO_4, NO_3,NH_3

The above results on pollution sources and pathways with reference to Figure 6 Figure 7 and, concludes that Tailco channel, KCM plant channel, Ericson, Tailings channel and mine catchment channel were collecting dirty water from KCM to the Return Water dam, and discharge to downstream of Sandspruit through a return water dam unlined channel. The unlined crocodile farm channel was collecting dirty water from the crocodile farm and discharge to the downstream of Kroondal tributary. The overflowing vent shaft of KCM was collecting water from underground mine and discharge to the farmer's dam via a natural channel (unlined) and farmers dam discharge at the upstream of the Kroondal tributary. Pollution sources start from KCM and crocodile farm to Kroondal tributary to Sandspruit and accumulate in the downstream of the Hex River. Other pollutions sources were coming from the upstream of the Sandspruit and upstream of the Hex River.

DISCUSSION

Chapter 5 discusses the results in chapter 4, from study area point of view, where the water pollution of Hex River, Sandspruit, Kroondal tributary and KCM were interpreted in terms of the activities around the pollution sources (mining, agriculture, industries, sewage treatment works, and informal settlements) and pathway. Chapter 5 also outlined the issues, roles and responsibilities of Hex River catchment stakeholders in dealing with the cumulative impacts of the water shared recourse (Hex River catchment).

5.1 Water quality of KCM

According to the results in Chapter 4, water quality of Hex River (KMS15) is influenced by pH, EC, TDS, NO_3, Cl, SO_4, NH_3, $CaCO_3$ and PO_4. The results also portrayed the presence of some metals (Mn, Al, Cr^{6+} and F) in the Hex River, although in minimal concentrations. The presence of some heavy metal in negligible concentrations could be attributed to the solubility, transportation and toxicity of different metal species. According to Appelo and Postma (1999), the transportation of metals via surface or groundwater is normally affected by sorption to solid aquifer material. Other chemical processes of importance are redox reactions and complexation. An increased aqueous complexation often makes an element more soluble but the form is often less toxic, hence redox status decides the speciation of some redox-sensitive elements. Espeby and Gustafsson (2001) argue that different redox species have different retention capacities and the redox status is important for transport of metal and heavy metals in surface or groundwater. A number of different parameters – e.g. the oxidation state of the metal ion, pH and Eh (Appelo and Postma 1999) – affect these mechanisms and the mobility of metals in surface or groundwater.

The dirty water from KCM sampling points show the presence of lower concentration of some metal and heavy metals such as Cr^{6+}, Mn, Al, F and Fe. Constituents including pH, EC, TDS, NO_3, Cl, SO_4, NH_3, $CaCO_3$ and PO_4 were subjected to solubility, transportation, between different constituents species, redox reactions and complexation as contaminated water was transported out of the mine to Hex River and its tributaries. This means that the concentration of these constituents was portrayed in different concentration in the downstream point of Hex River (KMS15). An example of this is the pH in most sampling points (mine and Hex River catchment) ranged between 9.0 and 10, which is an indication of the limits of pH and redox potential where the upper limits were associated with carbon dioxide (CO_2) free water in contact with carbonate rocks and some silicate (Delaune et al ., 2005). Concentration (below 0.05 and 0.002) of metal such as Cr^{6+} in the downstream of Hex River (KMS15) was owing to the redox condition of metal chemistry where Cr was stable and toxic within Kroondal Mine (oxidation state). Cr^{6+} reduces to Cr^{3+} as water is transported to Sandspruit and Hex River under reducing environment where the oxygen became less available under water.

The study revealed a high nutrient concentration that raises a concern as the Hex River system does not show any sign of recovery from the previous studies conducted in the

catchment. The continuous hypertrophic nature of the catchment suggested possible contamination arising from the sewage treatment works located in the upstream of the Hex River. (See Figure 7 (KMS14), agricultural run-offs, urban run-offs and re-circulation of nutrients from bottom sediments (Mogakabe and van Ginkel, 2008).) One of the major concerns in the Hex River Catchment is an increase in chlorides, sulphate and general salinity. The study area revealed that there were a number of human activities within the Hex River Catchment vicinity that have likely resulted in impacts on aquatic resources, including activities that were associated with settlement, agriculture, and mining (chrome and platinum) (Figure 1.).

The pH levels were more alkaline, which was associated with the soil profile of KCM. The presence of dissolved salts in water increases its electrical conductivity, which was suspected to have varied according to different temperatures of different seasons as water conductivity increases with increasing mobility of ions in water (Stednick, 1991). Conductivity and TDS are used to measure the water quality. Very high values of dissolved ionic matter are good indicators of possible water pollution sites, and this was evident in the water-quality results of KCM downstream of Hex River. Industrial discharges, mine waste, sewage and agricultural run-off – identified in Chapter 4 – have the potential to raise conductivity of surface and groundwater of the study area.

High sulphate (SO_4) concentration in the water quality of the Hex River was linked mostly to common constituents of water that arise from the dissolution of mineral sulphate in soil and rock, particularly calcium sulphate (gypsum) and other soluble sulphate minerals. Since most sulphate becomes soluble in water, and calcium sulphate is relatively soluble, sulphate – when added to water – tends to accumulate (progressively) to increasing concentrations. According to Berner and Berner (1996), the source of sulphate in water is from the weathering of rocks, and the main sources include the iron sulphide (FeS_2, FeAsS), calcium sulphate as gypsum ($CaSO_4.H_2O$), and anhydrite ($CaSO_4$).

According to figures 7 and 16, high TDS became less concentrated as they were transported from the discharge outlet of Crocodile Farm KMS09 to the upstream point of the Kroondal tributary KMS12, discharging to Sandspruit (KMS08) and Sandspruit discharging to the main catchment Hex River (KMS15). The decrease in concentration of chemical parameters in the receiving environment localities was associated with TDS major species: HCO_3, Ca, SO_4, Cl, Na+, Mg2+, K. These are largely derived from rainfall and from soil solution after it has interacted with soil particles (exchange reactions), bedrock (chemical weathering) and particulate matter. The major elements of particulate matter include Al, Fe, Si, Ca, K, Mg, Na, and P that are derived from mechanical weathering. These elements represent erosion and transport from soil surface including suspended load and bed load with material ranging from colloidal clays to boulders, leaves to logs.

According to the results in Chapter 4, physical and chemical constituents of concern were often higher at the pollution sources than at the receptors and pathways. The results from

the initial discharge of concentrated waters during low-flow periods were very high, for example sediments transported during heavy rains/run-offs or wind blow that often exceeded the total transport during long periods of normal flow. Patterns are not consistent, which is why it is necessary to measure concentrations under all flow conditions and to integrate data over a long periods of time. Examples of concentration of TDS were related to discharge rate and to the origin of waste waters. TDS concentrations were highest at the low-flow monitoring localities within the KCM, where the process water is mostly contained in the dam or is flowing on a very small channel. Most waste waters were derived from soil profile, where it is in equilibrium with rock weathering and exchange reactions. TDS levels decline at the receptor-monitoring localities outside KCM and Crocodile Farm, with an increasing flow because of dilution by water derived from precipitation and surface flow, with minimal contact with soil and bedrock.

According to results in Chapter 4, Figure 7, Figure 8and Table 11, nitrate portrayed its concentration in the upstream of Hex River, upstream of Sandspruit and Crocodile Farm where agricultural activities, settlements and Rustenburg sewage treatment work are located. Sources of nitrates in natural water are known to result from the oxidation of vegetable and animal debris and of animal and human excrement. Treated sewage wastes also contain elevated concentrations of nitrates. Nitrates tend to increase in shallow groundwater sources in association with agricultural and urban run-off, especially in densely populated areas. In aquatic systems, elevated concentrations generally give rise to the accelerated growth of algae and the occurrence of algal blooms. Natural soil is generally nitrate-rich. According to results in Chapter 4, Table 7, and Table 11 at KCM water-quality locality points, an increase the presence of ammonium (NH_3) and nitrate (NO_3) in the water resources can be seen. This is owing to the increase use of ammonium nitrate fuel oil, commonly known as ANFO, or ANFEX (a trade name registered by AECI). According to Kabongo (1995), it is an excellent explosive charge for large-scale blasting as it combines both performance and is low cost. It is used mainly in dry holes, but is also used in wet holes, provided it is properly packed in special waterproof packages before being inserted into the blast holes (Kabongo, 1995).

5.2 Influenced of pollution from KCM in the Hex River Catchment

5.2.1 Hex River Downstream of KCM

According to the results on Sandspruit tributary (KMS08), discharged pollutant associated with the mining activities – such as EC, TDS, Cl, SO_4, NO_3, NH_3, and PO_4 to the downstream of Hex River. Upstream of Hex River pollution sources (KMS14) only discharged NO_3 and NH_3. Therefore, the results suggests that possible contamination arising from the sewage treatment works upstream, agricultural run-offs, industrial waste water, urban run-offs and re-circulation of nutrients from bottom sediments of the Hex River. Therefore, it can be concluded that the pollutants downstream in the Hex River come from Sandspruit (KMS08) tributary of the Hex River.

5.2.2 Sandspruit tributary of Hex River

The impact pathway analysis of the return water dam (KMS11), Kroondal tributary (KMS12) and Sandspruit upstream pollution sources (KMS13) to downstream of Sandspruit (KMS08) from 2008 to 2013 revealed that the return water dam (KMS11) Kroondal tributary (KMS12) discharges pollutants associated with the mining activities or pollution sources such as EC, TDS, Cl, SO_4, NO_3, NH_3 and PO_4. It should be noted that during the 2012 to 2013 sampling period, Kroondal tributary (KMS12) suffered no discharge of pollutant into downstream of Sandspruit (KMS08). These suggest that return water dam (KMS11) was the most polluting or supplied most of the pollutants to downstream of Sandspruit (KMS08) over seven years.

Again, Kroondal tributary pollutants were mostly characterised as organic material such as PO_4, whereas EC, TDS, Cl, SO_4, NO_3 and NH_3 mostly characterised as return water dam pollutants. These results suggest that, in the return water dam (KMS11), there was constituent of water that arises from the dissolution of mineral sulphate in soil and rock, particularly calcium sulphate (gypsum) and other soluble sulphate minerals. The presence of dissolved salts in water increases its electrical conductivity, which varies according to the temperature. It suggests that in the downstream of Kroondal tributary (KMS12), there was a constituent in the water that arises from agricultural run-off with fertilisers, industrial waste water domestic sewage and detergents. The phosphate (PO_4) content in the Kroondal tributary (KMS12) was found in the range of 0.164 mg/l to 2.72 mg/l.

The results showed that upstream of Sandspruit tributary (KMS13) did not discharge any of the pollutant found to be problematic to downstream of Sandspruit (KMS08). Therefore, it was concluded that the pollutant in the downstream of Sandspruit come from the return water (KMS11) as it was reported to be overflowing and discharged straight to Sandspruit and downstream of Kroondal tributary (KMS12) as it connected to Sandspruit (KMS08).

5.2.3 Kroondal tributary downstream

The results showed discharge from Crocodile Farm (KMS09), impacts of upstream Kroondal tributary (KMS01) and impacts of Farmer's Dam (KMS17) receiving water from overflowing vent KMS16 to downstream of Kroondal tributary (KMS012). These portrayed that discharge from Crocodile Farm (KMS09) discharged pollutant or pollution sources associated with EC, TDS, Cl, SO_4, NO_3, NH_3, and PO_4. Upstream of Kroondal tributary (KMS01), discharged pollutant associated with EC, TDS, Cl, and SO_4 only during 2009 sampling period and Cl during 2008. It was noted that in 2007, 2010 to 2013 there was no discharge of pollutant found in the downstream of Kroondal tributary (KMS12) coming from the upstream of Kroondal tributary (KMS01). Farmer's Dam (KMS17) receiving water from overflowing vent (KMS16) discharged pollution sources associated with EC, TDS, Cl, SO_4, NH_3 and NO_3. It was noted that in 2007, 2011 and 2013 there was no discharge of pollutant found in the downstream of Kroondal tributary (KMS12) coming from Farmer's Dam (KMS17).

These results suggest that discharge from Crocodile Farm (KMS09) was the most polluted or constituted most of the pollutants to downstream of Kroondal tributary (KMS12). One of the pollutants that were only concentrated in the discharge from Crocodile Farm (KMS09) was PO_4. Phosphate, nitrate and ammonia in this location specifically may have occurred in water as a result of agricultural activities with fertilisers, animal waste and domestic sewage (Nirmala et.al, 2012). The phosphate content in the study area was found in the range of 0.747 mg/l to 44.3 mg/l. This was an indication of anthropogenic inputs from domestic sewage, agricultural and industrial practices in addition to natural sources of rock weathering and phosphate cycles in water. Farmer's Dam (KMS17) receiving water from overflowing vent (KMS16) constituted some of the pollutant to downstream of Kroondal tributary (KMS12). These pollutants were suspected to be associated with the anthropogenic inputs from domestic sewage, agricultural and industrial practices in addition to natural sources in water. Upstream of Kroondal tributary (KMS01) had very fewer impacts to downstream of Kroondal tributary (KMS12) as it was reported dry in most of the sampling water-quality reports reviewed during the research.

5.2.4 Return/catchment/containment water dam

Impact pathway analysis of seepage from the slimes dam (KMS06), plant run-off (KMS07) and Ericson Dam (KMS03) to the return water/catchment dam (KMS11) from 2007 to 2013, portrayed that seepage from the slimes dam (KMS06), discharged pollutant of pollution sources that is associated with EC, TDS, Cl, SO_4, NO_3, NH_3, and PO_4. Run-off from the plant (KMS07) discharged pollutant of pollution sources that is associated with EC, TDS, Cl, SO_4, NO_3, NH_3, and PO_4. Underground water stored in the Erickson Dam (KMS03) discharged pollutant of pollution sources associated with TDS, Cl, SO_4 and PO_4. It was noted that Ericson Dam did not discharge nor had an impact on the return water dam during 2007 and 2013. It was less polluted as compared to the slimes dam and the plant run-off.

These results suggest that seepage from the slimes dam (KMS06) and plant run-off (KMS07) was the most polluted or constituted most of the pollutant over time to RWD. These pollutants are associated with the dissolution of gypsum and water-rock interaction. A high concentration of SO_4 in the mine-monitoring locality point suggests the dissolution of anhydrite/gypsum as well as oxidation of pyrite. The high sulphate levels in seepage from the slimes dam (KMS06) were a reflection of the low pH levels of 5.4 recorded in 2007 and 6.6 recorded in 2008 (Ansa-Asare and Asante, 2000).

A high concentration NO_3 and NH_3 at KCM mine-monitoring locality point was attributed to the increased use of ammonium nitrate fuel oil, commonly known as ANFO, or ANFEX (a trade name registered by AECI), described as an excellent explosive charge for large-scale blasting as it combines both performance and low cost by Kabongo, (1995). A high concentration of PO_4, TDS, Cl and EC in the mine-monitoring locality point suggests that water sources in its natural form itself might contain a variable quantity of inorganic salts, or serves as an indicator of pollution by sewage as there is a sewage treatment plant within the

boundaries of the mine. Phosphate may also have occurred in the groundwater as a result of domestic sewage, detergents, and industrial waste water.

5.2.5 Farmer's Dam receiving water from the overflowing vent shaft underground water dam

The impact pathway analysis of vent shaft sampling point (underground water dam (KMS16)) to the Famer's Dam, ((KMS17) receiving water from the vent shaft (KMS16)), showed that, the vent shaft (underground water dam (KMS16)) discharged pollutants associated with EC, TDS, Cl, SO_4, NO_3, NH_3, and PO_4 to the Famer's Dam (KMS17). With reference to Figure 6, the results conclude that the water discharge to the downstream of Kroondal tributary (KMS12), from the farmer's dam sampling point (KMS17), was carrying the mixing pollutants from the mine and the farm.

5.3 Pollution sources and pathways from KCM and/or other land uses to the Hex River

According to the results in Chapter 4, pollutants from different pollution sources and pathway responsible for water-quality problems in the Hex River were examined and identified. The overflowing vent shaft underground water dam (KMS16) was identified as a pollution source owing to chemical pollutants such as EC, TDS, Cl, SO_4, NO_3, NH_3, and PO_4. KMS17, KMS12 and KMS08 were identified as the pathway of pollutant from the overflowing vent shaft underground water dam (KMS16). Discharge from Crocodile Farm (KMS09) was identified as a pollution source attributed to chemical pollutant such as EC, TDS, Cl, SO_4, NO_3, NH_3, and PO4. KMS12 and KMS08 were identified as the pathway of pollutant from discharge from Crocodile Farm (KMS09) to Hex River.

Seepage from the slimes dam (KMS06), run-off from the plant (KMS07) and underground water stored in the Erickson Dam (KMS03) were identified as the pollution sources attributed to chemical pollutant such as EC, TDS, Cl, SO_4, NO_3, NH_3, and PO_4. Tailings channel, secondary plant channel and Ericson channel were identified as the pathway of pollutant from seepage of slimes dam (KMS06), run-off from the plant (KMS07) and underground water stored in the Erickson Dam (KMS03) to return water dam (KMS11). Return water or containment dam (KMS11) was also identified as a pollution containment source of pollutant washed out from Kroondal Mine. The dam channel (not indicated in the module) also acted as a pathway of pollutants from dam to Sandspruit and Hex River.

The physical and chemical constituents average concentration displayed in the form of tables in Chapter 4 (Table 1 up to **Error! Reference source not found.**), for different sampling locations mostly revealed increased concentrations of EC, TDS, Cl, SO_4, NO_3, NH_3, $CaCO_3$ and PO_4, between 2012 and 2013. This increased concentration was attributed to the new processing plant erected next to the rock dump by an external company called Tailco mining during 2012 – 2013. The impact of water quality from the mine was because of the changed operations of KCM. The Tailco chrome processing plant was also identified as

a potential pollution source that had not been sampled or analysed for water quality since its inception to KCM. Tailco channel was identified as the pathway of the pollutant from Tailco process plant to Kroondal water channel that drained to the return water dam (Figure 10).

5.4 Hex River water pollution implication to the catchment stakeholders

The study confirms that Hex River downstream of KCM is polluted by different activities surrounding the catchment. Upstream to the downstream activities have contributed owing to the kind of pollutants that relate to those activities, e.g. PO_4, NO_3, HO_3 from the upstream activities such as agriculture, informal settlements with poor sanitation and municipal sewage treatment plant. Other examples include CI, SO_4, EC, TDS, and CaCo3 from the Hex River downstream activities such as mines and other industries.

The Hex River water-quality problem involves different stakeholder – as outlined in Figure 2 – and is currently being addressed in a traditional way by the DWS (regulator) setting limits on the amount and quality of water that can be discharged to the water bodies or off site. This is based on the established standards and the demands of other water users and stakeholders, individual actors, mine design and manage operations to only meet their own water use licence condition. However, the Hex River water quality problem can be managed through concept of applying the concept of cumulative dimensions of impacts – proposed by Franks et al. (2013) in Figure 3 – to improve the Hex River catchment poor water quality.

This section discusses number of cumulative impact management methods to manage poor water quality in South Africa, including the Hex River catchment. These are:

- Strategic and regional planning,
- Information exchange, networking and forums,
- Pooling of resources to support initiatives and programmes,
- Multi-stakeholder monitoring,
- Collaboration and coordination,
- Cross-sector partnerships, and
- Multiple company and cross-industry approaches.

5.4.1 Government/ regulators (DWS, DMR, DEA, Local Government, Community representatives etc.)

South African environmental legislation has transformed over time since 1994, with the intention to improve the quality of our environment and well-being. Owing to the environmental challenges encountered on a daily basis with regard to the impacts on the environment and water quality, the exploration of cumulative influence of impacts and benefit agreements on mining policy and legislation is vital. The role of communities affected should be outlined and allowed for participation and inputs their views and challenges in to the mining and environment policy making process, considering the influence on local norm setting from lower level to the higher level policy and legislation. Le Meur et al. (2013) outlined the role of communities in government policy-making initiatives, where the negotiation of local agreements had an influence on the adoption of impacts and benefit agreements. Several of local communities, government policy makers and industry experts will have a chance to exchange their experiences to influence policy, wide environmental legislation and catchment management programs across the country.

local community and/or social partnerships can add value by providing shared learning opportunities, regain of trust between local communities and mining companies along the Hex River, and creating unique venues to formulate and implement strategies, plan and programs that responds to Hex river water quality issues at hand and informs collaborative solutions to communities along the Hex River catchment. Government partnerships with the affected communities can help on formulating a strategy to document cumulative health impacts of multiple types and sources of pollution; to inform water quality policy change to improve environmental and health policies; and to empower community members by participating to advocate the on their own behalf the cumulative health impacts associated with water pollution in the Hex River.

Cumulative impacts should be the strategic drivers for the development of mining, environmental and water policies or legislation. Water policies and legislation should focus on improving the assessment and management of social thresholds, adaptive capacity and resilience, allowing for much coordination and collaboration among government stakeholders, and covering the resource issues on multiple scales. The policies should also aim to broaden the opportunities for environmental and water-quality improvement and avoid significant environmental impacts including water pollution and social impacts. South African water or environmental legislation could be complemented to achieve sustainable water usage by multi-stakeholder partnerships between the government ministries and different shares of government. These collaborations will share strategic information, develop and coordinate solutions, undertaking of research into best practice and assessment methodology and facilitation of the cross-sector communication (Frank et al ., 2012). At the catchment regional levels, local government groups should focus on reginal planning and development of projects that address the cumulative effects within their respective catchments (Frank et al., 2012).

Government or policy makers should avoid fragmentation of water and environmental legislation or policies as fragmentation causes limitation and coordination challenges which results in poor implementation of the legislation or policies. This was the lesson learned by the government of New South Wales, where the department of planning – which was made responsible for issuing planning approvals for new mines – relegated control of rehabilitation and post-mining land use to another sphere of government, the department of primary industries. Similarly, approvals and regulation of biodiversity offsets was the responsibility of the department of conservation and environment. According to Frank et al ., (2012), the 2005 reforms of New South Wales government have removed the fragmentation by "clearly defining the department of planning as the pre-eminent planning body for New South Wales. In case of mining, the powers of the department now include the right to determine what offsets and rehabilitation will be required for new mining developments and shape of final mining voids. Reforms were designed to simplify planning controls and improve development assessment process" (Frank et al., 2012).

5.2.1. Industries (including mines and famers)

In this research project, industries (mines, famers and others) have been identified as the primary sources of pollution of the Hex River Catchment. Other researchers have also made this identification (Du Plessis, 2006; Van der Merwe, 2005). As responsible industries, identified as the source of pollution to the catchment, they have the responsibility of leading the collaborative planning initiatives to improve the catchment and life of the communities around Rustenburg and Kroondal. Industries operating along or within the Hex River catchment can collaborate and have one water quality monitoring programme or one water management system for Hex Hiver catchment to achieve the common goal of improving the water quality of Hex River and communities involved. Currently there is duplication on water quality monitoring in the catchment by individual companies with the focus on achieving their set discharge limits, with no focus to improve the quality of water in the catchment and the life of the communities affected.

Rustenburg town is mostly economically dependent on the mines, and partially agriculture. Local government and other industries, collaborative planning initiatives between industries, and institutions of higher learning could provide opportunities to target future developments and investments to enable a positive post-mining legacy in terms of water-quality projects and other social impact improvement. According to Frank et al. (2010): "research can be undertaken in collaboration with other stakeholders to develop and test methods and understand systems in more detail, giving the example of temporal and spatial extent of impacts, interaction between impacts, and the pathways of effects."

The Upper Hunter River rehabilitation initiative took an alternative approach to collaborate on a programme of polluted river rehabilitation for about 10km. This was supported by different mining companies, government departments, and other corporates. Anglo-American was the first company to transform coal mine waste water into drinking water. Purifying contaminated water in South Africa has become so successful that Anglo's plant in Witbank is doubling in size and being replicated by other companies in the Mpumalanga Province. While the $130

million (R1.3 billion) plant will not upset the $600 bn world water industry, Anglo's treatment centre in Witbank is estimated to be providing as much as 12% of the area's municipal drinking supply and serves as a good model for how the industry could treat waste water in the future. It also shows how companies and municipalities are collaborating to mitigate the water stress process in South Africa. In the Rio Tinto Clermont coal mine case study, the company responded to local government request for infrastructure development by facilitating a community strategic planning initiative. The initiative was driven from targeted community consultation and inputs from different committees.

Industries can share or exchange information through networking and attending catchment forums. According to Frank et al., (2010), informal and formal networks provide important opportunities to exchange experiences at operational and strategic levels to improve the impact of multiple activities in the catchment. Informal networks are normally within the industries and/or among companies. This is an opportunity for the companies operating in the vicinity of Hex River to exchange ideas and advise on communications methods. More formal networking arrangements by stakeholder forums – such as Hex River catchment forum lead by DWS, environmental officer's forum, and mine managers forum – provide an ongoing opportunity to discuss common issues and coordinate activities. Frank et al., (2012) outlined some of the good examples of information exchange and networking forums such as: internal professional networking for exchange of ideas and advice for Rio Tinto, the Muswellbrook Mine Managers Forum in the Hunter Valley (more formal network to discuss common issues across multiple operations), Muswellbrook Environmental Officers forum and Queensland Mining Rehabilitation Group, where members share their experiences and information about environmental management of their mine sites.

Pooling of resources in support of catchment management initiatives and programmes will be very significant in the multiple mining projects operating in the same area, as indicated in Figure 1. The industries operating along the Hex River catchment – together with government (DWS) – may focus and coordinate investments to target water-quality problem in the Hex River Catchment and generate the best value for each spend through pooling resources (Frank et al ., 2012). The same approached was implemented successfully in the Upper Hunter River Rehabilitation initiative in about 10km of Hunter River south of Muswellbrook, and jointly funded in the Bowen Basin to assess the cumulative impacts of longwall coal mining on a 100km distance of the Isaac River in Central Queensland (Frank et al .2012).

Currently, individual mines along the Hex River Catchment monitor water quality, strive to prevent off-site waste water discharges, and manage their single operations to meet their specific water use licence conditions. Unfortunately, this was proven to be insufficient by Frank et al. (2013) because cumulative impacts may extend beyond single mine location (KCM) and may add to the systems already impacted by other mining operations, industries agriculture and informal settlements activities. With regard to single-operation water quality monitoring, sampling and analysis methods limitations, the aggregation of water quality data

may fails to present a full picture of the whole catchment. The regional and multi-stakeholder monitoring can be adopted as the tool that can help to address the cumulative impacts of multiple mining and industries for Hex River water-quality problem that are of great stakeholder concern in the Rustenburg region of the North West Province. Frank et al. (2012) explored some good examples of regional and multi-stakeholder monitoring such as the Hunter River salinity trading scheme, regional approach to monitor water salinity, mitigating and reporting on cumulative impacts in New South Wales and regional monitoring of the mine waste water discharges in to the Bowen Basin of Queensland, Australia.

5.5 Personal reflection on the research project

During the research project – as part of fulfilling the requirements of completing the Master of Science in Environmental Science degree – the researcher was challenged and motivated.

5.5.1 Experiences of interacting with the supervisor

It was important, for the researcher, to have constant interaction with her supervisor. The supervisor and the researcher had several meeting between June 2013 and November 2015. Their initial meeting was based on the clarification of the research topic, conceptualisation, expectations, research methodology and research questions and objectives. The researcher found it very easy to follow on the guidance she was getting from her supervisor. However, at some point the researcher experienced challenges in understanding some of feedback she was getting regarding water-quality data analysis, presentation and relevant literature to review in order to be able to answer the research problem. The feedback the researcher received, every time she submitted research findings to her supervisor – motivated and inspired her to do more on the project. The researcher found her interaction with her supervisor to be a very informative experience which accelerated the level of her interest in conducting impact assessments of mining activities on the water resources.

5.5.2 The level to which research questions have been answered

The research questions raised were extremely relevant to the research topic. However, in the beginning the researcher took the research questions to be straight forward in terms of answering as the raw water-quality – over a period of seven years – was already available.

When the researcher started to map out different methodology to answer all the six questions, she realised that her task was not as simple as she has originally thought. The comprehensive review, analysis of different reliable sources used, various science journals, and the water-quality data helped her to come up with appropriate methods to answer all the research questions. The method selection for conducting the research was guided by the reliability of the data analysis approach, relevance to the research project and guidance from her supervisor. It is fair enough to reveal that the research questions for the entire project have effectively been addressed considering the following facts:

- The data used in the research was from a reliable source, water-quality data analysed at a certified laboratory, mine EMP reports, site layout plans, mine exemption permits and process flows.

- Appropriate methods – such as case study, quantitative methods, "impact pathway analysis" – have been followed during the course of conducting the research work.

- The research findings agree with the findings by other researchers in the same catchment (Hex River).

- The research findings have also been critically discussed at the case study level and on the broader level of the problem in the Hex River Catchment and involvement of different stakeholders in addressing the water-quality problem.

I should acknowledge that, I have found it very challenging to answer question three, four and five and presenting results differently as the questions were much related to each other and the method used to answer these questions were very similar.

5.5.3 Communication and interpersonal skills and significance of the project

The researcher has displayed competent interpersonal and communication skills during the stages of the research. Her listening skills were vital in understanding information and guidance given by her supervisor on the improvement of the quality of her research work and report. Her interpersonal skills were very vital when she interacted with some of her colleagues during the research for expert opinions and various positive comments on her results and discussion.

5.5.4 The relevant contribution of the research to the practical development of the researcher

Conducting this research work has improved the level of the researcher's professional competency, in terms of analysing and understanding the huge amount of water-quality data, water as a shared resource, pollution sources and pathways, mining and environment, cumulative and impacts, cumulative dimensions and management, water policy of South Africa and the gaps in knowledge. The work done on the critical impact pathway analysis has increased the value of the research and improved her analytical skills. Although it was not an easy task for her to complete the work, she appreciated the value of critical analysis towards the completion of the final research report.

Conducting the research was equivalent to managing a project in the corporate environment. The research project has involved proper planning and organising, strict submission deadlines, feedback and updates to the researcher's supervisor, managing resources and scientific report writing. All the project management principles applied to this work have improved the researcher's professionalism as an environmental scientist. The experiences

while completing this research report have made the researcher develop more of an interest in mining and cumulative impacts analysis.

5.5.5 The contribution of the research experience to the researcher as person

The researcher has benefitted self-esteem and discipline from conducting the research on impacts of chrome mining in the environment, using Kroondal chrome mine as my case study. The research experience with the mine and Wits University has developed an interest of studying further on the subject matter, setting gallant goals for my career development. The experience has improved the level of self-confidence in the work produced by me.

CONCLUSION AND RECOMMENDATIONS

Chapter 6 outline the conclusion of the research project from case study level and Hex River catchment as a water shared resource. An answer for research question 6 is also presented in chapter 6 in the form of recommendations for the case study mine and the overall Hex River catchment stakeholders.

6.1 Conclusion

The study was successful in identifying the pollution sources and pathways of constituents of concern such as pH modifying compounds, EC, TDS, Cl, SO4, NO_3, NH3, $CaCO_3$ and PO_4 in the Hex River and determining the contribution of KCM to the pollution problem of Hex River over the period 2007 until 2013. The results revealed a clear distinction in the water quality of the 15 water-quality monitoring points in relation to the water quality effect of Kroondal chrome mining activities, Hex River upstream platinum and chrome mining activities and municipal sewage treatment works, Sandspruit upstream agricultural and industrial activities. The constituents of concern above have accumulated and settled out in the receiving environment and have a direct impact on the surface water of the Hex River Catchment AH22. Physical and chemical constituents were regularly mobilised when KCM containment dams, slimes or tailing, vent shaft and crocodile farm dam overflow mostly during rainfall. The constituents of concern were transported by runoff into the Hex River tributaries (Kroondal tributary and Sandspruit), where they have cumulative effects on the components of irrigation, livestock watering, ideal domestic used and aquatic ecosystem.

The profiles of water quality at Kroondal water monitoring localities remained relatively stable during 2009, 2010 and 2011, but notable fluctuation in salts and NO_3 concentrations were evident during 2012 to 2013 owing to a new development with the Tailco plant, which was attributed to the increased concentrations of salts and NO_3 in the return water dam. The return water dam was identified as the main source of pollution from the KCM: it discharges water into the Sandspruit and alters the water quality significantly. A significant impact on the Sandspruit and Kroondal tributary- especially in terms of NO_3, PO_4, $CaCO_3$ and NH_3 – were noted following the confluence of discharge from Crocodile Farm (KMS09), upstream of the Hex River (KMS14) and upstream of the Sandspruit (KMS13). The other source of pollution from Kroondal is the vent shaft discharge: this is not as polluting as the return water dam discharge, but still needs to be addressed as the Crocodile Farm discharges into the Kroondal tributary monitoring point KMS12.

The above-mentioned pollutants or physical and chemical constituents, in average concentration, exceeded the TWQGR for irrigation, livestock watering, ideal domestic use and aquatic ecosystem (DWAF, 1996) and KCM exemption permit by the Department of Water Affairs in 2007 in the Kroondal mine, Hex River and its tributaries (Kroondal tributary and Sandspruit). It is currently known that other mines (platinum and chrome), industries, informal settlements and agricultural activities have negative impact on the water quality of the Hex River. Based on the water quality monitoring data from 2007 until 2013, and impact

pathway analysis conducted, this research concludes that KCM had a negative impact or influence on the water quality of the Hex River Catchment**.**

The analytical results indicate that the surface water of the KCM is a unique example of the compound impact of weathering, hydrologic and anthropogenic processes. The chemical composition of surface water in each sampling location is strongly influenced by rock-water in tractions; dissolution, dilution; and anthropogenic inputs. This study demonstrates the usefulness of descriptive statistical techniques for analysis and interpretation of complex data sets, and for identification of pollution sources and better understanding of site variations in water quality for effective mine water quality management.

Key insights drawn from the study is that cumulative impacts in the Hex River catchment present different issues, roles and responsibilities for industries, government/ regulators and community stakeholders. Practical and cooperative management of cumulative impacts will benefit regional environments and communities of Rustenburg and the North West Province at large. Currently, individual mines, industries, famers and the DWS are channelling resources to monitor the water quality of the same catchment without understanding the impact from the perspective of entities that experiencing impacts. Currently, the resources are not the limiting factor in addressing the water quality of the Hex River. More effective coordination of existing resources will improve mitigation and enhancement through elimination of duplication and efficiency gains, as well as better strategic planning and assessment to manage adverse impacts from various sources. Collaborative actions are very significant in distinguishing cumulative impacts from other impacts as they cannot be properly managed by focusing on the impacts of individual industries, mines, agriculture and others. Development of strategies and policies by government requires an understanding of the catchment systems or receiving environment in which they occurs.

6.2 Recommendations

6.2.1 Case study

The results showed that waste water from the Kroondal Mine return water dam (KMS11) and downstream of Kroondal tributary (KMS12) had an impact on the Sandspruit (KMS08) tributary of the Hex River. Wastewater from Crocodile Farm (KMS09) and Farmer's Dam (KMS17) had an impact on the downstream of Kroondal tributary (KMS12). Wastewater from the vent shaft underground water dam (KMS16) had an impact on Farmer's Dam (KMS17). Wastewater from the slimes dam (KMS06) and plant run-off (KMS07) had an impact on the Kroondal Mine return water dam (KMS11).

Below are the recommendation made during the outcomes of the study in order to improve the water quality of Kroondal Chrome Mine and the water catchment as a whole:

- Process water in the return water dam (KMS11) entering the receiving environment should be prevented at all costs as it has significant impacts on the Sandspruit that

discharges to Hex River. This will eliminate the Kroondal contribution to the water quality impacts that goes to KMS08 and ending up in the Hex River.

- Underground water discharged to the Farmer's Dam (KMS17) via an overflowing vent shaft should be prevented or eliminated by managing and re-incorporating de-watering from underground into increased water use for the plant. Managing and re-incorporating de-watering from underground will eliminate KCM contribution to the water quality impacts that goes Kroondal tributary (KMS12).

- Update the water-quality monitoring programme to include a sampling point at Tailco plant areas, return water dam channel as well as more water-quality monitoring points in terms of the diffuse seepages and groundwater flows into the stream from the tailings and slimes facilitates.

- During the investigation of the impact of Kroondal Mine on the Hex River Catchment, there were some limiting factors with regard to the climate data that correspond to the period that water-quality data was analysed (2007 until 2013). Further studies should be conducted to investigate the effect of climate on the water quality of the mine and the catchment. It is recommended that KCM start to keep their own rainfall records. This could be the responsibility of the mine surveyor.

- Further analysis should be conducted to examine the seasonal effect on the above results as the seasonal effect analysis was not part of the scope of the study.

- KCM should consider monitoring attenuation of the catchment dam, as well as physical intervention to minimise pollutant release, by putting a liner as prescribe or specified by the DWS and approved storm water management.

- KCM should also consider active and passive water treatment technologies to treat their process water before it can make discharges to the environment as and only if required.

- It is also suggested that waste water sampling consider the measurement of water temperature on site during sampling. This will assist in collecting the exact part of the climate data required to investigate the impact of climate on the current water quality status. Following recognised sampling procedures, quality assurance and quality controls on the sampling and laboratory results is also recommended for the mine water-quality data.

- Although concentrations of physical and chemical parameters gave an indication of impact from the mine and other sampling points (pollution sources) to Hex River catchment, the real information required for the catchment management is "loading".

This would require the measurement of the flows within the rivers at the time of sampling.

- It is also suggested that, KCM review the current sampling location and frequency of sampling to refine the pollution pathways and sources by doing the following:

  - Checking the suitability and number of sampling points in relation to the pollution sources; and
  - Conduct stream profiles of the tributaries (Sandspruit and Kroondal Tributary) to pick up any diffuse or point pollution sources not currently recognised by the sampling strategy in place.

- The waste water pollution controls suggested above can or should form part of the mine's environmental objective and target or environmental management plan. These should also form part of the mine risk profile, which can be monitored in order to track progress on the water-quality status.

- After the mine has put all the pollution controls recommended in this research in place, a follow-up study may be conducted to check the effectiveness of these measures.

6.2.2 Hex River catchment stakeholders

The growth of the mining industry has increased the extent, degree and profile of cumulative impacts in the Rustenburg mining region. Mining and industries have generated impacts that aggregate and contribute towards existing stresses of social and environmental resources. In Chapter 2, a number of methods – that can assist to address cumulative impacts – were reviewed. (These were gathered from different papers).

Owing to the current status of the water quality in the Hex River, focused attention is required to address the cumulative impacts aggregating and interacting from differ mines and industries. The cumulative impact management methods discussed in chapter 5 outline the range of institutional forms, from individual company initiatives and programmes to cross-industry and multi-stakeholder partnerships and networking. According to Franks et al. (2012), these methods differ in complexity with each requiring a different point of maturity in the collaborative relationship. Cumulative management methods – such as information exchange, networking and forums – are relatively simple and are currently practised in the Rustenburg mining area, whereas the advanced methods – such as coordination, planning and multi-stakeholder monitoring – can be more difficult to implement. However, these offer greater opportunities to improve the water quality of the Hex River and other affected catchments. The stepped approach to understanding cumulative impacts – by Franks et al., (2010) – is recommended for consideration by all collaborative stakeholders of the Hex River Catchment. The steps are as follows:

- Determine the key areas of concern to all stakeholders and determine the priority impacts through engagement with all stakeholders, including informal settlements and rural areas.

- Define the type of receiving environment or system to studied, looking at the scale of the environment, special and temporary boundaries, and development of the baseline considering the historical trends and historical information about the pre-impacted environment and the capacity of environmental and social systems to absorb impact.

- Determine how the impacts are accumulating in the system or catchment. For example, are they generated as part of a causal pathway or are they the results of the aggregation or interaction of impacts from multiple unrelated sources?

- Determine what actions contribute to the generation of the impacts – and which activities or industry are responsible – by conducting collaborative research and collecting data on the impacted environment or catchment. In this case, the Hex River. Methods such as modelling scenario analysis and forecasting can assist to project how actions of different polluters lead to the impact on the catchment.

- Review the strategies available to eliminate and mitigate significant cumulative impacts and improve positive impacts. Regulators (government) can consider whether and how proposed and future developments within the impacted environment should proceed and focus on the past and existing development.

- Consider whether – and with which stakeholders or industries – collaboration is required to coordinate catchment or system-wide management responses. These stakeholders or industries required for collocation include other industries contributing to the impact and those with expertise or knowledge about a solution to the impacted environment or catchment.

- Select and monitor priority receiving environment or receptors of concern, determine system-level indicators and targets, and agree with other stakeholders including rural communities. Monitoring will strengthen the partnership with other stakeholders and should correspond with the types of impacts and receiving environment.

- Determine the best approach to report and communicate information on significant cumulative impacts to stakeholders, such as what is happening in the catchment or receiving environment; what is causing it; and what is being done or to be done to mitigate it. Communication or reporting through an industry association or collaboration rather than mine by mine or farmers or other industries will be the best approach to report and communicate information on significant cumulative impacts to stakeholders.

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