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EVALUATION OF THE MANAGEMENT STRATEGIES OF MINE WASTEWATER IN WEST RAND AREA, GAUTENG PROVINCE IN SOUTH AFRICA

By

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DECLARATION AND COPYRIGHT

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DMoshobane

Signature

25/09/2019

Date

DEDICATION

This dissertation is dedicated to my beloved family. Nothing can replace the time I spent on this work while depriving them of my presence.

Tribute is paid to the struggle icon, a fearless fighter who sacrificed much of her life for freedom in South Africa and for women everywhere, Winnie Madikizela- Mandela. May your soul rest in peace.

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KEY DEFINITIONS

Mitigation: the action of reducing the severity of acid mine drainage.

Management: the process of dealing or controlling acid mine drainage issues.

Effectiveness: producing the desired results of the treated acid mine drainage by means of complying with waste water discharge limits guidelines.

ABSTRACT

This study was undertaken to assess the “effectiveness” of acid mine drainage (AMD) mitigation and management strategies in the West Rand region, Gauteng, South Africa. It involved the determination of water quality at selected points along Twelopiespruit stream. The water quality data was analysed using Microsoft Excel and Geographical Information System (GIS) modelling technique to determine river water quality against the regulatory wastewater standards and legal framework.

The findings showed that Fe (II) was reduced from a high concentration of 490 mg/L from Winze 18 to 9.57mg/L at the discharge point (Pit), which is an over 95% removal of Fe (II) from the AMD. Water from Winze 18 shaft was acidic and was treated to raise the pH to between 8 and 10 leading to the precipitation of metal hydroxides and oxides. Sulphate concentrations at the discharge point were as high as 2700 mg/L against the DWS sulphate effluent limit of 600 mg/L. High concentrations of sulphates at the discharge point clearly showed that water treatment technologies within the study area were unable to lower the sulphates levels to meet the regulatory sulphate standards in the effluent.

Further, findings revealed that current legal and policy factors do not promote uncompromising control measures to the mines in addressing the detrimental impact of AMD. Thus, alternative ways to remediate AMD, particularly options that remediate high concentration of sulphates, were recommended.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

ABC:	Alkali-Barium Calcium
AMD:	Acid Mine Drainage
ARD:	Acid Rock Drainage
$CaCO_3$:	Calcium carbonate
CMA:	Catchment Management Agency
CSIR:	Council for Scientific and Industrial Research
DMR:	Department of Minerals and Resources
DWA:	Department of Water Affairs
DWS:	Department of Water and Sanitation
ECL:	Environmental Critical Level
Fe:	Iron
FeS_2:	Iron sulphide
GIS:	Geographic Information Systems
GTT:	Government Task Team
H_2O:	Water
H_2SO_4:	Sulphuric acid
KOSH:	Klerksdorp, Orkney, Stilfontein and Hartebeesfontein
MPRDA:	Mineral and Petroleum Resources Development Act.
NEMA:	National Environmental Management Act
NH_4^+:	Ammonia

NWA:	National Water Act
pH:	Potential of Hydrogen
SRB:	Sulphur Reducing Bacteria
TCTA:	Trans-Caledon Tunnel Authority
TUT:	Tshwane University of Technology
UNEP:	United Nations Environmental Programme
WSA:	Water Services Act

CHAPTER 1:

1.1 Introduction and background of the study

Acid Mine Drainage (AMD), also described as Acid Rock Drainage (ARD) is one of the most remarkable environmental pollutant produced by the mining sectors, globally (Sharma, 2010).The problem of AMD is not a recent issue, nor is it restricted to South Africa. This problem has already been experienced in many countries, including Peru, Canada, the United States of America, Germany and Australia (Bobbins, 2015).The study by Coetzee et al. (2010) noted that AMD has been experienced in many provinces of South Africa, including Gauteng, Kwa-Zulu Natal and Mpumalanga. Durand (2012) indicated that AMD transfusion from overflowing gold mines was first noted in August 2002 in Randfontein and Krugersdorp areas. AMD occurs through a natural process and its formation is highly activated by mineral extraction activities, with gold and coal mining industries being the main contributors.

The challenge of AMD is experienced in both operating and abandoned mines alike, and its management is difficult and comes with a lot of expenses. Low pH, high levels of sulphates (SO_4) and metals (e.g. iron, zinc, copper, nickel, arsenic and cadmium) lead to harmful impacts on the surrounding ecosystems (Kuyucak, 1999). For example, the percolation of AMD into the ground could lead to degradation of both surface and groundwater quality making it unfit for human and animal consumption or crop irrigation (Masukume et al., 2014). The flooding of AMD to the environment has enormous potential to degrade shallow groundwater resources and regional major river systems. The study by Masukume et al. (2014) reported that heavy metals in AMD are not decomposable and tend to build up in living organisms, leading to various illnesses. Therefore, mitigation and management of AMD required to comply with wastewater discharge limits in West Rand, Gauteng, South Africa, is mandatory.

1.2 The formation of AMD

Reinhardt (1999) indicated that AMD is normally generated when mining activities expose pyrite (iron disulphide minerals) to water and oxygen in the presence of micro-organisms such as *Thiobacillus ferrooxidans*. Once exposed to water and oxygen, pyrite oxidises to form acidic drainage rich in dissolved metals. There are two-stage processes that pyrite undergoes. The initial stage involves the process where sulphuric acid and ferrous sulphate are formed, and orange-red ferric hydroxide and more sulphuric acids are formed in the second stage (McCarthy, 2011).

The study by Ford (2003) described processes leading to the generation of AMD using the reactions described below:

$4FeS_2 + 15\ O_2 + 14\ H_2O \rightarrow 4Fe\ (OH\text{-})_3 \downarrow + 8H_2SO_4$ [1]

Pyrite + oxygen + water → "yellow boy" + sulphuric Acid

$2FeS_2 + 7O_2 + 2\ H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$ [2]

Pyrite + oxygen + water → ferrous iron +sulphate + Acidity

$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4\ Fe^{3+} + 2\ H_2O$ [3]

Ferrous iron + oxygen + Acid → Ferric Iron + water

$4Fe^{3+} + 12\ H_2O \rightarrow 4Fe\ (OH\text{-})_3 \downarrow + 1m2H^+$ [4]

Ferrous iron + water → ferric hydroxide (yellow boy) + Acidity

$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO4^{2-} + 16H^+$ [5]

Pyrite + Ferric iron + water → ferrous iron + sulphate + Acidity

In addition, the reaction of micro-organisms with sulphide minerals contributes mainly to the generation of AMD. *Thiobaccilus ferroxidas* and *Thiobacillus thio-oxidans* are extensively found in sulphide mineral-bearing ore deposits, mine tailing and abandoned mines, and they also play a major role in AMD generation due to AMD's potential to rapidly oxidise reduced forms of iron and sulphur, which can result in the formation of sulphuric acid (Natarajan, 2008).

1.3 AMD challenges in South Africa

Mining operations contribute to economic development in South Africa. However, these processes may leave a remarkable legacy of AMD in South Africa. AMD has a notable and uncompromised environmental impact, worldwide (Coetzee et al., 2010). AMD's effect on the environment, associated with its decanting to the surface, has been comprehensively analysed. The Inter-Ministerial Committee report by Coetzee et al. (2010) noted that West Rand was one of the areas that had endured adverse effects of AMD at that time.

The detrimental impact of AMD led to contaminated water in the Tweelopiespruit Catchment in Gauteng, South Africa and has already compromised people's lives. Additionally, soil in the surrounding area was also polluted by AMD, thereby rendering it unfit for agricultural purposes. This is an issue greatly impacting West Rand.

According to the study by Oelofse (2009), West Rand has numerous abandoned underground mines and its AMD problem was first noticed in 2002. Gold mining in the West Rand area remains one of the key economic activities in the area, with 45% of gold mining emanating from the Witwatersrand Basin (Boyd, 2008).

1.4 Research problem

There is a problem of AMD in the West Rand area and has the potential to destroy the ecosystem owing to the existence of large concentrations of hazardous heavy metals, sulphates and acidity. According to Hobbs and Cobbing (2007a), AMD volumes as high as 15.5 mL/d were reported as the discharged volumes from West Rand at the time, and the volume had increased to 30 mL/d by the year 2009 (Maree et al., 2013). This, in turn, demonstrates the magnitude of the environmental challenge at hand.

The Department of Water and Sanitation (DWS) approximated that about 42 million litres (ML) of AMD was flowing into the Tweelopiespruit Catchment daily in January 2011, of which only 12 ML of this amount was partially treated by the mining company called Rand Uranium then. Eljhbadmin (2012) noted that Rand Uranium's partial treatment process was unable to remove heavy metals from the river system. McCarthy (2011) reported that the quality of water that was decanting from mine voids in the Western Basin was unhealthy, with sulphate concentration around 2500 mg/L and pH as low as 2, in most cases.

In response to this problem, several stakeholders including the government, mining industries and researchers came up with various AMD management and mitigation measures to arrest this problem before it caused more damage.

The expert team of Inter-Ministerial Committee on AMD studied the matter in 2010 and water quality management options such as in situ treatment, neutralisation and metal removal, passive treatment and desalination were analysed. The study by Liefferink and Pretorius (2011) has indicated that neutralisation was the recommended short-term (four years) treatment method for AMD in the Western Basin. However, the study of Novhe (2012) argues that this treatment method produces poor water quality that is unfit for a predetermined use, or for discharge to surface. As a result, there is a need to evaluate the already-implemented AMD mitigation and management measures in West Rand.

This study investigated the efficiency of the strategies which have been implemented in West Rand to alleviate the problem of AMD. Specifically, water quality in

Tweelopiespruit was monitored and the data was used to determine the success of the interventions in solving the problem of AMD in West Rand area.

This evaluation would also inform the efforts being put to alleviate similar problems in the Central and Eastern Basin of Witwatersrand Goldfields. Hence this study aimed to establish measures that have been put in place to resolve AMD challenges. Moreover, the absence of widely-accepted AMD management strategies, such as Alkali-Barium Calcium process (ABC) and Mechanical Biological and Chemical (MBC) treatment process in South Africa makes it a virgin area for further exploration.

This research provides valuable information for current and future fights against AMD, in West Rand. After a comparative analysis, this study will highlight the approaches that may need to be changed.

1.5 Research question

How compliant are the mitigation and management strategies of AMD in West Rand?

1.6 Objectives of the study

The main objective of this study was to assess the “effectiveness” of the AMD mitigation and management strategies in the West Rand area, South Africa.

The specific objectives were:

- To determine water quality at selected sampling points in West Rand;
- To model water quality along Tweelopiespruit using GIS.
- To assess the legal frameworks regarding AMD management in West Rand;
- To undertake comparative analysis and make recommendations on where to make changes.

1.7 Hypothesis

- **Null Hypothesis (H_0)**

  The AMD interventions in West Rand are not resolving the problem of AMD within the area.

- **Alternative Hypothesis (H_A)**

  The AMD interventions in West Rand are resolving the problem of AMD within the area.

1.8 Justification of the study

The government of South Africa and other stakeholders came up with several interventions to help address AMD in the West Rand region. Thus, this study was aimed at assessing the effectiveness of the AMD mitigation and management strategies. This research would provide crucial information that the current and future strategists may rely on in the processes of implementing mitigation and management strategies of AMD in South Africa.

1.9 Overview of the research design and methodology

A multidisciplinary research design was used in this study to meet the objectives outlined in 1.6, above. A mixed-method approach combines both qualitative and quantitative methods to answer the research question satisfactorily, through demonstration of acceptable scientific standards for rigor (validity, reliability and trustworthiness) (Zohrabi, 2013). For its robustness and pragmatic approach, mixed-methods research is suitable as a strategy were phenomena under investigation are located within array of multiple disciplines. This study used both non-empirical research (comprehensive literature review) and empirical research (primary data through the collection of water samples). Chapter three (3) gives an in-depth description of how this research was conducted, however, the process is summarised in the paragraphs below.

A comprehensive literature review was conducted, describing the multi-pronged approach for dealing with AMD problems in South Africa. The first objective is addressed through literature research (Chapter 2: Legal framework in addressing AMD issues).

The empirical part of this study included a visit to West Rand area, to observe the overflow of AMD seeping from Winze 18 shaft. This was followed by taking water samples from Winze 18 and Pit (effluent point) for analysis, to assess whether the treated AMD complies with the discharge limits outlined in the literature review. Moreover, Geographic Information Systems (GIS) was used to model pollution along Tweelopiespruit stream.

2 LITERATURE REVIEW

2.1 Introduction

To achieve the objectives of the study, it is very important to understand various concepts of this topic. Existing literature available on AMD will be presented in this chapter as designed to present them in a logic sequence. It begins with an introduction to the chemistry and bacterial communities behind the formation of AMD. Next, the negative impacts that AMD impose in various environmental aspects such as water resources, soils, biodiversity and infrastructure are reviewed. To identify the potential sources of AMD in the study area, Geographic Information System (GIS) technology has been identified as the most valuable technology for the environmental impact assessment of mining and has been reviewed in this chapter (Suh et al., 2017). This chapter emphasises that it is very crucial to review the role that GIS plays in evaluating the pollution levels in mines. In South Africa, AMD is managed through policy, and legislative and technological interventions. These multi–prolonged technological interventions used to address AMD issues in West Rand are presented in this chapter.

2.2 Theoretical Framework

Theoretical framework is one of the most vital aspects in the research process and gives a clear structure and vision of a research. The following image presents a combination of conceptual and theoretical framework including major theories that anchors this study (Osanloo and Grant 2016).

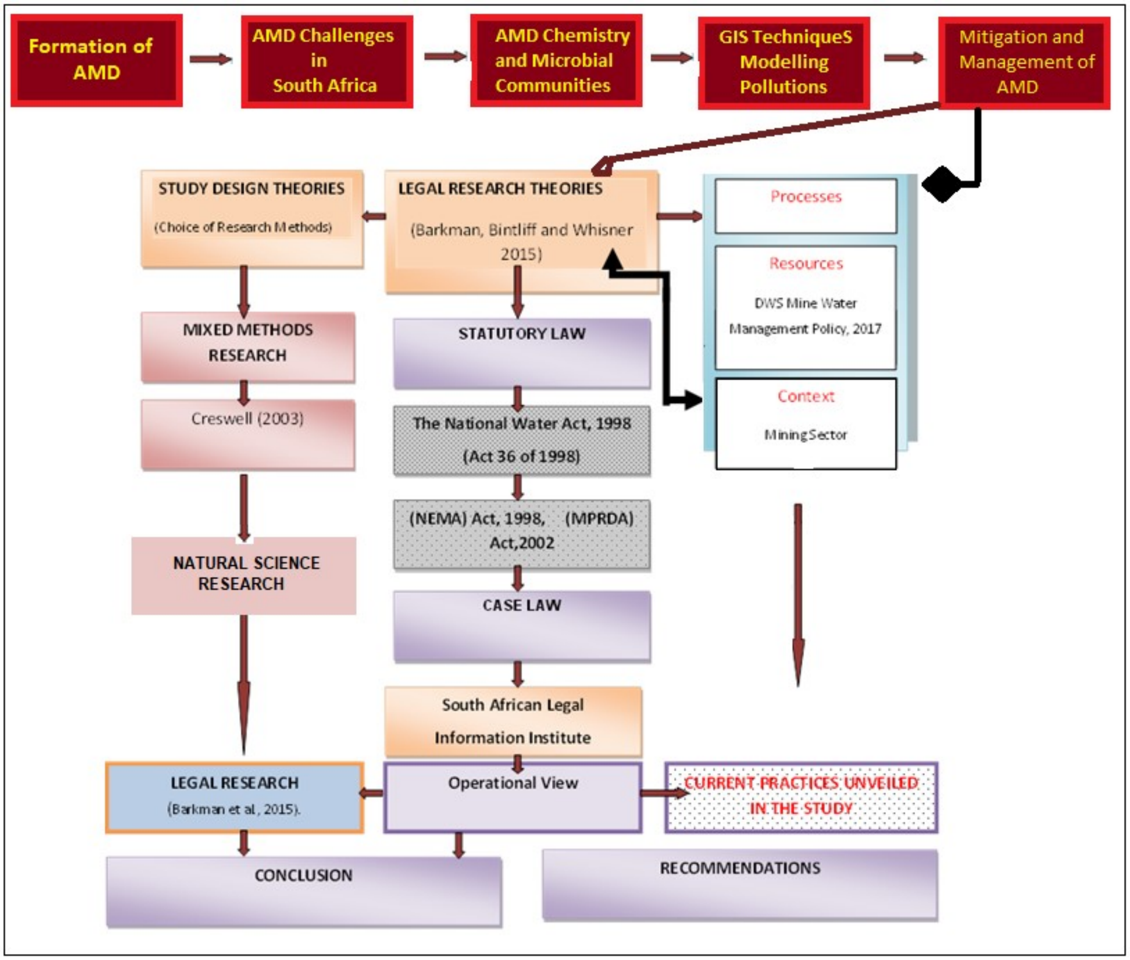

Figure 2-1: Theoretical and conceptual framework and major theories anchoring this study – adopted from Osanloo and Grant (2016)

2.3 AMD chemistry

AMD occurs when pyrite and/or other sulphide minerals are oxidised due to the exposure to oxygen and water, thus producing sulphuric acid that can dissolve metal species, resulting in the environmental contamination (Nascimento, 1998; Sicupira et al., 2014). AMD is usually produced by the accelerated oxidation of iron pyrite, which is the most common sulphide mineral worldwide (Johnson and Hallberg, 2005; Simate and Ndlovu, 2014; Johanna Obreque-Contreras et al., 2015). Moreover, when the old mine shafts fill up with water that oxidises with the sulphide mineral iron pyrite, it usually leads to the generation of AMD (Naidoo, 2014). Most studies describe AMD similar to Acid Rock Drainage (ARD), while a few studies describe them in different terms. The study by Kagambega et al. (2014) defines ARD as the interaction between minerals and oxygen and/or water that lead to their oxidation, whereas exacerbated ARD through mining is known as AMD.

AMD is basically characterised by one or more of the following: low pH, high total dissolved solids, high sulphates, and high levels of heavy metals - particularly iron, manganese, nickel and/or cobalt (Nordstrom, 2011; Mačingová and Luptáková, 2014). Simate and Ndlovu (2014) indicated that there was a large group of sulphide mineral which can be referred to as “pyrite type”, which include pyrrhotite, chalcopyrite, arsenopyrite, sphalerite, galena and others with the potential to initiate similar processes leading to the generation of AMD.

The study by Simate and Ndlovu (2014) further revealed some crucial metal sulphides in AMD formation, with pyrite and marcasite being predominant acid producers, listed in table 2-1 below.

Table 2-1 Metal sulphides with potential to generate AMD

Metal Sulphide	Chemical Formula
Pyrite	FeS_2
Marcasite	FeS_2
Pyrrhotite	$Fe_{1-x}S$
Chalcocite	Cu_2S
Covelite	CuS
Chalcopyrite	$CuFeS_2$
Molybdenite	MoS_2
Millerite	NiS
Galena	PbS
Sphalerite	ZnS
Arsenopyrite	FeAsS

2.4 Bacterial communities in AMD

Micro-organisms play a very crucial part in weathering sulphide minerals globally and thrive in metal-rich and highly acidic environments. More evidence reveals that several micro-organisms can survive in AMD and perform crucial ecological functions (Huang et al., 2016; Teng et al., 2017). The micro-organisms that oxidise sulphur are categorised as gram-negative bacteria, which are the species of *Thiobacillus*, *Thiomiscrospira* and *Thiosphaera*. On the other hand, heterotrophs, such as some species of *Paracoccus*, *Xanthobacter*, *Alcaligens* and Pseudomonas can also exhibit *Chemolithotrophic* growth on inorganic sulphur compounds (Kuenen and Beudeker, 1982; Vidyalakshmi et al., 2009).

The most extensively studied group relevant to AMD formation are the Y-proteobacteria, specifically *Acidithiobacillus* spp – formerly *T. ferrooxidans, Thiobacillus caldus* and *Thiobacillus* spp – (Kelly and Wood, 2000; Olsen, 2015).

The bacteria of *Acidithiobacillus* genus usually start the AMD genesis. *Thiobacillus ferroxidas* and *Thiobacillus thi-oxidans* extensively found in sulphide mineral-bearing ore deposits, mine tailings and abandoned mines, play a critical role in acid formation due to their ability to rapidly oxidise reduced forms of iron and sulphur which can lead to the generation of sulphuric acid (Bruynesteyn and Hackl, 1982; Nyavor et al., 1996; Natarajan, 2008; Sangita et al., 2010). Sulphide minerals are very liable to micro bio-chemical biodegradation by acidophilic chemotrophic micro-organisms (namely, genera *Acidithiobacillus* and *Archaea*) and, as a result forming AMD (Druschel et al., 2004; Máša et al., 2012).

The sulphide ore deposits may generate during the mining process but, mostly after mining closure, the natural "biogeoreactors" leading to the toxic waters (Luptakova et al., 2012). The heavy metals found in sulphides may be either released into pore water or isolated by secondary minerals via adsorption or co-precipitation. In this zone, the pore water is often acidic (pH < 4n.0, generally), and autotrophic (i.e. capable of fixing inorganic carbon to organic carbon), oxidising bacteria prevails in its microbial community (Lu and Wang, 2012).

2.5 Impact of mining activities on water quality

Foli et al. (2011) reported that mining and mineral extraction processes result in the pollution of water resources which in turn creates imbalanced contaminant conditions between the land and water regimes in both qualitative and quantifiable ways.

The study by Ay (2016) described four primary ways in which mining causes water pollution:

1. Release of harmful metals: harmful metals such as cadmium, copper, lead and zinc unearthed with the ore can easily spread through the environment;
2. Use of chemical agents to separate and recover minerals such as cyanide ;
3. Erosion and sedimentation: eroding mine waste mineral carried off-site where it settles and causes the clogging of river beds; and
4. Formation of AMD which contaminate water resources.

The release of AMD from both active and abandoned mines is described in the study by Balintova et al. (2013) as one of several mechanisms by which mining negatively affects the environment. The study further indicated that the seepage from waste rocks have negative impacts on the surrounding aquatic environment (Balintova et al., 2013). Research has shown that AMD is not only characterised by high acidity (low pH) and high concentrations of sulphate, but metals and metalloids, such as iron (Fe), manganese (Mn), aluminium (Al), zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), cadmium (Cd) and arsenic (As) (Kawatra and Natarajan, 2001; Kagambega et al., 2014).

2.6 Environmental impact of AMD

AMD is documented as one of the most serious environmental challenge facing the mining industry, and is a major challenge experienced by coal and gold mines in South Africa and globally. It has been noted for its devastating ecological impacts and its toxicity to water resources (Durand et al., 2010; Feris and Kotze, 2014). The study by Ochieng et al. (2010) revealed that water oozing from coal and base metals mines often is laden with high concentrations of sulphuric acid and heavy metals with the potential to contaminate streams and agricultural land. Once contaminated, the receiving environment is automatically rendered useless.

The contamination of both surface and groundwater resources by AMD presents long-term stressful implications. These implications include low quality of water resources; harming of food crops; risking human health; and eradicating wildlife and eco-systems, infrastructure and heritage sites (Groenewald, 2012). AMD can be more acidic than acid rain and can burn human skin and kill fish and other aquatic life. Owing to its high acidity, AMD also discharges toxic metals, including cadmium, chromium and lead from waste rock, which may cause further damage (FNEHIN, 2012).

2.6.1 Impact of AMD to the groundwater and surface water

Mine waste issues are countless, but the most challenging one to address is AMD. AMD emerges from both surface and underground workings, waste and development rock, and tailings dams and ponds (Durkin and Herrmann, 1994; Oelofse et al., 2007). The quality of groundwater and surface water is negatively affected by surface impacts which are mostly from tailings and rock dumps. The underground impacts are normally associated with the inflow of water into the underground workings and the subsequent drainage of the aquifer (Banister et al., 2002; Oelofse et al., 2007).

The study by Durand et al. (2010) revealed that adverse impacts of mine water in the propinquity of mines are more devastating than that on surface bodies. Toxic pollutants remain stagnant in groundwater for many years whereas pollutants may be drained out from rivers during rainy seasons.

2.6.2 Impact of AMD on soil

AMD can destroy soils due to low pH and high concentrations of metals and other toxic elements (Guo, 2014). Soils that have been contaminated by AMD have a lower pH, generally between four (4) and six (6), which is acidic to strongly acidic. The soil in the upper 0.3m of topsoil is shown to be the most contaminated with high levels of heavy metals such as cobalt, nickel and zinc (Rösner and van Schalkwyk, 2000; Bobbins, 2015). The acidification of topsoil leads to lifetime damage to the soil, resulting in serious challenges for future land use, as only acid-tolerant plants can be grown in acidic soils. Heavy metals in the soil that has been polluted with toxic metals are absorbed by plants and transferred to humans and animals through the food chain. This, therefore, poses a risk for the agricultural and livestock industries, causing severe health problems and the degradation of ecosystems (Ochieng et al., 2010; Bobbins, 2015).

2.6.3 Impact of AMD on the geotechnical perspective

AMD raises concerns regarding geotechnical impacts, namely; the flooding of underground infrastructure in areas where acidic water rises close to urban areas, the dissolving of cement structures by acid water, and the increased seismic activity, which could have an effect on property and infrastructure (Feris and Kotzé, 2014). Among other effects, the report by Ekolu et al. (2016) indicated that AMD can result in adverse impacts on engineering infrastructure, including corrosion of plumbing and water conveyance systems, corrosion of pumps and water pumping equipment, and the deterioration of roads, bridges and other highway structures.

2.6.4 Impact of AMD on biodiversity

South Africa is rich in natural resources and has a great agricultural heritage, and these play major roles in the country's economy. However, DEA (2010) reported that biodiversity in South Africa is adversely affected through air, water and soil contamination from mining sectors, power stations and many other industries. Bray et al. (2008) reported that AMD contamination of streams results in species diversity loss and structural changes to freshwater organisms. Iron hydroxides and oxyhydroxides may physically coat the surface of stream sediments and streambeds destroying habitat, diminishing the availability of clean gravels used for spawning, and minimising fish food items such as benthic macroinvertebrates (Mukhopadhyay and Mukherjee, 2013).

The United States Environmental Protection Agency (1999) report indicated that AMD destroys fish and negatively affects them from hatching eggs and eventually die at pH five (5) and two (2), respectively. Koryak et al. (1972) noted that a high concentration of iron in streams leads to a small fish population. The major cause of fish death in water pollution by AMD is the loss of sodium ions from blood and loss of oxygen in the tissue. Jennings et al. (2008) reported that AMD, characterised by acidic metalliferous conditions in water, is responsible for physical, chemical and biological degradation of stream habitat.

2.7 The role of GIS in evaluating pollution levels in abandoned mines

GIS is a system that uses computer technology to capture, store, manipulate, analyse, model and display spatial data (Clarke, 1986). Geospatial technologies provide a plethora of tools that are useful in the evaluation of pollution levels in the abandoned mines. Some notable studies (Norman et al., 2008) used sediment deposition to trace pollution levels caused by AMD.

An integrated watershed analysis using GIS tools was undertaken to examine erosion and sediment transport characteristics in the watersheds. Yenilmez et al. (2011) reported on the successful application of GIS tools to evaluate pollution levels at an abandoned coal mine site at Ovacik-Yaprakli, Turkey, concerning topography and surface runoff pathways. The results of the study indicated that the site was contaminated with heavy metals, such as chromium (Cr), copper (Cu) and nickel (Ni), with higher metal concentrations being recorded close to the contamination sources and along the surface runoff pathways.

Estimates of stream deposits of sediment from mine tailings were related to the chemistry of surface water, to assess the effectiveness of the methodology used to assess the risk of AMD being dispersed downstream of abandoned tailings and rock waste piles. Findings showed progress in the prediction of streams that are likely to have a severely degraded water quality as a result of mining that operated in the past (Yenilmez et al., 2011). Similarly, an actual bathymetric map was created from a data pool of Mining Lake 111, Brandenburg, Germany, and that map was the basis of the selection of sampling sites where the study obtained sediment cores to describe the geochemistry of the lake sediments. With a fusion of Principal Component Analysis (PCA) to examine patterns and similarities between concentrations of different heavy metals, the study was able to depict the spatial variation in metal concentration of AMD (Yenilmez et al., 2011).

2.8 The role of geospatial technologies in AMD remediation options

Generally, wetlands are used as passive and cost-effective treatment options for AMD and mining pollution (Johnson and Hallberg, 2005). However, most developments destroy most natural wetlands. This, however, leads to the desire of new wetlands construction to control pollution from mines (Peter, 1992). GIS plays a vital role in mapping and monitoring such aquatic environments (Kaymaz and YabanlI, 2017). There is a number of studies that used GIS to select sample sites and mapping (Szücs et al., 2002).

The study by Wildeman et al. (1990) tested the process for remediation of iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn). The results in this study showed that copper and iron seem to be strongly adsorbed as compared to manganese. Similarly, in the natural wetland stream environment in Central Swedan, the attenuation of copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn) originally from acidic ore mine leachate was studied (Szücs et al., 2002). It was deduced from the analysis that apart from adsorption of organic matter, adsorption and co-precipitation with iron oxy-hydroxide are the main processes. Manganese might be specifically adsorbed on iron oxy-hydroxide and, besides zinc, it is least preserved in the sediment.

2.9 Mitigation and management of AMD in South Africa

South Africa has used a multi-pronged approach for dealing with AMD problems (DWS, 2017). Legislative interventions by various government departments and integrated policy interventions are used as the mitigation measures for addressing AMD, whereas treatment technologies are used as technological interventions for managing AMD.

2.9.1 Constitutional Act relevant to the environment

According to Section 24 of the Constitution of the Republic of South Africa, 1996 – Act 108 of 1996 – (the constitution), “everyone has the right to environment that will not harm their health and wellbeing, and to the environment that is taken care of, for the benefit of the current and the future generation”. This constitution is aimed to be achieved through legal framework and other measures that prevent issues such as pollution and ecological degradation, and also securing the natural resources (Du Plessis, 2010).

2.9.1.1 Legal framework on AMD management

Oelofse (2008) indicated that South Africa has made huge progress in shifting policy frameworks to address mine closure and mine water management. According to Oelofse (2008), the mining industry has changed its practices to comply with new legislation and regulations. However, despite significant progress being made, the implemented legislations do not describe the risks posed by AMD in a satisfactory way (UNEP, 2012). Mine closure and mine water management in South Africa are governed largely by the Mineral and Petroleum Resource Development (MPRDA) Act, 2002 (Act 28 of 2002) and the National Water Act, 1998 (Act 36 of 1998). Additionally, The National Environmental Management (NEMA) Act, 1998 (Act 107 of 1998) also addresses the challenge of mine wastewater.

South African legislation now requires the polluters to take responsibility for the remediation and alleviation of water pollution, including pollution that occurred previously (Feris and Kotze, 2014). The legislation is more effective in addressing the polluters that are identifiable and that still exist, however, the most challenging part of the historic pollution is that most of these mines have been deserted and have no ownership (Feris and Kotze, 2014). The DWS Mine Water Management Policy report (2017) added that this current legislation may continue to disrupt the procedure of tackling the issue of AMD.

The purpose of the NWA, 1998, as one of the major pieces of legislation consisting the bearing on AMD, is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways that take into account "promoting equitable access to water; re-dressing the consequences of past racial and gender discrimination; promoting the affluent, sustainable and beneficial use of water in the public interest; facilitating social and economic development; protecting aquatic and associated ecosystems and their biological diversity; meeting international obligations", to state the least. Furthermore, The NWA is crucial at governing water resource management in South Africa. This Act gives DWS a responsibility to make sure that water resources remain fit for use on a sustainable basis.

This responsibility is exercised through the implementation of regulations, such as the regulations on the use of water for mining and related activities aimed at the protection of water resources (NWA, 1999). Additionally, NWA supports the 'Polluter Pays Principle' with the direct implication for the mining industry specifically associated to AMD. This principle requires that those responsible for producing, allowing or causing pollution be held responsible for clean-up costs (Taviv et al., 1999; Hobbs et al., 2008).

The MPRDA was authorised to regulate the mining industry in 2002. This Act authorizes mining rights, recognising that resources of the country belong to, and are for the interest of the nation. The Act also ensures that mining is conducted in a sustainable, social and environmental friendly manner. Further, it ensures transformation of the industry, rectifying racial unfairness of the past (Ajam and Padia, 2014).

Despite MPRDA's authority to regulate mining industries, mining companies have long been held responsible for their actions. There have been statutory obligations imposed upon mining companies for over 70 years not to discharge polluted water (Mujuru and Mutanga, 2017). Mining regulations that were promoted thereafter, in relation to the same provision, also clarified the issue, by providing (in regulation 7(b) that: "water with toxic substances will not be authorized to be released as a harmful source to the environment". Section 45 of the MPRDA, dealing with the Minister's rights to redeem costs during the time of urgent remedial measures, stipulates that:

"(1) If any survey, mining, observation or production operations lead to land degradation, and damage the environment which may be harmful to the health or well-being of anyone and requires urgent remedial measures, the Minister may direct the holder of the relevant right, permission to:

(a) Investigate, evaluate, assess and report on the impact of any pollution or ecological degradation;

(b) Take such measures as may be specified in such directive; and

(c) Finish such measures before a date specified in the directive.

(2) (a) If the holder does not comply with the mandate, the Minister may take such measures as may be necessary to protect the health and well-being of any affected person or to remedy ecological degradation and to stop pollution of the environment.

(e) The Minister might claim the full amount needed to apply all necessary measures from the person responsible".

NEMA and NWA give the responsibility to the government representatives to take administrative actions in dealing with historical pollution. These two regulations include pollution that occurred in the past as one of the triggers for the obligation and require reasonable measures to be taken only where activities are currently causing damage, or where they may in future cause damage, but also where previous activities have caused pollution, which contamination remains evident in the environment (Madalane, 2012).
Section 28 of the NEMA, dealing with the duty of care and remediation of environmental damage, stipulates that:

"Every person responsible for causing pollution to the environment must take responsibility to prevent such matter from recurring, to ensure the protected environment. Any source of pollution should be eliminated by taking control of any activity causing pollution".

Section 3 of the NWA (Act 36 of 1998) allows the public servants of the nation's water resources serving under the Minister of Water and Sanitation to ensure that water is protected and well preserved in a sustainable manner, for everyone to benefit from it in accordance with its constitutional mandate.

Section 19 (1) of NWA provides that "a person in control of the land on which any activity or process is or was undertaken, or any other situation causing or likely to cause pollution on water resource, must take an action to prevent such pollution from occurring, continuing or recurring".

Catchment Management Agency (CMA) "has the responsibility of directing any person failing to take reasonable measures and commence taking specific measures before given date outlined in terms of Section 19(3) (a-c). In terms of section 19 (4) and (5) of the NWA, “the Catchment Management Agency is responsible to recover all costs incurred as a result of a person not complying with a directive given in terms of sub-section (3). These include any person who is or was responsible for, or who directly or indirectly contributed to the pollution or potential pollution”.

Section 151(i) and (j) further states that: “no person may unlawfully and intentionally or negligently commit any act or omission which pollutes or is likely to pollute water resources, or which detrimentally affect or is likely to affect water resource. Such action constitutes an offence subject to penalties included in section 151(2) of the Act”. “The provisions apply to water contamination or detrimental effects to water resources that are caused by hydraulic fracturing” (Motala, 2013).

2.9.1.2 Discharge limits standards for wastewater compliance

The legal document by DWA (2013) describes the revision of general authorisations in terms of section 39 of the national water act, 1998 (Act 36 of 1998). Section 21 (f) and (h) of the NWA focus on the legal discharge limits for water quality compliance required for all entities discharging wastewater into the environment. These two sections focus on the “authorisation of the discharge of wastewater into water resource through a pipe, canal, sewer or other conduits; and disposing of water containing waste from, or which has been heated in any industrial process”. The water user in terms of this authorisation is exempted from compliance with section 22(2) (e) of National Water Act (DWS, 2013). The above mentioned legal document stipulated wastewater limits applicable to discharge wastewater into water resources as indicated in tables 2-2 below.

Table 2-2: Wastewater limits for discharge into water resources

Substance parameter	General limit
pH	5.5 – 9.5
Sulphate (mg/L)	600
Dissolved Iron (mg/L)	0.3

2.9.2 Policy framework on AMD management

South Africa has begun to take action in various areas facing the challenge of AMD and has employed mitigation measures such as technologies, policies and legal frameworks (Mujuru, 2014). A Government Task Team (GTT) consisting of personnel from DWS – previously known as DWA (Department of Water Affairs), DME (Department of Mineral Energy) and DEA (Department of Environmental Affairs) has been in place since 2005. The GTT facilitates solutions and high-level decision-making on water management and related issues, and the implementation of safe and sustainable mine closure options in South Africa (Mujuru, 2014).

There has been progress in shifting policy structures for strategising and water authorisation for mining, and making AMD manageable, however, stagnation in taking effective action on the current policies remain (DWS, 2017). The DWS has recently developed a policy to deal with the AMD issues that degrade water quality, resulting in increased health risks for humans upon the ingestion of the toxic water (DWS, 2017). NWA, 1998 (Act 36 of 1998) expand in strategies to facilitate the thorough management of resources. The National Water Resources Strategy, on the other hand, provides the overall structure for the management of water resources in the country (DWS, 2017).

Despite shifting of policy structures, some challenges dealing with AMD management were revealed in the policy, discussing the issue of addressing the approaches of closing mines through integration, division of liabilities and categorisation of mines (DWS, 2017).

2.9.3 AMD treatment technologies

There are numerous potential AMD treatment technologies that have been developed to help resolve the problem of AMD. The study by Trumm (2010) stipulated that there are different chemical, physical and biological technologies for the treatment of AMD, which may be classified as either “passive” or “active” processes.

2.9.3.1 Active AMD treatment options

There is a wide range of active AMD treatment technologies that are currently being explored. These include neutralisation (including chemical precipitation), membrane filtration, ion exchange processes and biological processes (INAP, 2013; Pondja et al., 2014).

Chemical neutralisation

The most widely used technology is the chemical neutralisation using various neutralisation feed stocks, such as limestone, hydrated lime, pebble quicklime, soda ash, caustic soda, potassium hydroxide, barium carbonate, ammonia, fly ash and steel slag, which elevate the pH of the AMD with the resultant precipitation of metal ions (Chockalingam and Subramanian, 2006). Each one of these chemicals has properties, costs, and some differences in how they can be delivered (Kirby, 2014). Although effective in buffering pH and removing metal ions from AMD as hydroxides, these chemical techniques are often expensive to implement due to the costs of feed stocks and operations and maintenance (Name and Sheridan, 2014). In addition, the other disadvantage with neutralisation and chemical precipitation is that it generates sludge which is an environmental challenge on its own. Kaksonen and Sahinkaya (2012) reported that the extensively used active AMD treatment technology is characterised by chemical neutralisation and hydroxides precipitation of metals. In South Africa, the ABC (Alkali-Barium Calcium) process developed by the Council for Scientific and Industrial Research (CSIR) utilises neutralisation and chemical precipitation (Beer et al., 2010).

AMD treatment approach relies on the understanding of the integrated mine water system and specific objectives needed to be achieved. Flow chart to design a site for specific active treatment system for AMD is shown in figure 2-2 below:

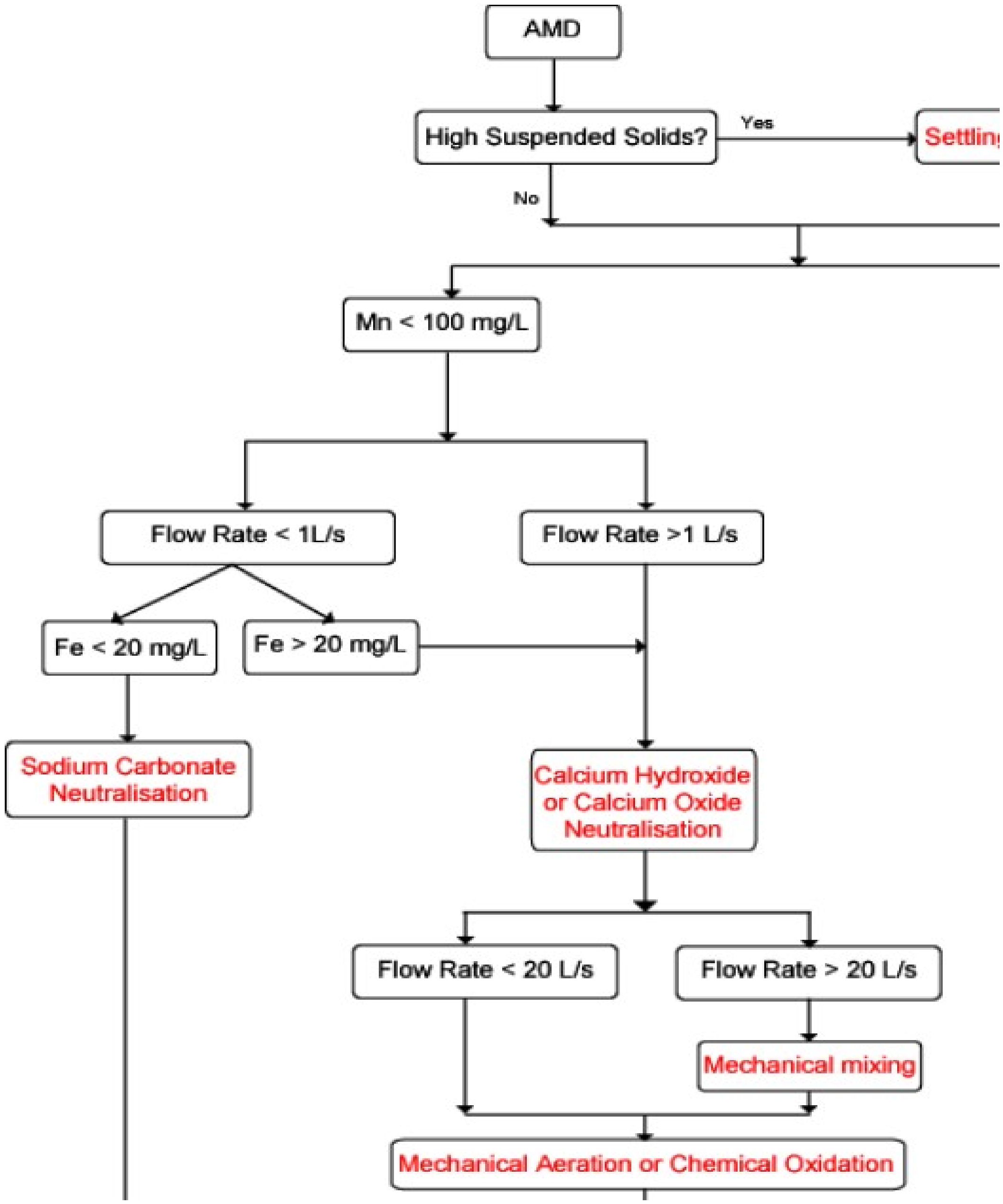

Figure 2-2: Flow chart to design a site-specific active treatment system for AMD – adopted from Trumm, (2010).

Ion exchange

The Ion exchange technology encompasses the passage of AMD through a resin bed containing either cationic or anionic exchange resins, on which ions are stoichiometrically exchanged until the resin's exchange capacity becomes exhausted. Ion exchange technology has been demonstrated as effective processes for the remediation of AMD. Feng et al. (2000) demonstrated the effectiveness of the combination of chemical precipitation and ion exchange to get rid of pollutants from AMD in South Africa. Gaikwad (2010) demonstrated the applicability of ion exchange technology for the removal of heavy metals from AMD. In South Africa, Earth Metallurgy Solutions developed the Filtration and ion exchange to treat AMD and recover valuable resources (Kardas-Nelson, 2010). The application of ion exchange in AMD treatment is prone to limitations, such as the generation of highly concentrated secondary wastes that can present serious disposal challenges. Another shortcoming of ion exchange is that its performance is high when there are low levels of ions in solution, yet AMD is made up of excessive concentrations of sulphates and heavy metals, this consequently limits its applications.

Adsorption

Adsorption, generally, is a process that occurs when a gas or liquid solute accumulates on the surface of a solid forming a film of molecules. Adsorption has been utilised for the removal of cationic and anionic contaminants from AMD with good removal efficiencies having been recorded (Westholm et al., 2014). Adsorbents such as activated carbon, zeolites, lignite, chitin, have found wide applications as adsorbents for water treatment. Motsi et al. (2009) utilised natural zeolites as low-cost adsorbents for treating heavy metals laden AMD. Preliminary results using natural AMD water samples from Wheal Jane Mine, UK, showed that clinoptilolite has great potential as a low-cost adsorbent for treating AMD (Motsi et al., 2009).

2.9.3.2 Passive treatment

Passive treatment can operate through chemical and biological processes that occur naturally, to elevate the polluted water. The construction of this treatment method is low at cost, as well as during operation and maintenance (Luković and Stanković, 2012). Nkonyane et al. (2012) noted that passive treatment technologies depend on naturally occurring biological, geochemical and physical processes without a mechanical assistant, unlike the active treatment systems. Skousen et al. (2017) argue that passive AMD treatment systems can be efficient, effective and long lasting if properly designed and maintained.

Biological processes

Several biological processes can be utilised to remove or reduce contaminants from wastewater. These comprise bioreactors and wetlands. Generally, biological processes are dependent on the activity of bacteria, fungi and plants for AMD treatment. Johnson and Hallberg (2005) noted that the foundation of biological treatment of AMD stems from the abilities of some micro-organisms to generate alkalinity and immobilise metals, thereby essentially reversing the reactions responsible for its formation. The CSIR developed microbial reactors that use microbes found in cow guts to treat AMD (Kardas-Nelson, 2010). Burton (2001) also reported on the bioreactor system developed by Rhodes University to help treat AMD in South Africa. While competitive, biological processes are affected by operating conditions of pH solution and temperature which tend to negatively affect their efficiencies.

Biological passive treatment relies on bacterial activity, such as bacterially catalysed Fe and Mn oxidation and formation of alkalinity and metal removal via microbial sulphate reduction, along with the removal of metals via adsorption and exchange reactions with organic matter. Geochemical passive treatment relies on the formation of water with alkalinity-generating materials such as limestone and alkaline steel slag (Skousen et al., 2017).

The characterisation of water to be treated is a very crucial step in designing passive treatment technology. This can be done by measuring the discharge or flow of those waters and the concentrations of water quality constituents of concern over an extended period, ideally at least a year, to determine how these quantity parameters vary seasonally (Zipper et al., 2011). Geochemical passive systems include anoxic limestone drains, open limestone channels and limestone leach beds, while biological systems include aerobic and anaerobic constructed wetlands, vertical flow wetlands and bioreactors. Constructed wetlands utilise soil and waterborne microbes associated with wetlands plants to remove dissolved metals from mine drainage (Jha, 2017).

The succeeding paragraphs describe passive treatment systems in depth. Meanwhile, Figure 2-3 below shows the schematic diagram for the passive treatment of AMD by Jha (2017).

Scheme for passive treatment of mine drainage

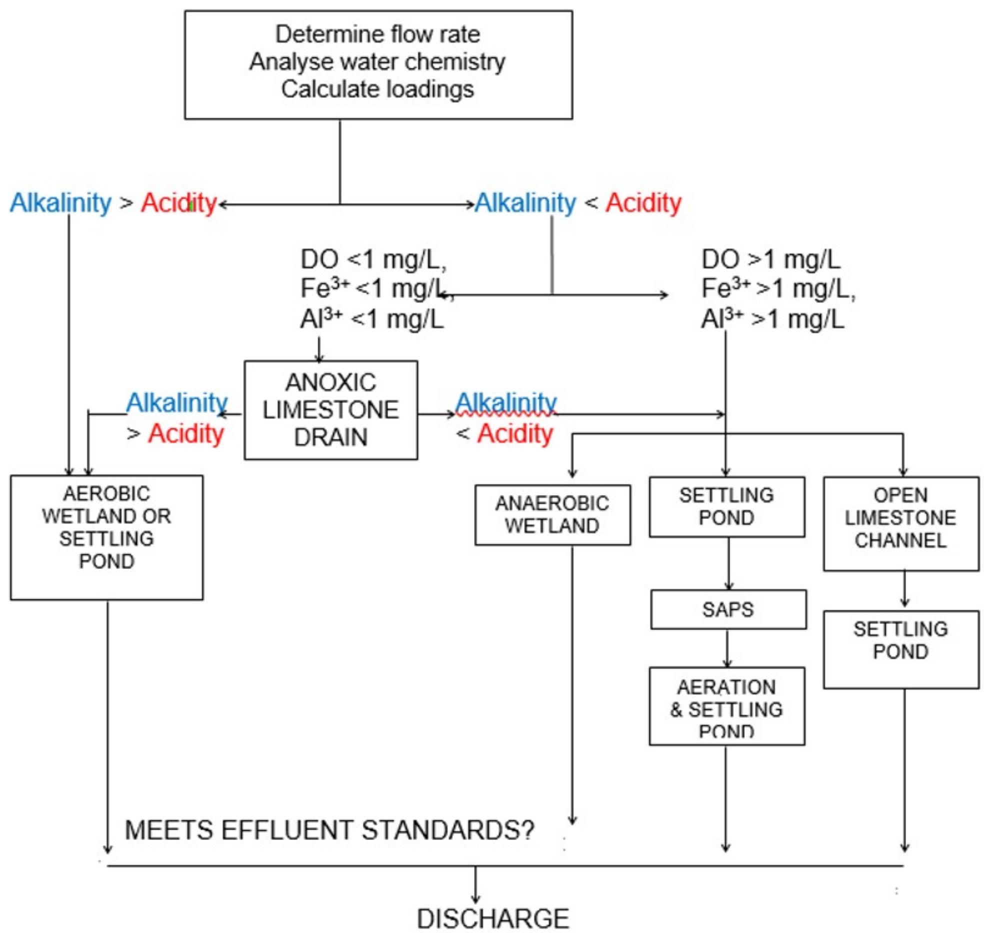

Figure 2-3: Scheme for passive treatment of AMD (Jha, 2017)

Anoxic limestone drains

The limestone is normally dissolved by the acid in water as it passes through the drain which elevates the pH. This treatment method is used in highly acidic water. The cell is covered with compacted soil or clay to form anoxic conditions so as to avoid the armouring of the limestone aggregates through iron hydroxides, due to Fe^{2+} not precipitating as $Fe(OH)_2$ at a pH less than 6 (Zipper et al., 2011; Zaal, 2016).

The study by Ziemkiewicz et al. (2003) stated that anoxic limestone drains are not suitable for water containing high concentrations of aluminium (Al) or ferric iron (Fe^{3+}) because these metals form solids within the limestone aggregate, decrease its permeability, and eventually plug the systems. For anoxic water rich in ferrous iron or manganese, the systems are effective and less expensive for treating acidity in AMD. If the dissolved oxygen is low in mine drainage, and iron and aluminium concentrations are low enough to control clogging, anoxic limestone drain systems can be applied. This passive system is essentially a buried bed or trench of crushed limestone through which AMD flow (MEND, 1999; Gibbens, 2012). Figure 2-4, below, shows the cross-section of an anoxic limestone drain system.

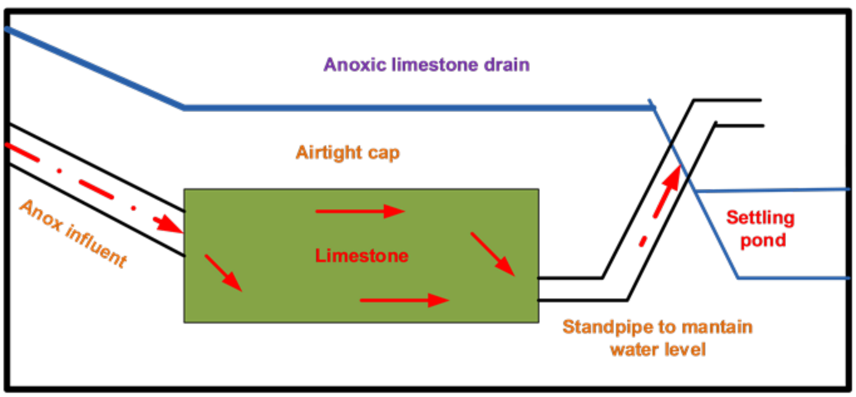

Figure 2-4: Cross-section of an Anoxic Limestone Drain system (Pondja et al., 2014)

Aerobic wetlands

Aerobic wetlands are either lined or unlined shallow ponds which are reasonably impermeable sediments comprised of soil or limestone gravel. They enable natural oxidation of heavy metals during AMD treatment. Oxidation reactions result in the precipitation of metals as hydroxides and oxyhydroxides (Dawohoso, 2013). Aerobic systems are effective for the removal of iron, arsenic and to some extent manganese. In contrast, anaerobic (compost) systems can attenuate zinc, cadmium and copper (Lamb et al., 1998; Jarvis et al., 2012). Aerobic processes are more effective when the influent pH is higher than 5.5. In addition, aeration prior to the wetland enhances the efficiency of the oxidation process and, therefore, the precipitation process. Gaikwad and Gupta (2007) reported on the effective application of aerobic wetland systems for the removal of iron (II) from AMD.

Anaerobic wetlands

Unlike aerobic wetlands, anaerobic systems rely on the alleviation of acidic water under anaerobic conditions. Anaerobic wetlands are founded on microbial sulphate reduction for the generation of alkalinity, neutralisation of the acidity of incoming waters and precipitation of metals mainly as sulphides. These systems generate alkalinity through a combination of sulphate-reducing bacteria and the addition of limestone. In order to create anoxic conditions, sulphate-reducing bacteria require a rich organic substrate (Gazea et al., 1996; Lekhanya, 2010). The design of the system is very important otherwise if low temperatures are encountered, the micro-organisms may die and, in turn, this negatively affects the system performance.

Sulphate-reducing bioreactors

Sulphate-reducing passive bioreactors have drawn the attention of researchers as possible AMD treatment technologies. Sheoran et al. (2010); Evans and Ko (2013) have reported that sulphate-reducing bioreactors can remove acidity, sulphates and heavy metals which – the main constituents of AMD. Sulphate-reducing bioreactors offer advantages such as high metal removal at low pH, stable sludge, very low operation costs, and low energy use (Neculita et al., 2007). Sulphate-reducing bacteria usually rely on simple carbon compounds, such as organic acids or alcohols to serve as electron donors for sulphate minimisation, though some are capable of using hydrogen (Logan et al., 2005; Doshi, 2006).

Sulphate-reducing bioreactors carry out the important process steps by reducing sulphate to hydrogen sulfide (Neculita et al., 2007; Kittrell, 2014):

$2CH_2O + SO_4^{2-}\ 2HCO_3- + H_2S$ [6]

The HCO_{3-} (bicarbonate) buffers total acidity and assist to neutralise low pH. Hydrogen sulfide dissolves readily in water (along with ionic species HS-) and can form metal sulfide precipitates:

$H_2S + M^{+2}\ MS_{(s)} \downarrow + 2H$ [7]

2.10 Advantages and disadvantages of passive AMD treatment systems

The study by Ford (2003) describes the advantages and disadvantages of passive ADM treatment systems mentioned below:

2.10.1 Advantages of passive AMD treatment systems

- AMD treatment systems do not require:
    - Any mechanical equipment;
    - Hazardous chemicals, or buildings;
    - Electrical power; and
    - Daily operation and maintenance.
- They are more natural and aesthetics in their appearance and may support the ecosystem.
- They are cost-effective as compared to the active water treatment systems.

2.10.2 Disadvantages of passive AMD treatment systems are as follows:

- They are prone to failure due to poor design and extreme weather conditions;
- They suffer from inefficiencies due to blockages as a result of precipitates; and
- May not meet the regulatory wastewater disposal standards.

2.11 AMD treatment technologies in Witwatersrand Basins

Efforts have been made to address the crucial issue of AMD in South Africa, particularly in the Witwatersrand Basins. Many technologies have been identified for the treatment of AMD and these include active, passive and in situ methods. Some of the technologies that are currently being implemented for AMD treatment in South Africa are:

- Reverse osmosis technology used in Witbank area (McCarthy, 2011);

- Ion exchange technology used in the Western basin (Howard et al., 2009); and

- High-density sludge (HDS) neutralisation technology used in the Witwatersrand Basins (DWS, 2013).

HDS treatment plant with a capacity of 30 mL/day was commissioned to manage mine water decant, and the neutralised product being released into the Tweelopiespruit, generating a perennial flow of similar magnitude (Deventer and Cho, 2014). This technology produces high-quality effluents, and is more cost-effective and reliable than other treatment processes (Knapp, 2004). Currently, AMD is treated by adding lime to neutralise the acid and precipitate the heavy metals as hydroxides. These heavy metals can be flocculated to form HDS and, once settled, it can give a relatively clear overflow (Fuzani, 2011).

2.12 AMD treatment technologies projects in the Witwatersrand Goldfields

Trans-Caledon Tunnel Authority (TCTA) is a crucial entity responsible for tackling AMD issues in the Witwatersrand Goldfields (Naidoo, 2014). The TCTA report (2015) indicated that TCTA project was implemented as an urgent task in terms of Section 103 (2) of the NWA and it was approved by the Minister of Water and Sanitation. In this regard, the Minister instructed TCTA in April 2011, to do the urgent work on AMD treatment in the Witwatersrand Goldfields. The report further stated that R225 million was allocated by the National Treasury for the implementation of the AMD treatment phase. The purpose of these funds was to cover project costs over a period of two years.

The Department of Water and Sanitation authorised TCTA to apply the necessary AMD water management and mitigation infrastructure. The project encompassed treatment plants in the Randfontein area (Western Basin), the East Basin Proprietary Mines (ERPM), South-West vertical shaft area (Central Basin) and the Grootvlei Mine Shaft 3 area in Springs (Eastern Basin) (Ncongwane, 2017). Ncongwane (2017) further revealed that the South African government applied two interventions in addressing the issue of AMD remediation. An amount of R6.9 million for AMD flooding into Tweelopiespruit was funded in 2009, whereas R400 million was funded for a short-term solution in 2011. The short-term solution was still tethered by a host of financial and technical constraints (Zvinowanda, 2016).

The study by Zvinowanda (2016) has also indicated that other companies are working together with the government nationally to solve the challenge of AMD included the Western Basin Environmental Corporation (WBEC), Central Basin Environmental Corporation (CBEC) and Eastern Basin Environmental Corporation (EBEC). The mines operating in the Eastern and Western and Central Basins responded by forming a water service company named Water Utility Corporation (WUC), which had spent more than R60 million on research and development (R&D) initiatives.

2.13 Conclusion

A literature review was done in all aspects of AMD issues and the mitigation and management strategies to resolve it. The South African government and all other stakeholders came up with various AMD management and mitigation measures. AMD treatment technologies that are being used in South Africa, particularly in West Rand were explored. Among others, ion exchange and chemical neutralisation were reviewed. Furthermore, South African legislation addressing AMD were described. Thus, this chapter aimed to assess various interventions used to resolve AMD problem not only in West Rand but worldwide. The following chapter focuses on research methodology.

3 METHODOLOGY

3.1 Introduction

The purpose of the research methodology section is to provide a step by step road map followed by the researcher in unswerving the research question. The research methodology includes articulations on what the researcher did with regards to the research design, research locale, data collection, data analysis, rigour determinations and ethical consideration.

3.2 Description of the study area

The West Rand Goldfields, which forms part of the Witwatersrand Basin in South Africa, is the focus area of this study. Killick (1992) pointed it stretches from Roodepoort (in the North East) to Krugersdorp (in the North West, then beyond Westonaria (in the South). West Rand is located within the Gauteng Province and situated 50 km West of Johannesburg. It is composed of four local municipalities: Randfontein, Mogale City, Merafong City and Westonaria.

West Rand is known for historical discoveries of natural resources, such as gold, since the 1800s (Thwala, 2014). Gold mining activities in the West Rand area proved a challenge due to substantial water inflows from dolomitic aquifers (Cobbing, 2008; Funke et al., 2012). Buchanan (2010) has indicated that “as these mines became deeper, increased challenges were experienced with water ingress into the underground workings”.

The West Rand Goldfields straddles a continental watershed, with the Northern portion of the area which drains into the Tweelopiespruit, a tributary of the Crocodile River which flows North, discharging into the Limpopo River and ultimately to the Indian ocean and the Southern portion draining into the Wonderfoteinspruit (Fyffe et al., 2014).

The Tweelopiespruit is the initial Catchment to receive AMD that is being discharged from West Rand Goldfields, namely; The Western Basin (Deventer and Cho, 2014). The Tweelopiespruit starts on mine property in Krugersdorp and flows through a game reserve and into the Limpopo Basin via the Cradle of Humankind (Liefferink and Pretorius, 2011).

The map below illustrates Tweelopiespruit Catchment in West Rand and tributary of the Crocodile River flowing to the North.

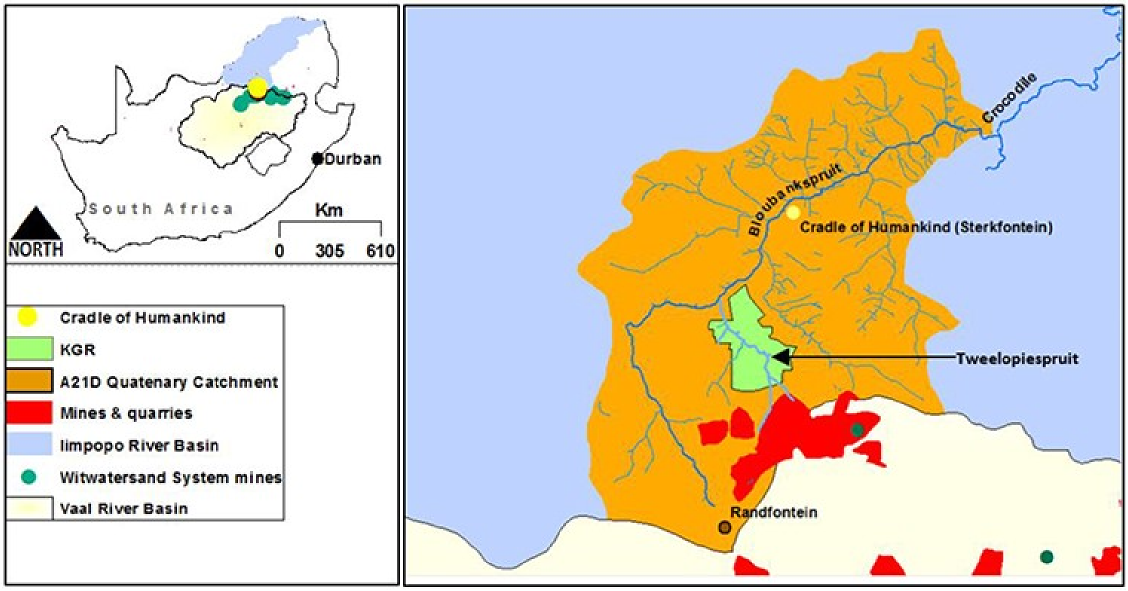

Figure 3-1: A map indicating Tweelopiespruit Catchment in West Rand (Dzwairo and Mujuru, 2017)

3.3 Geological setting

The Western, Central and Eastern Basins are the oldest mining districts of the Greater Witwatersrand Basin, a more or less oval-shaped depression about 300 km long and 200 km wide (DWA, 2012). The Witwatersrand Super Group comprises the West Rand Group having a maximum thickness of 5.15 km, which is overlain by the Central Rand group having a maximum thickness of 2.88 km (Grové and Harris, 2010). The West Rand Group comprises of quartzites, reddish and ferruginous magnetite shales and gritty and conglomerate horizons (Bamuza and Abiye, 2012). The locus of AMD is characterised at surface by dolomitic strata that represent an outlier associated with the Vaalian (2.65 to 2.43) GaChuniespoort Group and in particular the Malmani Subgroup within this lithostratigraphic unit (Hobbs and Cobbing, 2007).

3.4 Hydrogeology

The final scoping report compiled by Beringer (2012) for the immediate and short term interventions for the treatment of AMD in the Western, Central and Eastern Basins of the Witwatersrand Goldfields stated that the Witwatersrand Goldfields in the Western Basin comprised of the following three (3) golds:

- Black Reef;
- Kimberley; and
- Main Reef.

When mining activities stopped operating in the area in 1997, the mine void in the West Rand Basin was filled with water and later began to decant contaminated water onto the surface in the year 2002. Nadasan et al. (2014) reported that the initial surface decants took place from a borehole that is situated along the Tweelopiespruit, just below the position of the Black Reef Incline (BRL) portal. The study by Hobbs and Cobbing (2007b) has indicated that the region encompasses portions of the Karst Belt (#10) and Central Highveld (#17) groundwater regions as defined by Vegter (2001). The hydrogeological characteristics of the rocks in the study area have been impacted by geological activities, including sedimentation, intrusion, metamorphism, brittle and ductile deformations (Abiye et al., 2011). Groundwater contamination with the chemical characteristics of West Rand Goldfields mine water has been detected at numerous sites in the dolomitic aquifer of the Zwartkrans compartment (Coetzee et al., 2009).

Currently, AMD is flooding naturally with the major part, flowing untreated down the Tweelopiespruit into Bloubankspruit, and then flowing past the Sterkfontein caves and across the Zwartkrans dolomitic compartment (Beringer, 2012).

3.5 Research design

Research design is the overall plan that connects the conceptual research problems to the appropriate empirical research (van Wyk, 2012). According to Kumar (2011), a research design is a strategic plan used by the researcher to answer the question of the study. Since this study uses a mixed method, the ontological position of the researcher is both interpretivist and positivist.

An interpretivist approach lies within the qualitative research paradigm. With this paradigm, the researcher persuaded a systematic literature review method, randomly drawing research data from published studies, policies and statutes located within the following databases:

- Government gazette;
- Feasibility study for a long-term solution; and
- DWS Mine Water Management Policy.

The justification for the choice of a systematic review is based on the fact that the researcher intended to extract information pertaining to legal research in as far as the concept of mitigation; wastewater discharge compliance and management are concerned as per research question.

Legal research is a process that involves the identification and extraction of legal information necessary to support a legal-based decision (Barkman et al., 2015). In this study, the interpretivist approach was used purely to investigate the legal imperatives of the study, as mentioned above.

The positivist approach was used for triangulation purposes, from the interpretivist perspective of this investigation. “The positivist approach lies within the quantitative paradigm and uses experiments and surveys and collects data on predetermined instruments that yield conclusions in a statistical format” (Creswel, 2003). The rationale for this aspect of the research (positivist approach) is specifically to determine legal compliance and adherence to standards set by the DWS, as stated in the main question of the study. The results obtained from this exercise will be compared with the findings from qualitative reviews of the interpretivist approach of this study.

To determine the water quality at the key sampling points that discharge into Tweelopiespruit stream, a quantitative method was used by taking water samples at two (2) selected points namely:

- The Wenzi 18 shaft – point where AMD is initially seeping from the underground and discharged from Mogale Gold; AMD is also pumped from underground tunnels for treatment from this shaft; and
- Pit– point where treated AMD is allowed to settle and the sludge settles out of solution and clear treated water that is allowed to flow by gravity to Tweelopiespruit.

The coordinates for the sampled sites in described from the table below:

Table 3-1: Water sampling points in West Rand near Mogale Gold Mine

Sampling Point	Latitude	Longitude
Winze 18	E 027’43.485”	S 26’06. 894”
Pit	E 027’43.143”	S 26’08.747’

The justification for these two key choices was from the fact that the researcher aimed to compare the water quality prior and after the AMD is being treated by Rand Uranium Treatment Technology in the area of the study.

3.6 Desktop review of legal and policy documents on AMD in South Africa

The purpose of this investigation from this perspective seeks to understand the compliance procedures of the AMD by the mining companies from the legal point of view. It therefore seems logical for the researcher to confine units of analysis to a legal research review. The procedure followed by the researcher involved an examination of the following databases and legal repositories:

- South African Legal Information Institute; and
- Revision of general authorisation, in terms of Section 39 of the National Water Act.

In legal research, data pertaining to all law-related information necessary to support decisions that are legally based need a thorough scrutiny (Barkman et al., 2015). In view of the above, the rationale for use of databases and legal repositories was enough to draw necessary conclusions of this study.

3.7 Qualitative data analysis

Qualitative data analysis sought to understand the procedures and the application of the legal prescripts as provided for by three (3) categories of legal research examined by the researcher, as follows:

1. **Statutes**

    - **The National Water Act, 1998 (Act 36 of 1998)**

        - Section 3 of NWA
        - Section 19(1) of NWA
        - Section 19(3) (a-c) of NWA
        - Section 19(4) of NWA
        - Section 19(5) of NWA
        - Section 21(f) of NWA
        - Section 21(h) of NWA
        - Section 22(2) (e) of NWA
        - Section 151(i) of NWA
        - Section 151(j) of NWA
        - Section 151(2) of NWA

    - **National Environmental Management (NEMA) Act, 1998 (Act 107 of 1998)**

        - Section 28 of the NEMA

- **Mineral and Petroleum Resource Development (MPRDA) Act, 2002 (Act 28 of 2002)**
    - Section 45 of the MPRDA

2. **Case law**
    - South African Legal Information Institute

3. **Departmental policies and procedures**
    - Department of Water and Sanitation Mine Water Management policy

3.8 Rationale for selecting qualitative data source

- **Statutes:** "take precedence over all other sources of law as contained in the Constitution – they are the Acts of Parliament of the Republic of South Africa promulgated specifically to address issues regarding management, relationships, duties and obligations that flow on a particular phenomenon" (Du Plessis, 2011). It was vital for the researcher to examine relevant acts to evaluate wastewater discharge compliance and AMD management.

- **Case law:** helps inform our knowledge and understanding of how the constitutional guidelines operate in a particular jurisdiction (Hart et al., 2012). Case law provides us with precedence on all judgements that happen in all levels of the court system of South Africa. It was important for the study to examine judgements on decided cases relating to disputes regarding the AMD. In this study, case law further provides a legal bird's-eye view of previous decisions regarding wastewater discharge requirements for compliance.

- **Departmental policies and procedures:** help clarify issues or activities that are important to an organisation, such as regulatory requirements (Jacobzone et al., 2007). These are vital guidelines for every organisation in terms of the execution of its operations.

3.9 Water sampling for determination of selected pollutants

AMD is a natural phenomenon within the domains of natural science approach. All the natural science studies/approaches fall under the positivist/quantitative research paradigm. The collected samples were carried out from 28 March 2014 to 30 May 2014.

Water samples were collected in a manner that wouldn't result in them losing their integrity. This was achieved by preserving each sample by adding nitric acid and using disposable gloves throughout the sampling process. The samples were collected using 250 ml plastic bottles which were rinsed three times with iodised water. They were sampled, filled and collected as full bottles to expel air and sealed correctly. They were labelled with collection location and date, and the geographic coordinates of each sampling site were recorded. The collected samples were transported to TUT laboratory for analysis on the same day.

3.10 Quantitative data analysis

As mentioned in the previous chapters, Trans-Caledon Tunnel Authority (TCTA), a government agency was tasked to urgently treat AMD so as to lower the ECL and stop decant. TCTA subcontracted Rand Uranium to treat 30 mega litres per day. The smaller research plants which were operated by TUT and Mintek also emptied treated water into Tweelopiespruit like Rand Uranium. To evaluate the effectiveness of these interventions, water samples were collected for the determination of pH, Iron II, acidity and sulphates as described below:

pH measurements

The pH was measured by using 250 ml of Erlenmeyer flask on site. The flask was cleaned and rinsed with several portions of the sample. The temperature of a final portion was adjusted to 25°C. The pH of the sample was measured using the Knick Portamess.

Iron (II) determinations

The sample was initially filtered to remove particulate matter which may interfere in the analysis. A graduated cylinder was used to measure and transfer 35 ml of the filtered sample into a 250 ml of Erlenmeyer flask. The chlorides in the sample were eliminated by adding 10 ml of 0.1 N sulphuric acid. A total of 10 ml of the prepared Zimmermann-Reinhardt's reagent was added into the sample solution. A 50 ml burette was filled to the zero mark with 0.1 N potassium permanganate solutions. The sample was titrated while swirling the flask until the solution changed from colourless to faint pink.

Acidity determination

The acidity of AMD was determined by initially filtering the sample to remove particulate matters which may interfere in the analysis. A pipette was used to measure and transfer 5 ml of the filtered sample into a 100 ml of Erlenmeyer flask. The sample was diluted to 50 ml by adding 45 ml of reagent grade deionized water. A magnetic stirrer was dropped into this sample containing flask. A 10 ml burette was filled to the zero mark with 0.1 N sodium hydroxide solutions. The sample was then titrated while stirring until pH showed an end point of 8.3.

Sulphates determination

"Sulphate is regarded as an ion which is abundant in the earth's crust and its concentration in water can range from a few milligrams to thousand milligrams per litre, and industrial wastes and AMD may contain high concentrations of sulphate" (Bartram et al., 1996). Sulphate was determined by placing 100 ml of a sample into a 250 ml Erlenmeyer flask. Five (5) ml of the conditioning reagent was mixed into the stirred reagent. During the stirring process, one (1) spoon of barium chloride crystals was added in the solution. This was followed by the measurement of barium sulphate turbidity by pouring the solution into the absorbance cell. Turbidity was measured at 30 seconds intervals for four (4) minutes and the maximum reading obtained in the four (4) minutes period was recorded.

3.11 Pollution modelling through the ArcGIS software (Esri)

To identify the potential sources of AMD along Tweelopiespruit, ArcGIS (Esri) software was used. The purpose of using Esri was to develop a map showing areas which are highly contaminated by AMD along Tweelopiespruit. GIS coordinates were taken and presented in Microsoft Excel spread sheet to build a spatial database based on sampled sites and geospatial techniques were used to analyse variations in the concentration level of stream pollutant parameters. The pollutants parameters that were analysed/ demonstrated were pH levels and Fe^{2+} .The spatial database enabled queries to be performed on different pH levels and Fe^{2+} concentrations. Surface models showing pollutants parameters were created.

4 EVALUATION OF TREATED WATER QUALITY COMPLIANCE

4.1 Introduction

To assess the effectiveness of the interventions by various players to ameliorate the effects of AMD, findings showed that there are various players working on treating AMD in West Rand. These players operate at various scales of treatment of AMD using various methods. The players include TCTA (a state entity), pilot plant by TUT, Mintek, Rand Uranium and some mines that are still in operation. It was also found that most of these entities treating AMD release the treated water into Tweelopiespruit, a stream which passes through West Rand. It was also found that the AMD now decanting on surface also flows into this stream. Various pollutants found in AMD were also determined at selected sampling points in West Rand. It was found that sulphates were above limit standards whilst pH and iron complied with DWS limit standards in most days. The results from monitoring of water quality at various points along Tweelopiespruit were modelled using GIS and it was found that Tweelopiespruit stream is characterised by a decline in pH and high metal concentrations. Evaluation of policy and legal interventions by government showed that there are laws and policies in place, but they are not being implemented consistently.

Figure 4-1, below, illustrates water overflowing from the underground at old Winze 18 Shaft in West Rand. The water is yellowish and it is a clear indication of the presence of pyrite, as outlined in chapter one. The overflow from this Shaft proves that the interventions by the various players to pump and treat AMD from underground to minimise this environmental pollution are not being effective. This shows that the rate at which AMD is being pumped and treated from underground is not enough to reduce the AMD level to below critical point, as anticipated by the inter-ministerial task force and TCTA. Furthermore, this polluted overflow poses a serious threat to the species diversity and may kill animals exposed to it. The study by Coetzee (2016) showed the flooding of the underground workings of the West Rand Gold Field as illustrated in figure 4-2 below.

Figure 4-1: Water overflowing from the underground at old Winze 18 Shaft

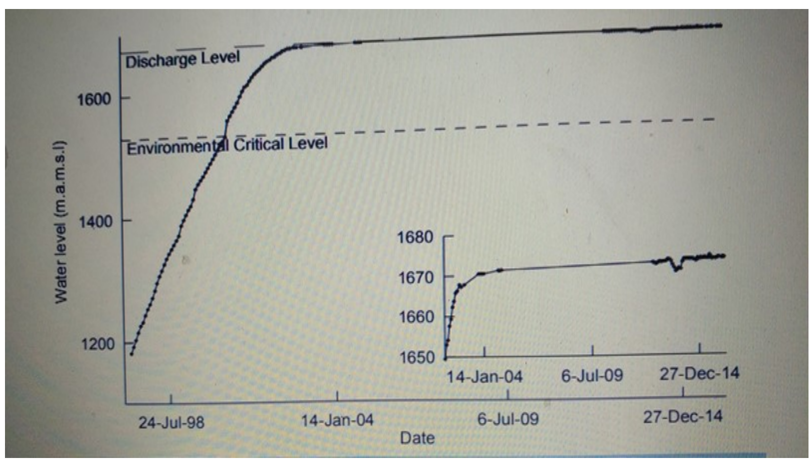

Figure 4-2: Environmental Critical Level of AMD in West Rand (Coetzee, 2016)

Samples collected from Winze 18 and Pit were analysed for iron (mg/L), pH, acidity (mg/L), sulphates (mg/L). Winze 18 is a point before treated wastewater is released into the stream. The point of discharge is located after the release of the treated wastewater. Treated wastewater from the TCTA, TUT and Rand Uranium facilities is pumped to the Pit to allow the sludge to settle and allow clear water to be released to Tweelopiespruit stream.

4.2 Determination of Iron (II)

Figure 4-3 below illustrates iron concentration at Winze 18 and Pit. Iron concentration observed in all sampled days was above 400 mg/L. However, the iron concentration decreased to the lowest results of 9.57 mg/L at the discharge point (Pit), from as high as 490 mg/L at Winze 18.

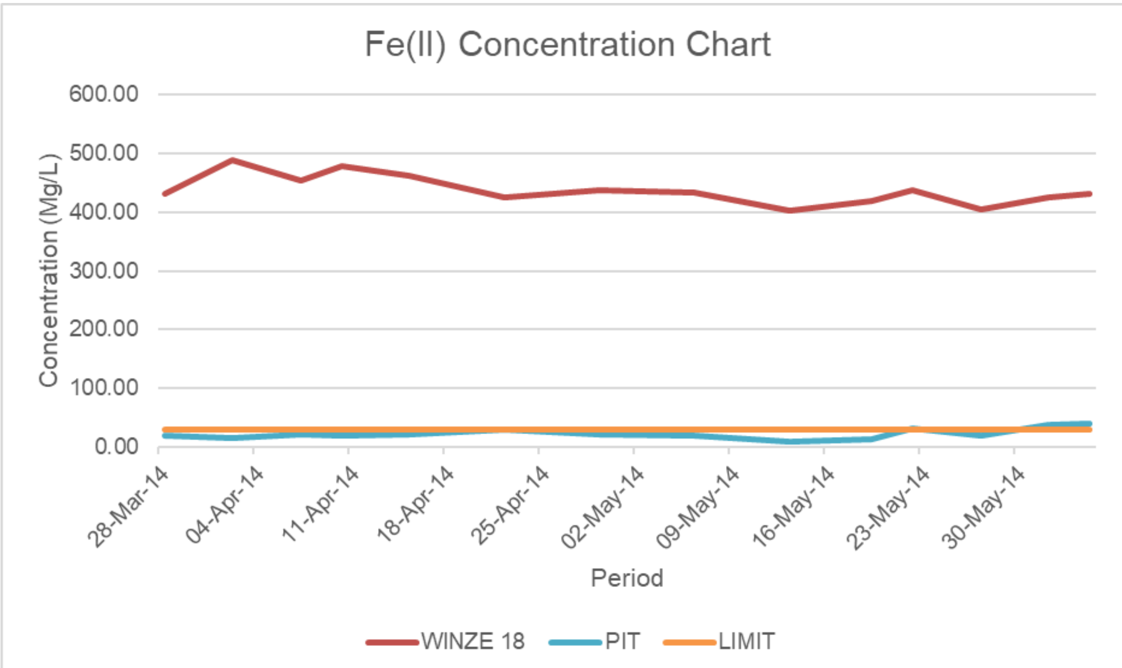

Figure 4-3: Fe (II) concentration at selected sampling points

These results show the efficacy of the neutralisation process used by the treatment facilities like Rand Uranium. The Fe (II) is reduced from a high concentration of 490 mg/L from Winze 18 to 9.57mg/L at the Pit, which is an over 95% removal of Fe (II) from the AMD. The AMD is pumped from underground with a very high Fe (II) content and neutralisation by limestone and lime raises the pH of the water causing the Fe (II) to precipitate as hydroxides and oxides which form the red sludge that is deposited in the Pit as the treated water is pumped to the river. The concentration of Fe (II) at the Pit is low because most of the Fe will have precipitated out of solution, as described above.

4.3 Determination of pH

The pH of the sampled points ranged from a low figure of 5.9 at Winze 18 Shaft to a high of 9.7 at the Pit. The variation of pH at the sampling points is shown in Figure 4.4 below:

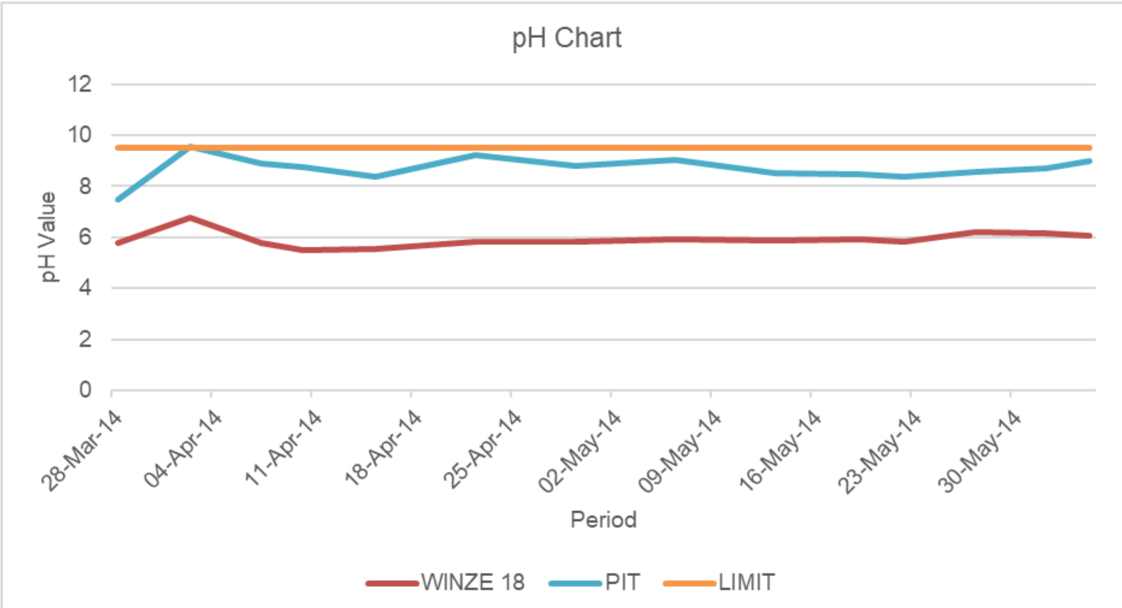

Figure 4-4: pH values at selected sampling points

Figure 4.4 above shows that water from Winze 18 shaft is acidic and the treatment process raises the pH to between 8 and 10 leading to the precipitation of metal hydroxides and oxides. The addition of limestone and lime results in the observed increase in pH. These results show that raising the pH is very critical in the treatment of AMD to make the metals precipitate out of solution.

4.4 Determination of Sulphate

High concentration sulphates ranging between 2700 mg/L and 2400 mg/L were observed at Winze 18. The concentration sulphates ranging between 2700 mg/L and 1500 mg/L were observed at discharge point respectively at the Pit. Figure 4-5 below show the variation of sulphates concentration with time.

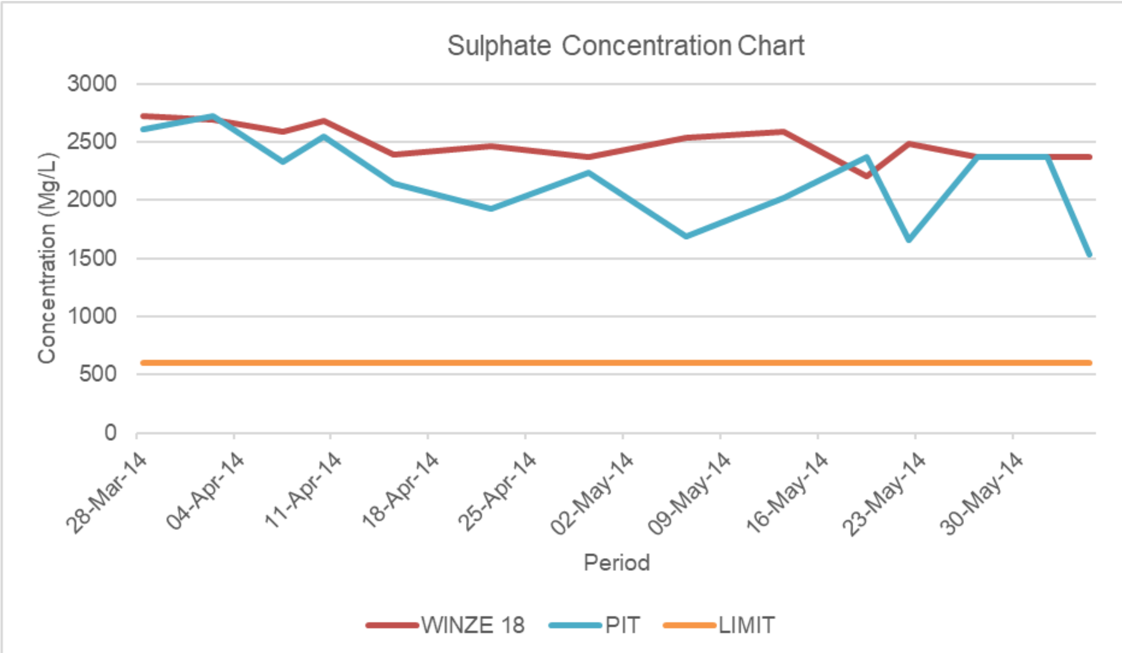

Figure 4-5: Sulphate concentration at sampled sites

The results show that the concentration of sulphates is higher than the accepted limit for both the treated and untreated wastewater. The levels for treated water are a bit lower than the untreated water. This shows that the neutralisation treatment option is not effective in removing sulphates from solution. Figure 4-5 shows that the removal of sulphates from AMD ranged from 0 mg/L to about 1500 mg/L. Some of the sulphates are removed from solution by the precipitation of metals from solution to form gypsum and related compounds.

4.5 Correlations between sampled parameters

4.5.1 Correlation between iron and pH

The correlation between solution pH and Fe (II) values was investigated as shown in Figure 4-6, below. Clearly, the Fe (II) concentration decreases with an increase in the solution pH.

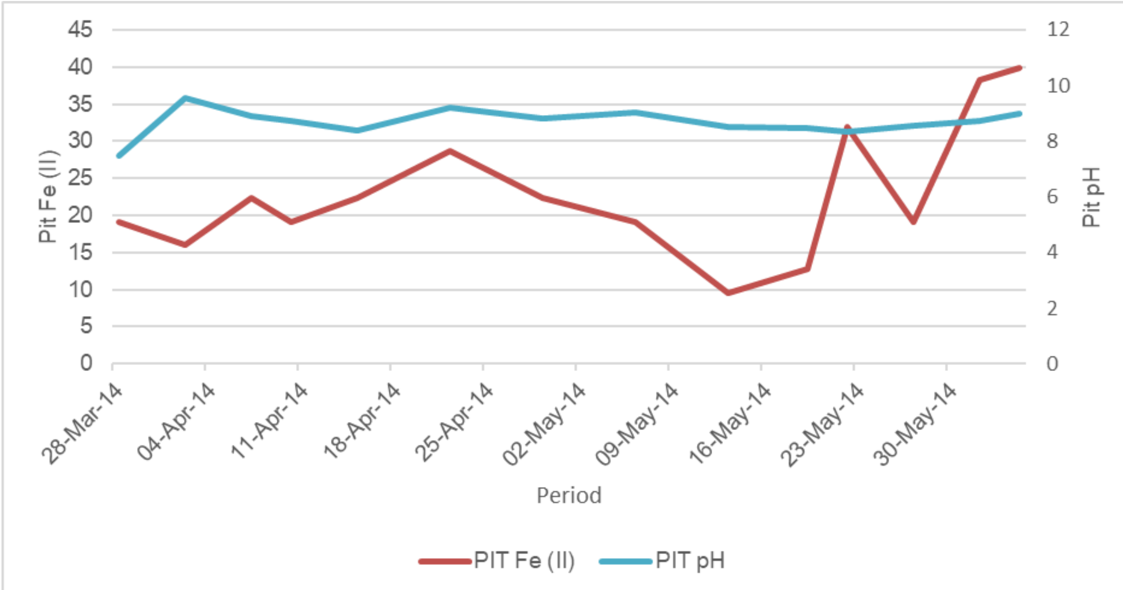

Figure 4-6: Correlation between iron and pH after treatment

Acidic solutions tend to keep iron in solution which presents corrosion challenges especially when solution pH is below 6.5. (Nagwa, 2016). The correlation illustrated above supports the use of neutralisation as a treatment option to precipitate Fe (II) out of solution as pH is increased.

4.5.2 Correlation between acidity and pH

Samples with high total acidity show strong pH buffering at pH range 3.5 to 4.5. Samples from Pit showed no amount of acidity resulting in a high pH volume of 9.5.

The volume of base required to accelerate the pH to 7.0 or higher depends on the strength (i.e. total acidity) of the AMD (Hatar et al., 2013). The use of chemical neutralisation treatment for the removal of heavy metals from AMD appears to be a common component of active water treatment technologies. This technology proved to be effective even though there is still a gap for more studies to explore full potentially innovative technologies.

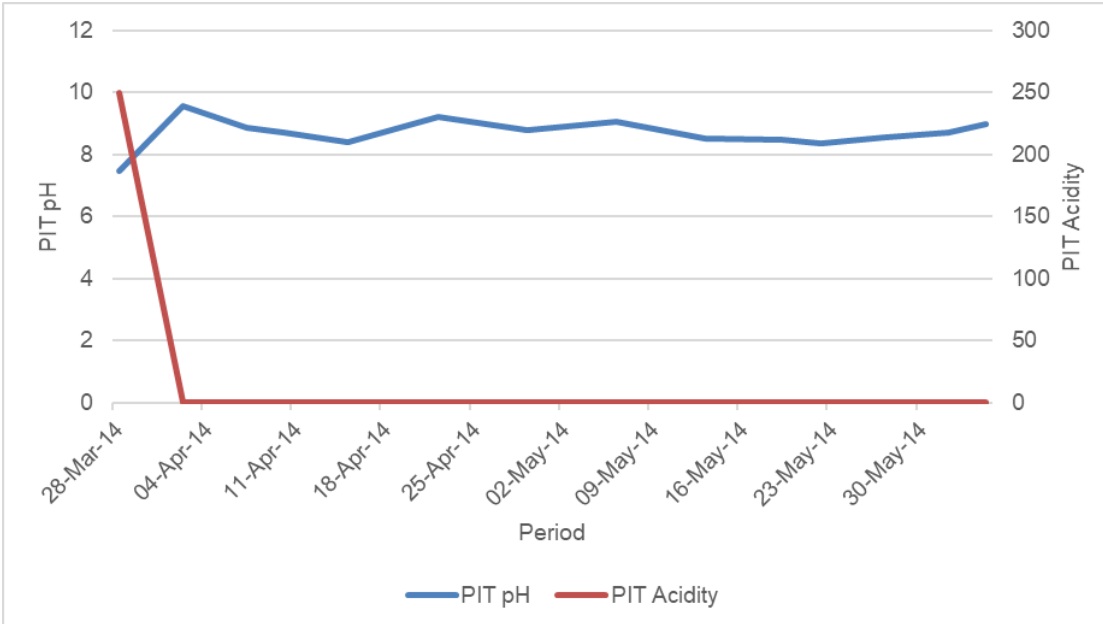

Figure 4-7: Relationship between the acidity and the pH at the discharge point

4.6 Section 2: Modelling water quality along Tweelopiespruit

The water quality data obtained during the course of this study was used in GIS modelling technology. The models produced by GIS modelling are shown in Figure 4-8. The Figure shows that pH increased from T1 to Q1 whilst the Fe(II) concentration decreased from T1 to Q1. The pH increased from 2, which is acidic to almost neutral at 6. These results show the effect of dilution as the pollutants are mixed with more water in the stream, as the stream flows to the South. As the pH increase, the Fe (II) is diluted and also possibly precipitate as it is oxidised to Fe (III) and hence the reduced concentration as we move from T1 to Q1. Modelling of the water quality helps us to know the quality of the stream water in between sampling points, and beyond the sampling points where sampling was not done. In this regard, the model shows improvement of water quality towards the DWS standards further away after the sampling points. This is probably because of further dilution of the stream water. However, a cautionary point is that this model holds true, provided there is no ingress of AMD into the stream downstream from unknown sources like other mines which may be dumping their wastewater into Tweelopiespruit.

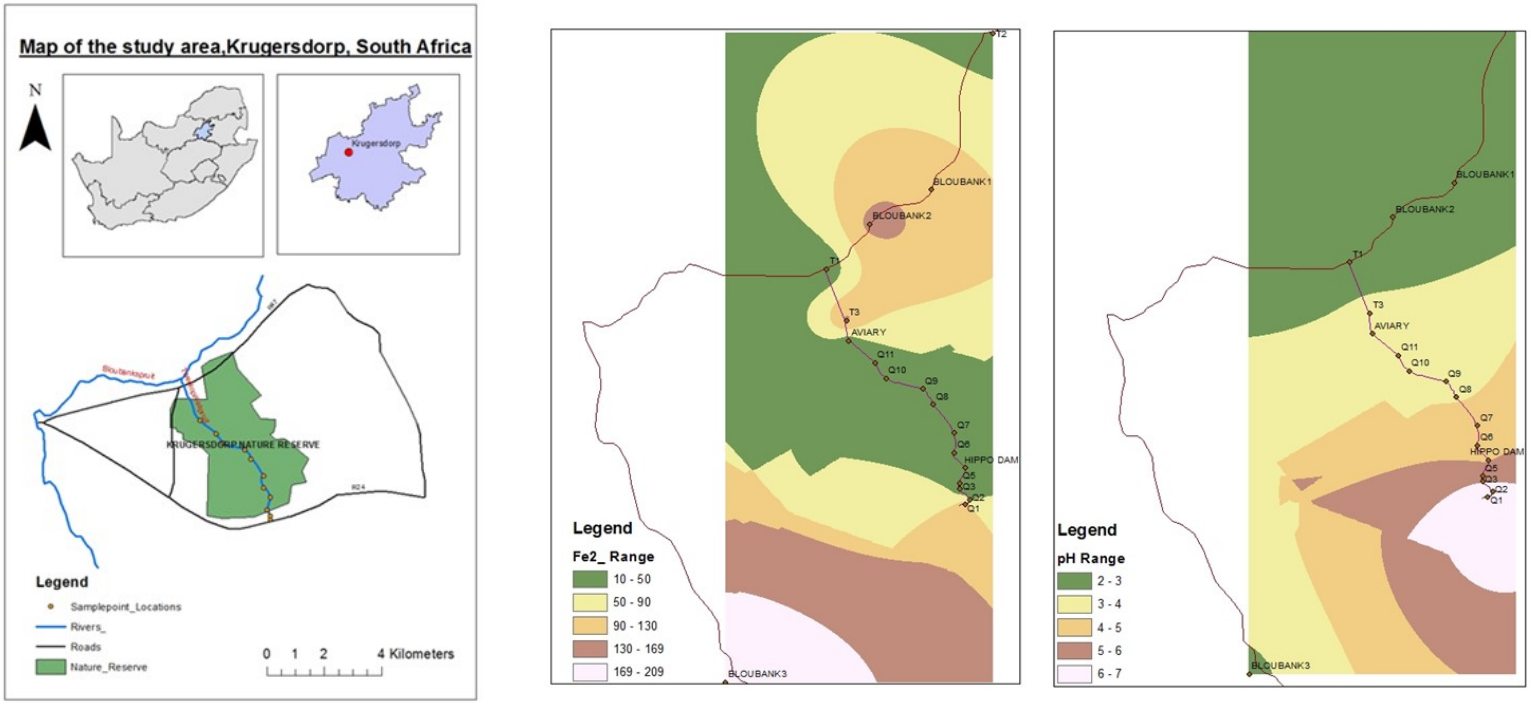

Figure 4-8: Predicted pH and Fe2 predicted levels along Tweelopiesspruit

5 EVALUATION OF IMPACTS OF POLICY AND LEGAL FRAMEWORKS ON AMD MANAGEMENT

5.1 Introduction

To comply with environmental legal requirements, so as to protect the environment from AMD impacts, DWS appointed TCTA, as discussed in Chapter 2, 3 and 4. Trans-Caledon Tunnel Authority (TCTA) implemented the recommendations of the inter-ministerial task team of experts (Bobbins, 2015). The task team recommended a number of measures to address the issue of AMD, including:

- Pumping out underground mine water to prevent it reaching the environmentally critical level;
- Controlling the ingress of water into mine shafts; and
- In the short term, treating acid water by neutralising the high acidity and high metal content, followed in the longer term by the desalination of the water before pumping it into the river systems.

As discussed in Chapter 4, neutralising the AMD with limestone and lime using HDS process by TCTA is pumping and treating 30 mega litres per day and as per DWS documents, the AMD underground is decanting at about 50 mega litres per day, and the pumping and treating by Rand Uranium treatment technology must be at such a rate that with time the AMD level underground will reduce below the critical level above which decanting continues. The South African Constitution, NEMA and NWA seek to protect the water resources from pollution. The results in Chapter 4 shows that the interventions by treatment technologies implemented by TCTA and other players in West Rand are not sufficient for compliance, specifically section 19(1) of NWA that says “a person in control of the land on which any activity or process is or was undertaken, or any other situation causing or likely to cause pollution on water resource, must take an action to prevent such pollution from occurring, continuing or recurring”.

The treated water being released into Tweelopiespruit is of quality that does not completely meet DWS limit standards for sulphates which is 600 mg/L and yet the treated water has 2700 mg/L.

These interventions by TCTA in West rand are not the only ones. To enforce the ‘polluter pays” principle as prescribed in section 28 of NEMA and section 19 (4) and (5) of NWA, the state has taken some players to court so that interventions by courts can set a precedent. Typical examples of such cases are now discussed below.

5.2 Impact of court interventions on the management of AMD

5.2.1 Harmony Gold Mining Company Ltd vs Regional Director

A petition was presented by the Regional Director of the Department of Water and Sanitation (DWS) to Harmony Gold, together with other mining companies operated in the Klerksdorp in the North-West Province (SALII, 2013). The Supreme Court endorsed the mandate which was issued by DWS in terms of Section 19(3) of the NWA to take appropriate control measures, which involve measures on landowners, to avoid and prevent damage from polluting water resources.

The Centre for Environmental Rights (2015) revealed very crucial information on Harmony Gold against the Regional Director vs Harmony Gold court case discussed below.

5.2.2 Importance of the case

The major obstruction was whether an instruction given to a landowner according to Section 19(3), to take adequate measures to remediate the contamination of water resource, remained valid once such landowner is no longer in charge of the land. The action which was taken in this case was that an instruction, given to a person while they were the landowner, remains authentic even after such landowner is no longer in charge.

5.2.3 Facts of the case

This case is associated to several instructions given according to Section 19(3) of the NWA in 2005, to a number of mines operative in the Klerksdorp, Orkney, Stilfontein and Hartebeesfontein (KOSH) Basin. The directive in disagreement had been given on 1 November 2005 and was to remain active until Harmony Gold and the other mining houses operative in the area (Anglo Gold Ashanti, Simmer & Jack, and Stilfontein) agree on dealing with the issue of long-term management of AMD in the KOSH Basin. However, the agreement was never implemented and there was no conclusion amongst these mines. Harmony Gold obtained all the shares in Arm Gold in the year 2003, and managed Arm Gold's mining thereafter. Arm Gold sold the mine and the land to Pamodzi Gold Orkney (PGO) in August 2007, and PGO became effective on February 2008. From that time onwards, Harmony Gold was no longer in control of the land on which the mine was based. Moreover, the land was transferred to Pamodzi by Arm Gold in January 2009; however, Pamodzi was placed in provisional liquidation. Harmony Gold wrote a letter to the DWS in May 2009, that it was no longer in charge of the land because Pamodzi took ownership of the land on February 2008. The DWS and other mines did not agree with Harmony Gold, and the matter could not be resolved. Harmony Gold engaged with the court for relief.

5.2.4 Legal issues and judgement

The major concern raised in this matter was whether an instruction given in terms of Section 19(3) of the NWA becomes invalid when a person stops being the landholder. The application was dismissed, and the court ordered that the instruction remained valid. Harmony Gold and all mining companies which were involved in this matter should have taken reasonable anti-pollution measures to minimise pollution during the mining operation. Moreover, these mining companies should have submitted conformity proposal towards minimising and managing water emanating from mining activities in the KOSH, as an instruction from court.

Section 19 of the NWA addresses this court intervention adequately. However, the judgement did not consider Section 19(4) and (5) in addressing the matter in depth. It has been stipulated in Section 19(4) and (5) that the Catchment Management Agency (CMA) has the duty to recover all costs if a person failed to comply with the directive given in sub-section (3) and this includes a person who is or was responsible for, or who directly or indirectly contributed to the pollution. In this case, sub-section (3) gives all the mining companies which were taken to court to take full responsibility to recover all costs

The court's intervention, in this case, used a selective view of mandate issued by DWA in terms of Section 19(3). A holistic approach when addressing this case in terms of Section 19 (4) and (5) would have been very adequate in resolving this matter.

5.3 Federation for Sustainable Environment versus Minister of DWS

The case was held in the High Court of South Africa, in 2012 (SALII, 2012). The main issue, in this case, was the polluted water supply to the town of Carolina and the township of Silobela. The case revealed that these two areas are supplied with water polluted by AMD, and the water is unfit for the community to use. Evidence revealed that the surrounding coal mining is the source of contamination (McCarthy, 2013). Water samples were examined for chemical analysis and revealed that the pollution originated from Witrandspruit sub-Catchment where seepage from the coal mines accumulated in a wetland upstream of the dam (McCarthy, 2013).

The study by Feris and Kotze (2014) indicated that the residents approached the court to give an immediate order to the national and local government to act in accordance for the provisions of the Water Services Act (WSA) to supply a regular quantity of safe drinking water. The applicants had complained about the poor water quality that they were being provided with. This poor water quality was being treated by the Carolina Treatment Works. They have reported that in some instances the water tanks were empty and not refilled at some point (SALII, 2012). Proper control measures for the provision of acceptable water to the residents was demanded by the applicants. The applicants further requested for mitigation and management of toxic water by the mining management in the area (SALII, 2012).

The local municipality strived to supply water, and water tanks were brought from neighbouring towns. However, the study revealed that this action was considered incompetent by the court as the tanks were not refilled and most of the residents walked long distances to access water from the tanks. The court ordered the district municipality to provide access to water within three (3) days and to engage with the residents on how water will be availed to them (SALII, 2012).

5.3.1 Legal issues and judgement

Section 19(4) and (5) of NWA is relevant in addressing this matter. Clearly, the surrounding coal mines are polluters in this case and should take reasonable measures in controlling the pollution. However, the judgement did not charge coal mines to take responsibility for dealing with AMD in Carolina and Silobela. Instead, judgement was given to the district municipality to provide access to water to the communities. This matter has indicated the inadequacy of South African laws in addressing who to take the blame in this case. This is another instance of selective view in legal approach as evidenced in the case of Harmony Gold vs the Regional Director.

5.4 Minister of Water Affairs and Forestry versus Stilfontein Gold mining company (Ltd) and others

This case is an outstanding example of the kind of judicial approach that is needed if South Africa is to develop a robust mining and environment jurisprudence, which will help in the mitigation of the effects of AMD on the environment.

5.4.1 Importance of the case

This case is one of the good examples of judicial approach for environmental protection. An order holding the Stilfontein Gold Mining (SGM) Company (Ltd), together with four directors was granted by Hussain J. This order was granted for non-compliance for pumping of underground water. The Centre for Environmental Rights (2018) mentioned that there was a previous order that compelled SGM and the directors to comply with directives issued by the directors of DWS in the Free State Province. Numerous arguments which were brought up by the respondents (SGM and the directors) were dispensed by the court, holding that the directives were intelligible. The court order given had to set an appeal in Kebble versus the Minister of DWS 2007.

5.4.2 Facts of the case

Stilfontein Gold Mining is one of the few remaining companies in the KOSH basin and it's in control of Margaret Shaft. The quantity of wastewater from this Shaft needed to be pumped daily to prevent groundwater pollution and the flooding of other Shafts. This pumping was to also avoid the loss of properties and life of mines positioned at a lower gradient. The Centre for Environmental Rights (2018) mentioned that at some point SGM was no longer active and as a result, had to stop pumping water. Consequently, the surrounding mines could not reach an agreement of the pumping costs and allocations amongst each other. Further to this matter, two directives were issued by the regional director of DWS in terms of section 19 (3) of the NWA. Mines were compelled to reach the solution by these directives; however, SGM could not comply with them, and as a result an order was given to this mining company by DWS. One of the respondents from mining companies in the KOSH basin raised numerous arguments and amongst others was that the nature of court order was not appropriate.

5.4.3. Legal issues and judgment

Some important issues raised in this case was that the respondents argued that the proceedings were not appropriate and also that SGM had financial challenges to comply with the directives, and above all, the respondents decided to abandon the application without any documentation and even failed to reappear in court.

In the judgment point of view, it is clear that the object and the responsibility of the directives are to prevent pollution to water resources. Allowing the mining companies and the directors not to adhere to the environmental obligations is against the constitutional law, MPDA, NEMA and NWA. It further allows these companies to simply walk away from their environmental obligations.

5.5 AMD Mitigation from South African jurisprudence

In the case of the Minister of Water Affairs and Forestry v Stilfontein Gold Mining Co. Ltd & Others the court relied extensively on King II. In this case, the Minister of Water Affairs and Forestry obtained a provisional court order with regard to environmental requirements against Stilfontein Gold Mining Co. Ltd and the directors of Stilfontein Gold Mining Co. Ltd who were the respondents had to adhere to. The court inter alia held that a director of a company who, with knowledge of an order of court against the company, causes the company to disobey the order is himself guilty of contempt of court. The court further held that the Code of Conduct of King II was almost uniformly endorsed by the corporate community in South Africa and that the conduct of Stilfontein Gold Mining Company flew in the face of everything recommended in the code of corporate practices and conduct recommended by the King Committee. Such a ruling sets a precedence that current directors of mining companies which result in AMD must ensure that the environment is protected from the deleterious effects of AMD.

The Supreme Court of Appeal had ruled that mining company is accountable indefinitely for rehabilitating land on which it previously mined, even if it has since sold the mining operations. The court relied heavily on the NWA to arrive at its decision that Harmony Gold remained liable for the remediation of the environment by obeying the directives of the state to continue to pump and treat AMD until the problem is solved. The ruling should be an incentive for the state to step up enforcement action, by issuing directives against polluters, particularly where disposal or liquidation is on the cards as in this case. The ruling provided clarity that it is important in circumstances where mining companies sell their operations when they become less profitable and before their environmental damage has been rehabilitated. This decision combined with the dismissal by the Constitutional Court of the appeal by Harmony Gold is a good way forward in the mitigation for negative environmental impacts of AMD in the future.

The decision made by the Constitutional Court recently has significant implications for mining companies. In the court case of Harmony Gold Mining Company Ltd vs Regional Director mentioned above, the Constitutional Court dismissed the application for leave to appeal against Supreme Court of Appeal (SCA) by Harmony Gold. The dismissal means that directives which were given by the SCA that Harmony Gold remained liable for remediation costs which included pumping and treating the underground water even if they are no longer mining there (Hofmeyr, 2014). The decision by the apex court of South Africa upholds everyone’s constitutionally guaranteed right to a healthy environment as regulated in the laws of South Africa such as MPDA, NEMA and NWA.

6 CONCLUSION AND RECOMMENDATION

6.1 Introduction

This chapter concludes the study and provides recommendation for future research, organisations interested in tackling AMD-related studies or mitigation processes, the state and the public at large.

6.2 Conclusion

AMD is an environmental problem whose harmful effects on the environment are well understood in South Africa. In response, the South African government and other stakeholders came up with various interventions, from policy frameworks to treatment technologies, to help manage and arrest this problem. It is against this background that this research study was undertaken to evaluate the mitigation and management strategies of mine wastewater in the West Rand area, Gauteng Province, South Africa. According to this study's findings, inadequate actions in the process of ensuring the mitigation techniques towards the management of AMD, and holding stakeholders concerned responsible, is still a concern in South Africa.

By determining the water quality at Winze 18 and Pit sampling points, this study assessed the efficiency of lime and limestone treatment technology used by Rand Uranium and research pilot plant by TUT and Mintek. The findings showed that Fe (II) was reduced from a high concentration of 490 mg/L by over 95% removal of Fe (II) from the AMD. Water from Winze 18 was found acidic due to treatment process raising the pH between 8 and 10 leading to the precipitation of metal hydroxides and oxides. Sulphate concentrations at the discharge point were as high as 2700 mg/L against the DWS sulphate effluent limit of 600 mg/L.

Of concern was the build-up of huge volumes of sludge that was generated in the treatment operation. Therefore, disposing sludge and safely removing sulphates from wastewater to regulatory standards before disposal is mandatory to guarantee environmental sustainability. The AMD treatment technologies in the West Rand area are moderately effective in treating AMD.

This study utilised a GIS modelling technique to identify the potential sources of AMD along Tweelopiespruit. The model showed improvement of water quality towards the DWS standards further away after the sampling points. This was probably because of further dilution of the stream water.

From a legal framework point of view, this study revealed some omissions that need to be addressed in order to provide a comprehensive solution to the problem of AMD in South Africa. There is a non-formalised approach to water quality management due to lack of alignment between various players and regulatory mandates. Regulators have a wide range of enforcement tools; however, using them efficiently is a matter that needs to be given serious attention.

6.3 Recommendation for future research

Based on the results and findings of this study, one could make the following recommendations for future consideration:

- AMD seeping from underground shafts should be prevented from polluting environment before even being treated;
- There is still a need to continue investigations into alternative ways on AMD remediation, particularly options that are effective in remediating high concentration of sulphates; and
- There should be regulations and strategies specifically addressing AMD, and these legal frameworks should formalise the DWS's position with respect to AMD management, and should include principles and statements.

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APPENDIX 01: UNIVERSITY OF SOUTH AFRICA ETHICS CLEARANCE.

UNISA university of south africa

CAES RESEARCH ETHICS REVIEW COMMITTEE

Date: 10/02/2015

Ref #: **2014/CAES/194**
Name of applicant: **Ms MD Moshobane**
Student #: **46563083**

Dear Ms Moshobane,

Decision: Ethics Approval

Proposal: Effectiveness of management strategies of mine waste water in West Rand area, Gauteng Province of South Africa

Supervisor: Dr M Mujuru

Qualification: Postgraduate degree/Non-degree output/Commissioned research

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Final approval is granted for the duration of the project.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 10 February 2015.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*
3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*

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Note:
The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

Approval template 2014

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APPENDIX 02: UNIVERSITY OF SOUTH AFRICA TURN-IT-IN REPORT.

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FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

DEPARTMENT OF ENVIRONMENTAL SCIENCE

Master of Science, Environmental Management

EVALUATION OF THE MANAGEMENT STRATEGIES OF MINE WASTEWATER IN WEST RAND AREA, GAUTENG PROVINCE IN SOUTH AFRICA

By

MASHILO DORIS MOSHOBANE

(46563083)

SUPERVISOR: DR M. MUJURU

CO SUPERVISOR: DR. M. MASUKUME

AUGUST 2019