Resource Efficient and Socially Responsible Approaches for the Integrated Management of Mine Waste: Understanding the Risks, Opportunities, Enablers and Barriers

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

Background

Although contributing significantly to the economies of mineral-rich countries such as South Africa and Zambia, the resource extraction industry is also responsible for a disproportionately large impact on the surrounding environment, with concomitant impacts on the health and well-being of local communities. A significant part of the environmental impact, particular over the long-term, is related to the large volumes of mine waste that the industry produces, which are typically disposed of in dumps or impoundments. These deposits can give rise to metal-rich emissions, such as airborne particulate matter and contaminated leachate, which impact on natural eco-systems, cultivated crops and mammalian health. Whist mine waste disposal and rehabilitation methods have evolved significantly over the past two to three decades, such techniques do not permanently eliminate these risks and liabilities. Even when effective in the short-term, remediation may be insufficient to deal with long-term degradation in many cases, while a loss of societal memory can mean that the sites may be excavated in the future, re-exposing the waste body to the elements.

An alternative management approach, and one that is more consistent with the goals of sustainable development, focuses on the generation of mine wastes that can be re-purposed for other uses. This so-called valorisation approach goes beyond the recovery of targeted value recovery, both removing intra- and inter-generational waste burden and simultaneously optimising efficient utilisation of mined resources. This study set out to support the development and implementation of such an approach for the management of large volume mine waste in the Southern African context, by developing an enhanced understanding of the key drivers, barriers and opportunities involved.

Aims

The specific aims of the project were to:

1. Develop a more detailed understanding of the inter-relationship between mining, environmental degradation and community impacts, in terms of health and livelihoods, with specific emphasis on mine wastes.
2. Identify key opportunities, drivers, enablers and barriers for the valorisation of mine waste in the South African context.
3. Establish potential roles of the relevant stakeholders (government, mining industry, SMEs) in enabling the implementation of mine waste valorisation opportunities.
4. Enhance current tools for assessing the potential metal and salt-related risks posed by coal wastes, and build an inventory database for such wastes in the local context

Methodology

The project combined critical analysis of the published literature, rigorous scientific analysis of wastes, and comprehensive stakeholder engagement in the form of consultations and semi-structured interviews with representatives from industry, communities, non-government organisations and government. This was done with a view to facilitating the development of approaches to the management of solid mine wastes that are supported by reliable data, whilst also taking into account the perceptions, concerns, goals, experience and expertise of interested and affected parties.

The scope of work comprised three main inter-related programmes, each of which were designed to address the specific project aims:

- **Programme 1**: Investigation of the relationship between mine waste, environmental degradation and community quality of life (Aim 1): This programme explored the facts, perceptions, concerns and conflicts in the context of the mine-environment-community cause-effect chain through three separate case studies, each of which is associated with significant environmental degradation and community conflicts and tensions. One case study focused on the impacts and conflicts associated with the coal mining sector in the Mpumalanga Province in South Africa; another case study on the defunct gold tailings dumps in the Witwatersrand Basin in South Africa; and a third on the copper mining sector in the Copperbelt region of Zambia. Each of these case studies entailed a detailed review of the published literature, as well as semi-structured interviews with relevant stakeholders.
- **Programme 2**: Analysis of opportunities and influencing factors for mine waste valorisation in the South African context (Aims 2 and 3): This programme entailed the identification of opportunities, barriers, enablers and drivers for the valorisation of mine wastes, with specific focus on gold tailings and coal processing waste (Aim 2), as well as the potential roles that stakeholders (government, mining industry, SMEs, community-based entrepreneurs, etc.) can play in enabling implementation of effective mine waste management approaches (Aim 3). As in the case of programme 2, this programme entailed the generation of both primary data, through semi-structured interviews with relevant experts, and secondary data, through a detailed review of the published literature.
- **Programme 3**: Characterisation of the properties and water-related environmental risks of South African coal processing wastes (Aim 4): This programme evaluated the applicability, reliability and shortcomings of current methods for the characterisation of coal waste and developed a more comprehensive understanding of the key environmental characteristics of specific coal processing wastes from different sources. These wastes included a discard sample from an ultra-fine slurry waste from the Waterberg coalfields and both an ultra-fine slurry waste and discard waste from a colliery in the Witbank coalfields. This programme was largely laboratory-based.

Results and Discussion

Programme 1: Investigation of the relationship between mine waste, environmental degradation and community quality of life

All three case studies emphasised the adverse effects of mining activities on the surrounding environment and the associated impacts on the quality of lives and livelihoods of surrounding communities. Environmental impacts reported to be of particular concern by local communities, community-support organisations and environmental experts include water pollution, physical and chemical land degradation, and air pollution through emissions of particulate matter (PM) and toxic gases. This environmental pollution was reported to have a significant effect on local eco-systems, as well as on community health and livelihoods, particularly through crop and livestock farming. In each case, mine waste deposits were considered a significant source of these environmental and associated social impacts, particularly in terms of metal-rich acid rock drainage and wind-blown dust emissions. Of particular relevance to defunct coal waste dumps, are the additional human health issues associated with the release of gaseous emissions as a result of combustion of coal wastes, whether spontaneously or as a result of domestic consumption. The gold tailings case study in the Witwatersrand basin, in particular, illustrated how defunct mine waste dumps can continue to impact on the local environment and surrounding communities for decades after mining operations in an area have ceased, and how difficult it is to keep such dumps isolated from human settlement developments over the long-term.

Despite evidence that the environmental impacts of mining are being responded to by the Government and by mining companies, local environments remain polluted and mining communities continue to suffer, resulting in a highly politicised scenario and on-going (and possibly escalating) conflicts between stakeholders. In general, all three case studies indicated that communities and community-support organisations feel that are not been taken seriously, and that government and industry are failing to alleviate the environmental degradation and human suffering in mining-intensive regions. Of particular concern is the lack of adequate and effective enforcement of regulations, which communities and community-support organisations attributed largely to unethical arrangements between government and mining houses. In terms of the expectations and aspirations of communities regarding actions and responses going forward, the coal and copper case studies both stressed the need for effective mine rehabilitation; more effective and consistent implementation and enforcement of regulations designed to protect the environment and society; as well as improved stakeholder engagement and communication.

Programme 2: Analysis of opportunities and influencing factors for mine waste valorisation in the South African context

This study indicated that there are a number of opportunities for the re-use or re-purposing of large-volume mine waste, such as gold tailings and coal processing slurries and discards. A review of the information procured through the published literature and stakeholder interviews has indicated that mine tailings have found fairly wide application as backfill for mines, and to a lesser extent, in construction or for landscaping. Other potential applications include the fabrication or amelioration of soils, and the manufacture of niche by-products such as pigments, coagulants for wastewater, sulphuric acid, ceramics and stone paper. Despite these opportunities, commercial application of options for the re-purposing of large-volume mine wastes remains relatively constrained, and many of the identified opportunities have not been developed beyond the laboratory scale.

Key factors identified as influencing the development and transfer of mine waste valorisation approaches include the availability of proven technology; the legislative and regulatory climate; health, safety and environmental issues; corporate culture and values; and economic feasibility. Techno-economic viability was considered a key determinant by most participants, with innovative mine waste valorisation approaches needing to be more profitable than conventional waste management approaches in order to be fully recognised. The relatively high risks and costs of implementing innovative and unproven technologies pertain not only to financial matters, but also to health, safety, environmental and regulatory compliance issues.

The study also highlighted the fact that effective communication and collaborative partnerships between all potential stakeholders in the technology innovation chain, particularly the developers, sponsors and adopters, will be required in order to overcome these constraints. Good working relationships, communication and trust between these stakeholders are imperative, as is the need to demonstrate efficacy. Whilst academia, government departments and research organisations, as well as the mining industry are key role players, this study also revealed original equipment manufacturers (OEMs) or technology providers to be an important group of stakeholders, who could be potentially be ideally placed to serve as commercial partners for developers, such as a university.

Programme 3: Characterisation of the properties and potential water-related environmental risks of South African coal processing wastes

The results of this study show that application of a combination of laboratory-scale tests and analytical methods needs to be applied to mine wastes, such as coal processing wastes, in order to develop a comprehensive understanding of the key properties of environmental significance and overcome the uncertainties of individual methods. Whilst chemical static acid base accounting (ABA) and net acid generation (NAG) tests are simple and fast tools for characterising the acid rock drainage (ARD) potential of mine wastes, the application of these tests to classify the acid generation potential of coal processing wastes may be uncertain. As sulphur in coal is present in different forms, only some of which are acid-forming, sulphur speciation is of critical importance in the classification of acid generating potential using static chemical tests. Whilst total sulphur in coal wastes can be reliably evaluated using the standard LECO combustion method, the standard ISO157:1996 method for determining the various sulphur forms (sulphate, sulphide and organic sulphur) makes a number of simplifying assumptions which affect the accuracy of the results. The ACARP C15304 method was developed to overcome some of the limitations of the ISO 157:1996 method, and also distinguishes between acid-forming and non-acid forming sulphates. This study showed that both biokinetic tests and mineralogical analysis can be used to compliment and validate chemical static tests, the biokinetic test providing a rapid method for assessing the time-related behaviour of coal wastes under conditions of microbial activity. However, these techniques require further development to maximise their potential, particularly in the case of coal wastes. Finally, this study demonstrated the application of sequential chemical extraction tests in combination with a relatively simple ranking and scoring method to identify elements of potential environmental significance under various weathering conditions.

With respect to the characteristics of coal processing wastes, the results of this study showed that South African coal processing wastes contain significant quantities of sulphur in the form of sulphide sulphur (0.55% to 1.13%) and are enriched in a number of trace elements, including Mo, In, Pb, Sn, Sb, Ge, Cs, Ce, U, Th and, in particular Bi and Se. Static chemical and biokinetic tests for characterising acid rock drainage potential indicated that the Waterberg slurry waste sample was potentially non-acid forming, the Witbank discard sample potentially acid forming, and the Witbank slurry waste sample uncertain in terms of ARD classification. These differences in the acid generating behaviour of coal processing wastes from different sources emphasises the importance of characterising samples on a case-by-case basis. Elements identified as being of potential environmental significance under acid generating conditions include iron, sulphur, lead, antimony, and in certain cases arsenic, manganese and mercury.

Conclusions

The combination of quantitative and qualitative methods used in this study, including literature reviews, stakeholder interviews and laboratory-scale testwork, bears testimony to the potential adverse impacts of mine waste deposits on the surrounding environment, and the potential risks that environmental pollution pose to the quality of lives and livelihoods of local communities. Of particular concern is the potential exposure of humans and livestock to metals released from mine wastes through the generation of contaminated seepage and run-off, as well as wind-blown dusts. The case studies, particularly the gold tailings study in the Witwatersrand basin, also confirmed that the impacts associated with mine dumps are protracted, extending across decades and generations. Maintaining reasonable buffer zones between human settlements and defunct mine waste dumps is, furthermore, unlikely to be feasible over the long-term.

This study has identified a number of valorisation options for gold tailings and coal processing wastes, confirming the potential viability of re-purposing such wastes as a potentially viable alternative approach to land disposal. Although more consistent with sustainable development goals, the systemic development and commercial implementation of these opportunities is currently constrained by a number of factors, both of a technological and non-technological nature. Of particular significance are the financial costs, as well as the potential non-financial liabilities, associated with the development and transfer of new or unproven technologies. Currently, the lack of adequate information and data on the compositions and properties of mine wastes creates uncertainties around the ability to produce products of the required quality, and the environmental and health risks associated with their processing and use. In this regard, the experimental testwork programme conducted in this study showed that a combination of laboratory-scale tests and analytical methods is required to effectively and reliably characterise the environmentally significant properties of mine wastes, such as coal processing slurries and discards. The testwork programme also highlighted some of the uncertainties and deficiencies with respect to current characterisation tools and showed how the characteristics of coal processing wastes from different sources may vary, highlighting the need to assess wastes on a case-by-case basis.

The different perspectives gained in this study have shown that good working relationships, communication and trust between the various stakeholders are imperative in the development and implementation of more environmentally and socially responsible management approaches for mine waste. Of equal importance in the transfer of innovative approaches, such as valorisation, is the need to engage with original equipment manufacturers or technology providers, and to demonstrate the efficacy of the technology. Mine waste valorisation could also be conducted by, or in collaboration with, local communities, thus providing opportunity to simultaneously promote local socio-economic development. This, together with the removal of long-term risk of environmental and social impacts associated with mine waste dumps, could serve to improve the currently fractious relationships between the mining industry and mine communities. Consultations with community representatives and community-support organisations has indicated, however, that this is likely to be dependent on the establishment of effective stakeholder engagement and inclusive partnerships.

Recommendations

On the basis of the outcomes of this study, further studies and initiatives are recommended with respect to the development and implementation of mine waste valorisation opportunities, with a view to:

1. Developing and optimising potentially viable mine waste valorisation opportunities for specific waste types on both a laboratory and pilot-scale. Such studies should be aimed at demonstrating efficacy, and obtaining operating parameters, for those options as potentially viable.
2. Conducting a more detailed study and comparison of the techno-economic performance of different waste management approaches. Such a study should include the development of a more detailed understanding of the indirect and less tangible costs relating to long-term environmental degradation and related socio-economic impacts, and the “true” value of mine wastes.
3. Extending current mine waste characterisation capabilities, so as to improve the reliability of techniques to assess both their ability to generate products of adequate quality, and the environmental and health risks associated with their processing and utilisation.
4. Exploring mechanisms for the establishment of effective partnerships between the various stakeholders from the early prospecting and development stages. It is further proposed that this would best be achieved through the establishment of a multi-stakeholder body, with representatives from all stakeholder groups including mining houses, government, research organisations, OEMs, business and community representatives.

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ACRONYMS & ABBREVIATIONS

ABA	Acid base accounting
ACARP	Australian Coal Association Research Program
AMD	Acid mine drainage
ANC	Acid neutralising capacity
ARD	Acid rock drainage
CER	Centre for Environmental Rights
CRS	Chromium reducible sulphur
ERP	Environmental risk potential
ICMM	International Council on Mining and Metals
IHRC	International Human Rights Clinic
ISO	International Standards Organisation
KCM	Konkola Copper Mines
LA-ICP-MS	Laser ablation-inductively coupled plasma-mass spectrometry
MPA	Maximum potential acidity
NAF	Non-acid forming
NAG	Net acid generation
NAPP	Net acid producing potential
PAF	Potentially acid forming
OEM	Original equipment manufacturers
OPC	Ordinary Portland cement
QEMSCAN	Quantitative evaluation of minerals by scanning electron microscopy
QXRD	Quantitative x-ray diffraction
ROM	Run-of-mine
SCE	Sequential chemical extraction
TSF	Tailings storage facility
UC	Unclassified (with respect to acid forming potential)
SACRM	South African Coal Road Map
WRC	Water Research Commission of South Africa
XRF	X-ray fluorescence spectrometry
ZCCM	Zambian Consolidated Copper Mines
ZEITA	Zambia Extractive Industries Transparency Initiative
ZEMA	Zambia Environmental Management Agency

GLOSSARY OF TERMS

Acid rock drainage	Acidic discharge generated from the weathering of sulphide-bearing rocks, mainly pyrite, in rocks. Also commonly termed “acid mine drainage”, when it is associated with mining activities.
Beneficiation	The act of processing a raw material so as to remove unwanted material (waste) and recover targeted components, considered to be of economic value. In the context of this study this is synonymous with “value recovery”
Fabricated soil	A man-made product containing an appropriate amount of organic carbon, macro and micro nutrients, porosity and texture capable of supporting adequate plant growth. Synonyms include “artificial soil”, “manufactured soil”, “anthroposol” or “minesoils” (when specifically related to the mining activities).
Metalloids	The elements found along the step like line between metals and non-metals of the periodic table, including boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb), tellurium (Te), polonium (Po) and astatine (At) are. Also frequently referred to as “semi-metals.(https://www.gordonengland.co.uk/elements/metaloids.htm)
Mine backfill	Soil, overburden, **mine** tailings or imported aggregate material used to replace excavated zones created by **mining** operations. Backfill material can be cemented or non-cemented **mine** waste rock or aggregate material placed underground by means of trucks, conveyors or raises. (http://minewiki.engineering.queensu.ca/mediawiki/index.php/Backfill)
Mine waste	The large-volume materials that result from the exploration, mining and primary beneficiation of minerals (see Table 2.2, page 8).
Particulate matter	Solid and liquid particles suspended in air, including dust, pollen, soot, smoke, and liquid droplets. (https://www.greenfacts.org/en/particulate-matter-pm/level-2/01-presentation.htm).
Resource efficiency	Entails using the earth’s limited resources in a sustainable manner while minimising the impacts on the environment.
Soil amelioration	A physical process in which soil is improved for agricultural use. This could entail ploughing, draining or using additives such as fertiliser to improve the quality and hence productivity of the soil.
Stakeholder	An interested and affected party. In the context of this study stakeholders refer to those interested in, or affected by, mining operations including mining companies (internal stakeholder), government bodies, local communities and businesses, as well as parties supporting mining these entities (consultants, academia, non-profit organisations).
Technology transfer	The process of **transferring** *or* disseminating **technology** to licensees (third parties such as entrepreneurs, new start-up companies, existing industry) who can realise value from these by making them available to the market as products and services for commercial gain or social impact.
Trace elements	A chemical element present only in minute amounts in a particular sample or environment. In the context of this study low means < 100 ppm. These elements are distinguished from those present in minor (100-1000 ppm) or major (> 1000 ppm) quantities
Valorisation	Any activity which entails the conversion of waste into useful products. In the context of this study this term would be synonymous with “resource recovery.
Value recovery	Processing of a raw material to recover economically valuable components. e. In the context of this study, this term would be synonymous with “beneficiation”
Waste characterisation	Determination of the compositional and behavioural properties of a particular waste material in terms of its potential environmental and/or health impacts, and consequently its suitability for further processing, treatment, storage or disposal.

CHAPTER 1: BACKGROUND

1.1 Introduction

The mining and minerals beneficiation industry contributes significantly to the world economy as it supplies materials that are used in manufacturing of consumer goods. The discovery of world-class gold deposits in the late 19th century led to the transformation of South Africa's economy from an agricultural to a modern industrial economy (Malherbe, 2000). Since then, the mining industry has contributed considerably to the country's economic growth and remains the cornerstone of the South African economy (Malherbe, 2000). South Africa has an abundance of mineral resources and produces a significant proportion of the world's minerals. It is estimated that South Africa has more than half of the world's reserves of gold (41%), manganese (80%), chromium (73%), platinum group (90%) and vanadium (45%) (Malherbe, 2000; Tucker, 2013). South Africa also extracts a substantial variety of other minerals such as iron ore, diamonds, coal, copper, nickel and other non-metallic metals. Although the mining sector's contribution has declined over the years (from 21% contribution to GDP in 1970), it continues to contribute significantly to the South African economy, most markedly in terms of job creation, economic activity and foreign exchange earnings (Antin, 2013; Chamber of Mines, 2014). Despite the industry's contribution to the economy, the industry has been plagued by labour disputes and is widely criticized for its negative impacts on the environment, both on a local and global scale (Antin, 2013).

Of particular concern is the fact that the extraction and beneficiation of mineral resources results in the production of large amounts of solid waste which pose a significant and often irreversible risk to the surrounding environment, and frequently also represent a long-term economic burden and loss of valuable resources (Franks et al., 2011; Godfrey et al., 2007). It is becoming increasingly recognised that conventional waste disposal techniques are inadequate in addressing the potential long-term risks associated with biodiversity losses, degradation and consumption of natural resources such as land and water, as well as health and socio-economic impacts on local communities. Changes in legislation and global thinking have prompted a growing trend towards the development of waste management approaches that remove these risks in perpetuity, whilst simultaneously providing opportunities for value recovery and re-allocation of unavoidable wastes as feedstock for other uses. Such approaches, commonly termed waste valorisation approaches, are aimed at improving environmental and socio-economic outcomes through the integrated application of re-use, recycling and re-processing options (either before or after separation), consistent with the principles of resource efficiency, cleaner production and corporate social responsibility. An example of one such process, currently under development at the University of Cape Town, entails the two-stage flotation process for the simultaneous recovery of coal and removal of sulphide sulphur from fine coal wastes, and the subsequent utilization or downstream processing of separated waste fractions as covers for overburden, construction materials, and soil amelioration amongst others.

To date, however, practical implementation of approaches and technologies for removing risk and reducing burden associated with large volume mine wastes, particularly in South Africa, remains limited, and value recovery has been largely limited to the extraction of precious high metals such as Au and PGMs. The current emphasis on land disposal and end-of-pipe rehabilitation of mine waste by the mining industry has done little to improve its reputation or relieve the continued tensions between mining operations and surrounding communities. On the other hand, there are a number of factors constraining effective utilisation of mine wastes, such as potential legal and environmental issues, direct costs and lack of effective engagement between various industry sectors and stakeholders (Godfrey, 2007). Overcoming these constraints and creating a business case for pro-active and integrated management of mine wastes within the context of sustainable development, requires a clear understanding of the complex relationship between mine waste, environmental degradation and community impacts.

Strategies also need to be supported by reliable data and information, viable technologies and an enabling legislative framework. Coal processing wastes, in particular, remain poorly characterised, and their potential long-term impacts, particularly in terms of elevated levels of dissolved metal and salts, largely unknown. Previous studies have mainly focused on acid generating behaviour, with broader studies on the mobilisation of salts and metals being limited to a few fine coal wastes. The lack of adequate information on the compositions and properties of coal wastes creates difficulties in rigorously evaluating the consequences of interventions to improve environmental performance, and in justifying their implementation.

This project sets out to address these requirements, by providing a better understanding of key drivers, enablers, barriers and opportunities for the effective re-use or re-purposing of large volume mine wastes, and by identifying potential stakeholder roles in this regard. In so-doing this project builds on and compliments the work done as part of the on-going WRC-sponsored project on the development of an industrial ecology approach to sulphide containing wastes to minimise acid rock drainage (ARD) formation (WRC report no. 2231/1/18, in press) under the leadership of Professor Sue Harrison at the University of Cape Town.

1.2 Project aims

This project aimed to generate knowledge that facilitates the development and implementation of sustainable approaches to the management of mine waste in the South African context, using a combination of quantitative mine waste data; comprehensive stakeholder engagement; and a qualitative analysis of public reports and literature.

This overarching objective was achieved through three parallel project “programmes”, which aimed to:

1. Develop a more detailed understanding of the inter-relationship between mining, environmental degradation and community impacts, in terms of health and livelihoods, with specific emphasis on mine wastes
2. Identify key opportunities, drivers, enablers and barriers for the valorisation of mine waste in the South African context
3. Establish potential roles of the relevant stakeholders (government, mining industry, SMEs) in enabling the implementation of mine waste valorisation opportunities
4. Enhance current tools for assessing the potential metal and salt-related risks posed by coal wastes, and build an inventory database for such wastes in the local context

1.3 Scope and limitations

The project scope comprised three main inter-related programmes, each of which were designed to address the specific project aims:

1.3.1 Programme 1

Investigation of the relationship between mine waste, environmental degradation and community quality of life (Aim 1): This programme explored the facts, perceptions, concerns and conflicts in the context of the mine-environment-community cause-chain, with particular emphasis on:

i. Historical incidences of environmental pollution from mining, the sources and origins of such pollution, the impacts that this has had on local communities, and the actions taken by various stakeholders to address these incidents.

ii. Perceptions and understandings amongst communities and community-support organisations with regards to the mine-environment-community cause-effect chain

iii. Current and emergent responses to these concerns
iv. The extent to which such concerns and responses are supported by data and factual information
v. The gaps and shortcomings with respect to (iv)

These studies were undertaken through three separate case studies, each of which is associated with community conflicts and tensions and associated with reports of environmental degradation. One case study focused on the impacts and conflicts associated with the coal mining sector in the Mpumalanga Province, South Africa. Another case study focused on the defunct gold tailings dumps in the Witwatersrand Basin, South Africa, whilst a third case study focused on the copper mining sector in the Copperbelt region of Zambia.

1.3.2 Programme 2

Analysis of opportunities and influencing factors for mine waste valorisation in the South African context (Aims 2 and 3): This programme set out to identify opportunities, barriers, enablers and drivers for the valorisation of mine wastes, with a specific focus on gold tailings and fine coal processing wastes (Aim 2), as well as the potential roles that stakeholders (government, mining industry, SMEs, community-based entrepreneurs, etc.) can play in enabling implementation of effective mine waste management approaches (Aim 3).

1.3.3 Programme 3

Characterisation of the properties and water-related environmental risks of South African coal processing wastes (Aim 4): This programme entailed an experimental study of laboratory-scale techniques to evaluate the applicability, reliability and shortcomings of current empirical methods for the characterisation of coal waste, and to build an inventory database for such wastes in the local context.

The project combined rigorous scientific analysis of wastes with comprehensive stakeholder engagement in the form of consultations and interviews with representatives from industry, communities, non-government organisations and government. This was done with a view to facilitating the development of approaches to the management of solid mine wastes that are supported by reliable data, whilst also taking into account the perceptions, concerns and goals of interested and affected parties.

1.3.4 Synthesis of Programmes

This report summarises and synthesises the outcomes of these programmes. Chapter 2 provides an introduction to the production and conventional management approach to mine wastes, as well as a review and analysis of the potential environmental and related social impacts typically associated with large-volume mine waste deposits. Chapter 3 explores the relationship between mining, environmental degradation and community quality of life, through three separate case studies, covering the South African coal and gold sectors, and the Zambian copper sector. Chapter 4 explores the opportunities, barriers and enablers for the implementation of so-called “valorisation” approaches to mines wastes in South Africa, with case studies on coal processing wastes and gold tailings. Chapter 5 investigates the current approaches and techniques for determining the key environmental characteristics of mine wastes, with a specific focus on coal processing wastes. Finally, Chapter 6 summarises the key outcomes of the study and makes recommendations for future studies and initiatives.

CHAPTER 2: AN OVERVIEW OF LARGE-VOLUME MINE WASTES: GENERATION, MANAGEMENT AND IMPACTS

2.1 Introduction

As highlighted in Section 1.1 of Chapter 1, the mining and primary processing of mineral resources generates vast quantities of unwanted “gangue” material which is mostly disposed of in waste piles or impoundments. In many cases, these deposits pose a significant and protracted pollution risk to the surrounding environment and, concomitantly, to the quality of life and livelihoods of local communities.

This chapter provides an introduction to mine waste generation (Section 2.2) and management approaches (Section 2.3), and a review and summary of the potential environmental and related social impacts typically associated with large-volume mine waste deposits (Section 2.4). A summary of key findings is provided in Section 2.5.

2.2 Generation of mine waste

The production of wastes from the primary minerals resource sector is significant, typically amounting to anywhere from 70% to more than 99% of the mined ore body, and accounting for between 75% and 90% of national waste burdens (Warhurst, 2000)

In South Africa, waste from the mining sector accounts for approximately 72.3% of solid waste generation, making it the biggest contributor to the National Waste Inventory (Nkosi et al., 2013). Currently available data on the annual mineral waste quantities that are generated in South Africa from both the mining and beneficiation processes are shown in Table 2.1 (Broadhurst, 2005; Godfrey et al., 2007; Makgae, 2011).

Table 2-1 Waste generation from South Africa's mining industry

Sector	Quantities of Solid Waste (Mt/year)
Gold	102-192
PGM	114
Coal	66-70
Base metal	60
Non-metal	24
Ferro-alloy	5

Although the properties of the waste are related directly to the ore body type, grade and the form of mining and beneficiation processes used (Broadhurst et al., 2007, Godfrey et al., 2007), the solid wastes arising from the mining and primary beneficiation of mineral resources can be grouped into a number of generic waste types, with each type of waste being linked to specific processing stages and/or associated technologies, typical of the industry (Figure 2.1). Whilst the share of ore generated as waste will depend on grade and is strongly linked to commodity type, according to average industry figures reported by Warhurst (2000), 42 per cent of the total mined material is typically rejected in the form of waste rock during mining; a further 52 per cent is discarded in the form of tailings during concentration of the run-of-mine ore; whilst metallurgical extraction typically results in the rejection of an additional four per cent in the form of various solid waste types (furnace slags, flue dusts, leach residues and/or effluent and wastewater treatment sludges).

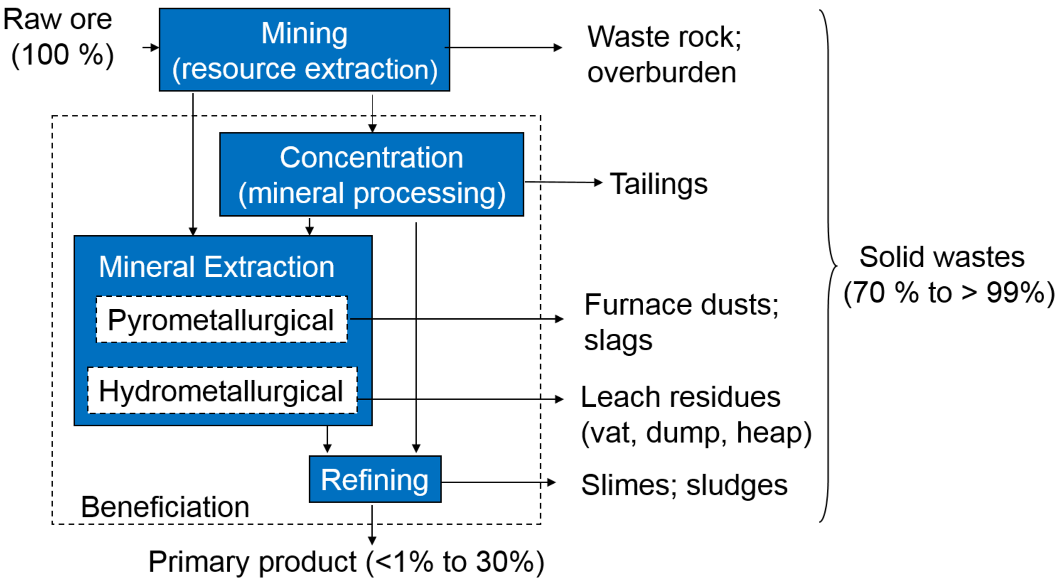


Figure 2-1 Waste generation in primary mineral extraction and beneficiation

The terms used to describe the various forms of waste arising from the extraction and primary beneficiation of ores and coal deposits, and their definitions, vary quite considerably in different parts of the world and have both reporting and legal implications. In this study the term mine waste is used in the broader sense and is defined as the large-volume mineral-bearing materials that result from the exploration, mining and processing of minerals. It includes the, waste rock or overburden, and tailings or discards from ore concentration and primary processing operations (Bellenfant et al., 2013; Godfery et al., 2007). The overburden is the surface material that consists of rock and topsoil that is removed in order to expose the mineral containing ore body. Waste rock typically consists of non-mineralised and or low-grade mineralised rock that has been removed during extraction to access the ore body. The processing waste, also referred to as tailings in the case of hard-rock ores and discards or slurry waste in the case of coal, constitutes the waste slurry and/or solids that result from the primary beneficiation processes that occur while extracting the valuable minerals from the ore body. These processes include crushing, grinding, size sorting, density separation, flotation and other chemical processes (Bellenfant et al., 2013). Wastes generated during pyrometallurgical extraction (e.g. slags, furnace dusts) and refining (e.g. slimes) are specifically excluded. The minerals have undergone chemical transformation and are no longer present in their natural form. A consistent set of definitions to describe mine waste is provided in Table 2.2 (Harrison et al., 2010).

Sulphidic mine waste can be considered as a special class of waste generated during the extraction of and processing of sedimentary coal and sulphidic metal-bearing ores, such as base metals and gold (Harrison et al., 2010). These wastes are of particular concern due to their potential to generate acid rock drainage, which is commonly associated with elevated metal and salt concentrations.

Table 2-2 Terminology for mine waste (modified from Harrison et al., 2010)

Waste Terminology and Description		Associated Waste Deposit
Solid Waste	***Solid waste***[1] is the general term to describe the various solid and/or slurry materials remaining after removal of the targeted materials.	Deposits, storage facilities, disposal facilities, piles, dumps
	Mine waste is solid waste arising specifically from the extraction and primary beneficiation of naturally-occurring minerals. Also known as ***mine residue***[2] or ***mineral waste***.	
Mining Wastes	***Waste rock***[3] is the barren or uneconomic mineralized rock that has been mined but is not of sufficient value to warrant treatment and is therefore removed ahead of processing. Also known as ***mine rock***.	Dumps
	Low-grade[4] ***ore stockpiles*** usually consist of run-of-mine ore which has been mined and stockpiled with intention to process in the future but is often left as 'waste'.	Stockpiles
	Overburden[5] is the material (rock and soil) above the mineral resource that must be removed in order to mine the mineral resource. Also referred to as ***spoil***.	Deposits, dumps
Ore processing wastes	***Spent ore*** is the rock remaining after recovery of metals and some soluble constituents through heap leaching and heap rinsing of ores	Facilities, piles
	Tailings[5] are the solid product of ore treatment and concentration processes that are considered too low grade to be treated further. Tailings are the finely ground host rock materials which have been processed for the separation of desired mineral values. A distinction is sometimes made between ***slimes*** or ***sands***[5].	Impoundment, dumps & piles (sand); dams and ponds (slimes)
	Coal discards are the solid wastes from coal cleaning that is of insufficient commercial value due to high ash content/low calorific value. Also referred to as ***rejects***.	Dumps
	Ultra-fine coal slurry is the fraction of coal which is too fine to be effectively beneficiated using conventional techniques.	Ponds

1. The EEC define waste as "any substance or object the holder discard, intends to discard or is required to discard" (European Waste Framework Directive 2006/12/EC, as amended by directive 2008/98/EC)
2. DWS and DMR in South Africa define mine residues as any debris, discard, tailings, slimes, screening, slurry, waste rock, foundry sand, beneficiation plant waste, ash and any other waste product derived from or incidental to the operation of a mine or activity, and which is stockpiled, stored or accumulated for potential re-use or recycling or which is disposed of
3. The term "waste rock" is normally associated with hard rock mining – although overburden is sometimes used in the case of waste rock from open-pit mining
4. The distinction between waste rock/overburden and low-grade ore is usually an economic one and may vary from site-to-site and year-to-year.
5. Normally used in reference to processing of hard rock ores. Slimes generally refers to finely divided tailings (90% < 0.43 mm), whilst sands in used to refer to coarser material (90% < 2 mm)

2.3 Mine waste management

Despite their large volumes, mine wastes were historically considered to be of low environmental risk, and until the middle of the 20th century were largely deposited in unengineered sites, frequently located in close proximity to the processing plants and/or local settlements. These disposal practises led to a number of catastrophic failures, resulting in extensive environmental damage and, in some cases, even death (see discussions by Environment Australia, 1997; van Zyl, 1993). Today strict legislative controls govern the site selection, design, management and rehabilitation of solid waste disposal sites, with significant technical advances having been made in the fields of geotechnical stability, and the control of dust and soil erosion (Malatse and Ndlovu, 2015). A review of available literature suggests that there are three main approaches to mine waste management in South Africa; namely rehabilitation, recovery and re-use. Godfrey et al. (2007) argues that the decision of how mine waste is handled is driven by three overarching policies, namely economic policy, environmental policy and integrated waste policy. Each of these favours different potential solutions, e.g. stockpiling, rehabilitation, and re-use (Adler et al., 2007). According to Adler et al. (2007) the factors influencing the management of mineral residue and mine waste are split between environmental protection and economic development (Adler et al., 2007). While this project focuses on the re-use of mine waste, an overview of each of the current management approaches is discussed in Sections 2.3.1 to 2.3.3.

2.3.1 Rehabilitation

Rehabilitation refers to the process of restoring land that has been impacted by mining activities back to a sustainable usable condition (Tanner, 2007). Rehabilitation of mine waste or residue deposits is often undertaken to reduce the environmental impacts associated with the deposits post mine closure (Godfrey et al., 2007). Godfrey et al. (2007) argue that rehabilitation of mine waste deposits is largely driven by environmental policy that aims at ensuring that the waste deposits do not pose (or minimise) a risk to both the environment and human health.

The most popular method for rehabilitation is the use of vegetation cover. Rehabilitation through vegetation can be done through planting trees and or grasses. Umba (2013) completed a comprehensive review on the rehabilitation of the tailings storage facilities around the Witwatersrand Basin using planted vegetation. This review indicted that, while the use of vegetative cover provides an effective way of controlling and reducing erosion and wind-dispersion of dust, maintenance of the planted vegetation is not always ecologically and economically sustainable. Revegetation is a particularly challenging aspect of rehabilitation. Topsoil harvested prior to the commencement of activities is limited and may often be contaminated or physically altered. Compaction of replaced topsoil, in particular, is reported to hamper revegetation efforts (SACRM, 2011). Another challenge is the availability of plant species that can tolerate the potentially acidic or highly saline conditions prevalent on coal mining sites.

Mine waste disposal and rehabilitation methods have evolved significantly over the past two decades, with improvements aimed at both meeting increasingly stringent legislative requirements and growing disposal costs. For example, in a method called integrated disposal, coal ultra-fine slurry is often pumped onto un-compacted discards, to form a matrix that is non-oxidising. Discard facilities are also now being clad with soil and vegetated to prevent all forms of atmospheric pollution and dumps are being constructed with run-off paddocks to control storm water run-off from (SACRM, 2011). Another innovation involves the use of chemicals to facilitate the rehabilitation of tailings storage facilities. The dumps surfaces are sprayed with various substances such as molasses, salt and hygroscopic material which bind loose particles, thus reducing wind-blown dust in the short-term. According to Umba (2013), the use of chemicals gives rapid results but requires continuous application and thus becomes expensive due to the high cost of the chemicals used. Other methods that have been used include rock cladding or gravel mulching and rehabilitation through the use of biological organisms (also referred to as bioremediation).

The biggest advantage of rehabilitation lies in the reduction of surface and ground water contamination, as it provides better control of rainwater run-off and mine drainage that would otherwise contaminate water bodies (Nzimande and Chauke, 2012). Further to this, rehabilitation of residue deposits also addresses the environmental issues such as air quality and erosion control. However, rehabilitation procedures often pose an economic burden on the mine and are generally seen as costly investments with no financial returns (Godfrey et al., 2007). Furthermore, it does not necessarily eliminate the long-term risks associated with mine waste (Godfrey et al., 2007). Although rehabilitation efforts can be successful, there are increasing concerns that the land will never be returned to its former state (GDACE, 2008). Remediation may be insufficient, incomplete, or of a poor quality while a loss of societal memory can mean that the sites may be excavated in the future, exposing the waste body once more (Brown Weiss, 1984).

2.3.2 Value recovery

In many cases mine wastes contain rare and scarce elements in highly elevated concentrations relative to their average crustal abundance. This may include residual precious metals such as gold, silver and the platinum group metals (PGMs), as well as other scarce elements such as thallium, indium, lithium or rare earth elements, which are of importance for modern, high tech applications. In the past, technologies to recover these elements were inefficient, or the elements were not considered to be sufficiently useful or valuable.

Beneficiation of mine wastes for mineral recovery involves reprocessing current arisings, or reworking mine residue stockpiles or dumps, in order to recover economically viable minerals. Mineral recovery from residue stockpiles can be undertaken to recover economic minerals, remove harmful substances and to make the land available for other uses (Van Heerden, 2002). According to Godfrey et al. (2007), the viability of mineral recovery from residue stockpiles is dependent on a number of key economic factors. These include (but are not limited to) the value of the metal or mineral to be recovered, the grade of the targeted commodity in the waste, extraction costs, scale of extraction, processing efficiencies and available technology. Over the past decade, the reprocessing of tailings containing high value commodities such as gold and PGMs has gained traction and attention. This is largely due to recent advances in technology which have enabled the mining sector to extract low concentrations and lower mineral grades in an economically viable manner (Davis, 2014), coupled with high commodity prices (Fleming et al., 2010).

Companies such DRDGOLD, Mintails, Goldfields and Sibanye are undertaking this approach and are re-mining gold dumps in Johannesburg with the aim of returning mining impacted land to a higher social and economic use (Davis, 2014). Similarly, recycling and reclamation of coal discards and slurry waste to generate saleable coal products has become a standard practice for many mining companies. Seepage from active dumps is normally collected and either re-used in the processing plant or gravitated to evaporation dams for evaporation purposes (SACRM, 2011). Coal discard is reprocessed to extract low-grade steam coal, mainly for use in local power stations (SACRM, 2011). In some cases, the ultra-fine slurry is beneficiated by froth flotation to produce power station feedstock or dewatered for use in its raw state or even as an export product (SACRM, 2011).

The extraction of residual minerals from mine waste deposits has many advantages. It leads to the rehabilitation of land currently occupied by historic tailings for alternative and productive land use, with the secondary tailings been dumped in re-engineered and safer ‘super-dumps”. Processing waste to unlock value also provides the opportunity for simultaneously improving the environmental characteristics, if so applied (Hudson-Edwards et al., 2011; Lottermoser, 2011). This approach has been taken by researchers at the University of Cape Town to simultaneously recover value and remove the risks of ARD generation from sulphide bearing wastes (Figure 2-2). In this approach physical separation techniques, such as froth flotation, are used to recover value from fine and ultra-fine (75% passing 0.15 mm) waste, and subsequently to separate the sulphide-bearing tailings into a low-volume sulphide-rich stream and a relatively benign sulphide-lean stream which can be disposed of in surface waste deposits (Hesketh et al., 2010; Kazadi Mbamba, 2011; Kazadi Mbamba et al., 2022). This approach has been successfully demonstrated on a laboratory scale with coal and copper-bearing ores (Hesketh et al., 2010; Kazadi Mbamba, 2011; Kazadi Mbamba et al., 2012).

Value recovery can help offset the cost associated with further waste treatment and waste, and can have a significant potential impact on current mineral reserves by deferring the exploitation of new deposits (Van Heerden, 2002). However, the drivers are largely financial, and the bulk of the mined resource usually remains condemned to landfill as unwanted material.

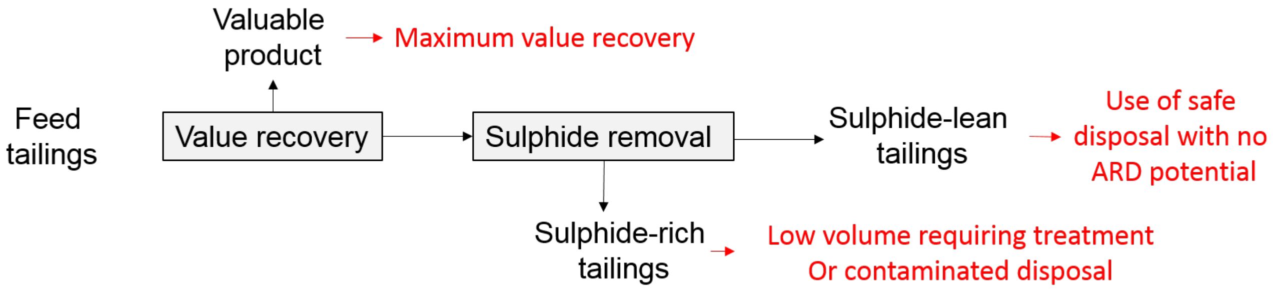


Figure 2-2 The two-stage froth flotation process for the separation of fine and ultra-fine sulphide waste (Hesketh et al., 2010)

2.3.3 Re-use or re-purposing

The separation process outlined in Figure 2-2 (Section 2.3.2) not only presents the opportunity to recover some of the mineral value still present in the waste, thus increasing the mine's production output, but also generates bulk waste streams that are potentially suitable for downstream utilisation.

The re-use of mineral residue stockpiles involves finding alternative and/or secondary uses for the mineral waste other than its intended primary use. An emerging term is that of "re-purposing" which essentially entails the re-allocation of waste as feedstock for downstream utilisation. It is driven by integrated pollution and waste policy that aims to ensure that waste is firstly reduced then re-used and recycled, with stockpiling seen as a last resort (Godfrey et al., 2007). The re-use or re-purposing of mine waste offers a number of potential benefits. It reduces the waste burden on the environment both through reduced waste footprint and a lower potential for long-term environmental pollution (Haibin and Zhenling, 2010; Lottermoser, 2011). However, despite the advantage of reusing or reprocessing mine waste, application remains constrained and is largely limited to using large volumes of waste as backfill for mines, or in construction or for landscaping (Dudeney et al., 2011). These applications require large volumes of relatively benign waste, and will only be viable in certain scenarios.

2.4 Mine Waste Deposits: an overview of potential environmental and social impacts

As indicated in the previous section, large volume mine wastes are typically still disposed of to landfill. The land disposal of large-volume mine wastes gives rise to environmental emissions which pose a potential risk to human health and biodiversity and also represents a loss of natural resources including water, mined mineral resources and useable land; ultimately impacting on our human, natural and economic capital (Figure 2.3).

A more detailed discussion on the generic environmental impacts and social implications of mine waste deposits is provided in Sections 2.4.1and 2.4.2.

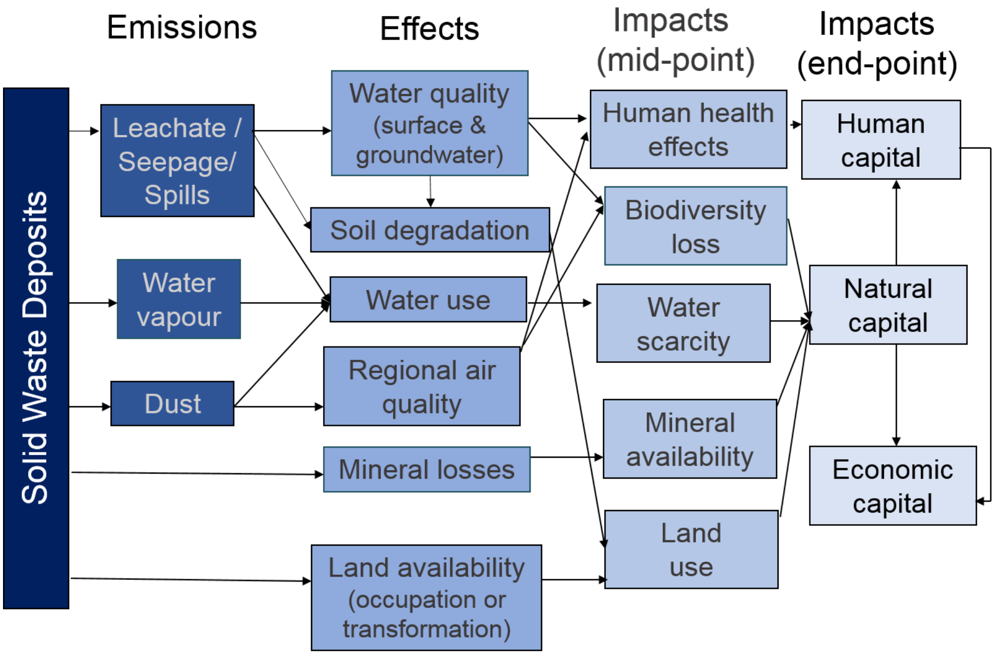


Figure 2-3 Overview of the mine waste deposit cause-effect relationships

2.4.1 Potential environmental impacts

Environmental impacts arising from mine waste deposits can be broadly categorised as land disturbances, water consumption and degradation and air pollution.

2.4.1.1 Land disturbances

Mining is largely associated with displacement of existing land use and dramatic landscape change. Land occupation and deforestation occurs as a result of excavations, erection of supporting and processing infrastructure and the disposal of waste in the form of overburden and tailings (Bell et al., 2001; Sonter et al., 2014; Zhengfu et al., 2010).

Land disturbances can also be indirect and extend beyond the mining site, affecting adjacent land-users. Several significant tailings dumps failures have been experienced by the mining industry over the decades; for example in Merriespruit, South Africa (1994), Omai, Guyana (1994), Los Frailes, Spain (1998), Baia Mare, Romania (2000), Aitik, Sweden (2000), Mount Polley, Canada (2014), and more recently in Bento Rodrigues, Brazil (Fundão tailings dump disaster, 2015). Apart from the immediate and direct physical destruction, environmental damage, economic costs and loss of life, these disasters can result in extended pollution plumes which adversely impact on the surrounding water sources and land for decades after the failure (Figure 2.4).

Figure 2-4 Three day pollution plume from the Fundao tailings dam failure of 2015 (https://www.miningreview.com/news/samarco-reaches-agreement-prosecutor-fundao-dam-failure/)

Despite advances in the design and construction of tailings dams to improve their geotechnical stability, tailings dam failures continue to occur (Figure 2.5), prompting the United Nations Environment Programme (UNEP) to release a report in October 2017 urging States and the industry to "*end deadly and damaging mining waste spills by enforcing a zero-failure objective*" (Roche et al., 2017).

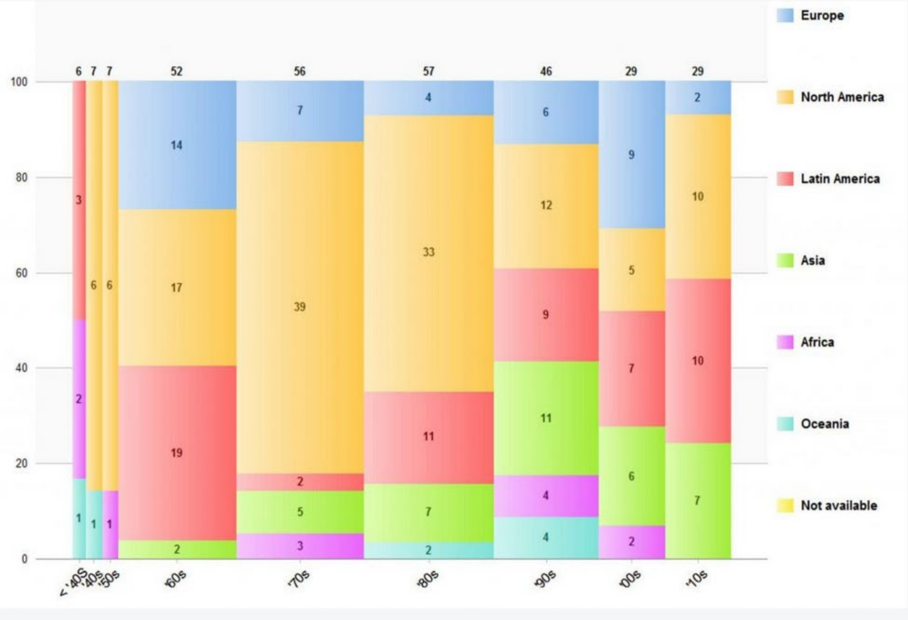


Figure 2-5 Tailings dam failures over the past 100 years (width of columns is representative of the number of failures, **https://www.riskope.com/2017/02/22/hundred-years-lessons-learned-tailings-dams-failures/**)

Whilst waste dumps constitute a blemish on the landscape and pose a risk of dramatic failure, of greater environmental concern in the long-term are the indirect impacts on air, water and soil quality. Land subsidence has been associated with underground mining, whilst soils can be degraded off-site due to dispersion of dust and contaminated water from operations and waste dumps.

2.4.1.2 *Air pollution*

As indicated in Figure 2.6, active and defunct mine tailings, which have not been properly rehabilitated and managed, are major generators of wind-blown dust and one of the main sources of air pollution, with concomitant risks to the local environment and to human health (Csavina et al., 2012).

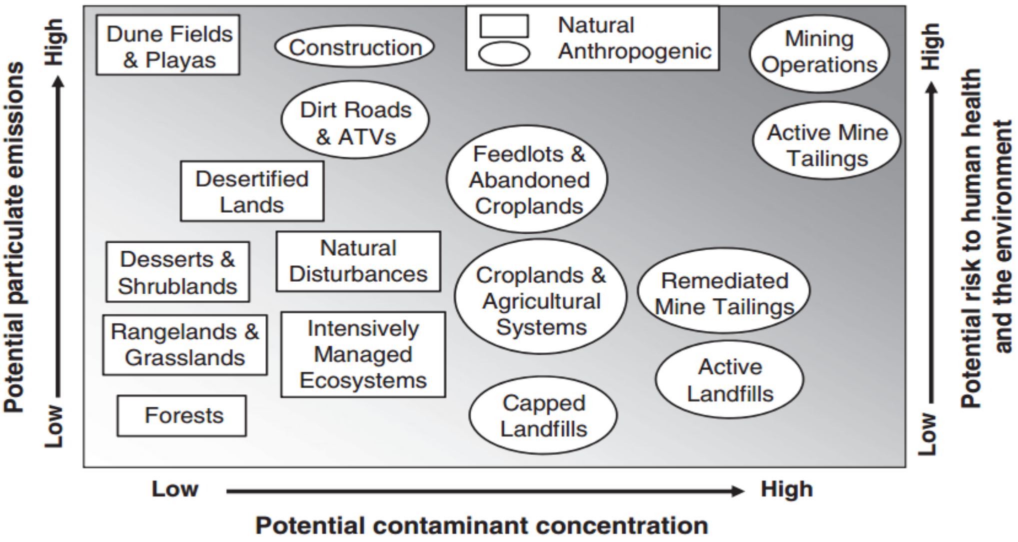


Figure 2-6 Natural and anthropogenic sources of dust associated with relative amounts of emissions, contaminant concentration, and risk to human health and environment (Csavina et al., 2012)

There are many different definitions for dust, some simple and some relatively complex. Whilst dust is defined as by ISO 4225: 1994 as "*small solid particles, conventionally taken as those particles below 75 µm in diameter, which settle out under their own weight but which may remain suspended for some time"*, airborne particles are often up to 100 µm in aerodynamic diameter. Although the density and shape does play a role, the behaviour and impacts of dust is typically related to particle size (Figure 2.7). The coarser fraction of airborne (> 10 µm to 30 µm), is often referred to as fallout dust and settles naturally from the air. Fallout dust is typically monitored on and adjacent to mine sites using buckets. All dust particles that are airborne have the potential to be inhaled through the nose and mouth, but larger dust particles (> 10 µm) do not necessarily pass further into the respiratory system (Goldstein and Webster, 1990). Fallout dust is thus typically considered as "nuisance dust" and is considered to pose a minimal health risk. Non settling dust, which usually lies in the smaller size ranges and is not usually monitored, is the most likely to be respired when coming into close contact with humans. *Thoracic particles* are defined as the inhalable particles which are small enough to pass into the head airways (typically between 2.5 and 10 µm, referred to as PM 10). These are more problematic than the larger (>10 µm) particles, as the head region and airways to the lungs may become lined in particulate matter. Whereas they may not be small enough to reach to alveoli region, they are still extremely dangerous as they can line the tracheobronchial airway region, as well as deposit in the lung. These particles may still enter the body through dissolution if soluble (Regan, 2007). The smallest particles are able to enter the lungs and penetrate to the alveoli. These particles are defined as *respirable particles*, and typically have particle sizes of less than 2.5 µm (PM 2.5). This is the area of greatest concern, as particles with harmful substances are able to diffuse straight into the blood and can lead to serious health effects (Maton et al., 2010). Smaller particles (< 0.1-1 µm) tend to remain completely suspended and exhaled without any contact with lungs or airways.

Apart from the "nuisance effects" and impacts on the general quality of life for nearby communities, the generation of dust from mine dumps, particularly during periods of high winds, allows for the wide-spread dispersion of, and exposure to, potentially harmful contaminants such as metals from mine waste dumps.

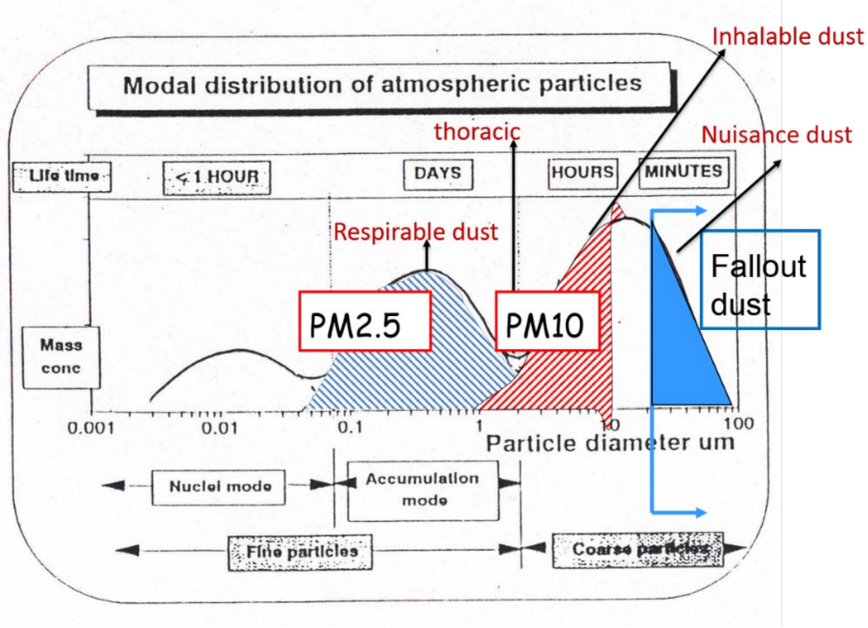


Figure 2-7 The distribution and classification of airborne dust and particulate matter (modified from Annegarn, 2016)

In the case of coal waste dumps, additional air pollution occurs through spontaneous combustion. This is discussed in more detail in the case study in Chapter 3.

2.4.1.3 Water consumption and quality

Water is essential to all mining operations, particularly in terms of cooling, processing and extraction, dust suppression and transport of materials. Although typically only accounting for between 3% and 6% of national water consumption, mining operations can have a significant impact at a local or regional scale, where they compete with other water users, and potentially disrupt surrounding groundwater tables and hydrogeological pathways. This is aggravated by the fact that mining operations frequently occur in water-stressed areas, placing additional strain on already limited water resources. Tailings deposits contribute significantly to dissipative water loss at mine sites (up to 70% of total losses). This is due to the fact that the tailings which have been dewatered in conventional cone thickeners still contain between 40% and 60% water (by mass). Only 25% of this water is typically recovered and recycled, with the remainder of the water being lost through evaporation, run-off, seepage and entrainment. In an effort to reduce their water footprint and simultaneously reduce the risks of failure, many mines have adopted more effective dewatering techniques, such as paste thickening and filtration.

Whilst maintaining the geotechnical stability of mine related structures during their operational life is paramount, it is in fact the continued generation of contaminated leachate and run-off from solid waste deposits, and the subsequent transport of contaminants into the surrounding environment, that is most often the more serious and pervasive environmental problem (Figure 2.8). Leachate generation occurs as a result of water coming into contact with, and percolating through, the solid waste, causing contaminants to leach (Hansen et al., 2008). Due to the complex nature of mine wastes these contaminants typically comprise a range of mineral phases containing a multitude of elements, including salts and metals, in varying concentration ranges (Broadhurst et al., 2007; Broadhurst et al., 2007a). Leachates from mine wastes also often exhibit extreme pH values. Highly acidic leachate (often as low as pH 2), termed acid rock drainage (ARD) or acid mine drainage (AMD) is typically associated with solid wastes arising from the early beneficiation of sulphide mineral (mainly in the form of pyrite, FeS_2) bearing metallic ores and coal deposits. Acid rock drainage is considered to be the most significant water quality concern relating to the mining industry in many parts of this world, including the Witwatersrand goldfields and the Mpumalanga coalfields in South Africa (Oelofse, 2007; Vermeulen et al., 2007). Whilst extreme acidity can have direct toxic or physical effects, the most significant consequence of low pH is the enhanced weathering of minerals and mobilisation of metals and salts. Metal pollution is a particularly serious consequence of human activities as metals are persistent in nature and have a tendency to accumulate in sediments and soils (Alkorta et al., 2004). The hazardous characteristics of mine wastes and leachates are summarised in Box 1. Unless contained the generation and dispersion of contaminated leachate from mine waste dumps can continue for hundreds of years making mine waste disposal both a post-closure and intra-generational issue.

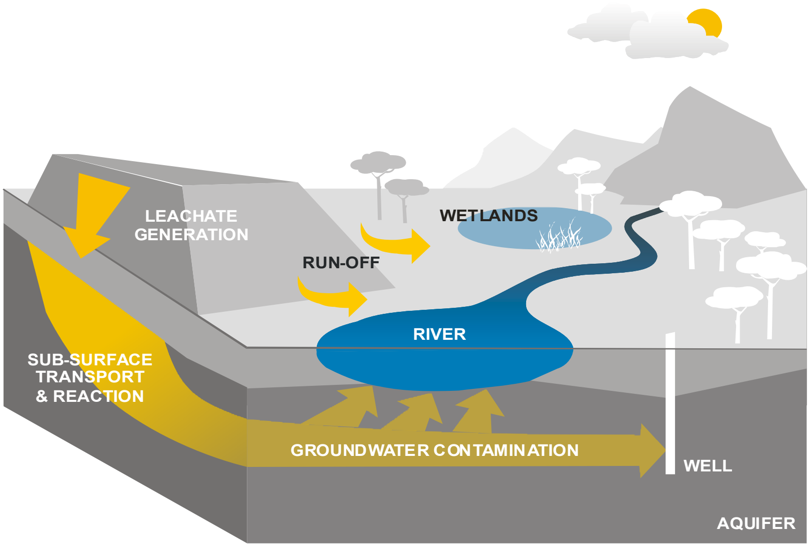


Figure 2-8 Generation and dispersion of contaminated leachate from mine waste deposits

2.4.2 Eco-system health effects

The impacts on land, water and air, as discussed in Section 2.4.1 above, pose a significant threat to biodiversity. The most obvious impact to biodiversity from mining is the removal of vegetation (for excavations and large volume waste deposits) which in turn alters the availability of food and shelter for wildlife. Andersen et al. (2014) note that the greatest potential for negative impacts on biodiversity is not from individual mines, but from the cumulative impacts of extensive development in highly prospective regions, or where diffuse development takes place over large regions. Given this cumulative effect, mining can potentially affect biodiversity regionally through a combination of the scale of exploration activity, the mine sites themselves and importantly the roads, towns, pipelines, water supplies and ports required to service them (Andersen et al., 2014). These ecosystems form the basis of all ecosystems upon which sustainable livelihoods and food security depend, and their full recovery may take many years, possibly even millennia (Limpitlaw et al., 2005).

Acid rock drainage (ARD), in particular, poses a significant threat to plants and living organisms, as a result of both acidity and elevated content of metals. The toxicity and acidity of ARD induces severe oxidative stress and impairs osmotic balance of fish by interfering with the uptake of salts through the gills (Chadwick et al., 2013). This results in mortality or stunted growth, reduced reproduction, and deformities or lesions. The fish populations can be

BOX 1: Hazardous Properties of Mine Wastes and leachates

- Extreme pH
  - ✓ **Low pH**: acid drainage (AD)
  - ✓ **High pH**: effluent neutralisation residues, alkaline leach residues
  - ✓ Aquatic toxicity, physical effects, indirect effects on metal solubility

- Deleterious metals
  - ✓ Major metals: **Al, Fe** - low toxicity; physical & aesthetic effects
  - ✓ Minor metals: **Cu, Zn, Mn, Ni** - moderate toxicity; physical & aesthetic
  - ✓ Trace metals: **As, Hg, Se, Te, Cd, Pb, U** - high toxicity

- Soluble salts
  - ✓ Major salts: **sulphate**, carbonate-high concentration & low toxicity
  - ✓ Moderate salts: **chloride, nitrate**-moderate concentration & toxicity
  - ✓ Minor salts: **fluoride, cyanide**-low concentration & high toxicity

severely reduced or eliminated altogether (Simate and Ndlovu, 2015). Chubuike and Obiora (2014) identified the negative impacts of metals in plants, which include oxidative stress, effects on fluorescence, stomatal resistance, chlorophyll and photosynthesis, reproductive processes, seed germination, seed morphology and seed physiology. High concentrations of metals also affect soil microbial activities negatively, causing reduction in soil microbial population and distribution and low microbial enzymatic activities (Sobolev and Begonia, 2008; Ngole-Jeme and Fantke, 2017). Due to the high concentrations of metals in soils, arthropod populations as well as small and large mammals are also negatively affected (Migliorini et al., 2004; Gall et al., 2015). Studies conducted by Eisler (2004) have shown that arsenic (As) doses of 17 mg/kg to 48 mg/kg body weight were terminal to birds, while some mammals were adversely affected by As doses of 2.5 mg/kg body weight after oral exposure (Ngole-Jeme and Fantke, 2017). The effects on plants can also be indirect. Contamination of soils by ARD presents adverse effects for plant growth and development (Sarma, 2005; Simate and Ndlovu, 2014). The toxicity and acidity (low pH) of the metals contained in ARD affects soil fertility; the soils become water logged and compact, forming crust which restricts seedling growth and entry of water and air into the soil system. Plants experience oxidative stress leading to cellular damage and disturbance of cellular ionic homeostasis.

2.4.3 Mammalian health effects

The majority of human and animal health problems are caused by the inhalation of airborne contaminates, and from the ingestion of water and food (crops, fish, livestock) containing dissolved metals as a result of water and soil pollution. Potential exposure pathways for harmful contaminants are presented in Figure 2.9. Exposure may be through dermal contact with the tailings, tailings contaminated soil, incidental inhalation and ingestion of contaminated suspended tailings and soil particles, ingestion of crops grown on tailings contaminated soils, or through deliberate ingestion of the tailings contaminated soils (Ngole-Jeme and Fantke, 2017). Humans are exposed to metals mainly through the lungs (in a form of dust) and gastrointestinal tract.

Of particular concern in terms of human and animal health are metals and semi-metals or metalloids. Some metals are either essential nutrients (for example iron, cobalt and zinc) or relatively harmless (such as the platinum group metals and gold), but may have physical or aesthetic effects and can become toxic at elevated concentrations. Other metals (for example cadmium, mercury, lead and arsenic), are highly toxic, even at relatively low concentration levels (Duruibe et al., 2007; Hawkes, 1997; Lenntech, 2004; Morais et al., 2012). Although the actual concentrations may vary quite considerably, metals are often highly enriched in ore bodies relative to their crustal abundance and can find their way into the air, water and food chains once they are released from underground mine workings or mine waste dumps. Since metals are not easily biodegradable they can accrue in human vital organs and glands such as the heart, liver, kidney and brain, impairing their function and causing varying degrees of ailments based on acute and chronic exposures (Dermirezen and Ahmet, 2006; Farooq et al., 2008). These ailments vary from neurotoxic to carcinogenic actions (ATSDR, 2008; Bobbins, 2015; Castro-Ganzalez and Mendez-Armenta, 2008; Jomova and Valko, 2011; Morais et al., 2012), with poisoning due to exposure to metals affecting most major human physiological systems including the skeletal, nervous, respiratory, excretory, and digestive systems. Children are often at higher risks of absorbing metals from the environment. This is due to the fact that their nervous system is still developing and they often place objects in their mouths, resulting in dust and soil being swallowed. Health effects reported for children include a reduction in IQ (intelligence quotient), inability to concentrate, anaemia, behavioural problems, poor school performance and abnormal development of organs (Harper et al., 2003; Tong et al., 2000). Arsenic (As), lead (Pb), cadmium (Cd) and mercury (Hg) are of particular concern, as they are commonly highly toxic and have little if any beneficial effects in trace quantities (Duruibe et al., 2007; Lenntech, 2004). The impacts of these elements are discussed in further detail in Appendix C.

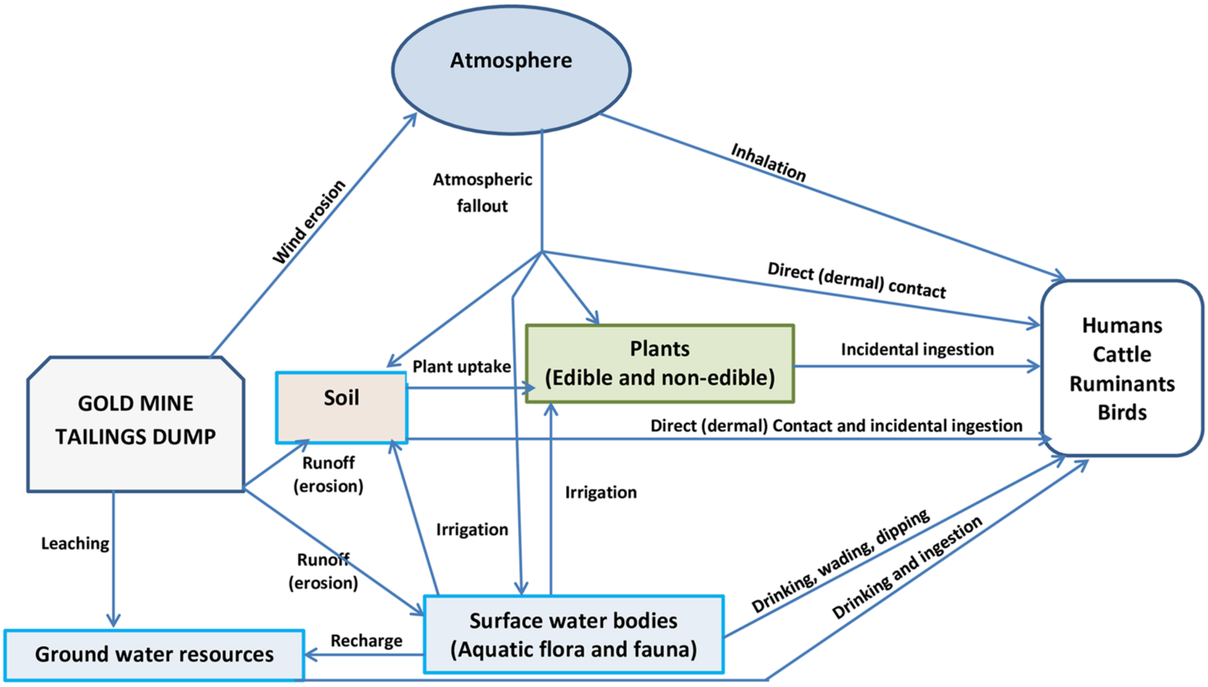


Figure 2-9 Conceptual illustration of pathways of contaminants from a mine waste dump to ecological receptors and humans (after Ngole-Jeme and Fantke, 2017).

Dispersion of dust creates a multiple exposure pathway for contaminants from mine waste dumps as the dust can be inhaled, ingested and/or exposed through dermal contact. As already discussed, finer dust particles (PM 10 and, in particular, PM 2.5) are particularly hazardous, as they can enter the respiratory system. Apart from metals, coal dust and minerals such as pyrite, quartz and kaolinite have all been linked to occupational lung disease (pneumoconiosis). Of particular relevance to mining operations are silicosis, a type of pneumoconiosis which is caused by the inhalation of quartz or crystalline silica, and coal workers pneumoconiosis (CWP), commonly known as black lung, which is caused by the inhalation of respirable coal dust fractions. Several epidemiological studies in the United States have also shown a general correlation exists between the concentration of pyrite (FeS_2) within coal and the prevalence of CWP in miners (Huang et al., 2005; Cohn et al., 2006). Often these diseases take a number of years to progress, as the inhaled minerals thicken in the lungs and harmful substances build in concentration. Lung failure, disability and even death are often caused when the diseases, in particular silicosis and CWP, become severe. Another disease which is often related to chronic exposure to dust is Chronic Obstructive Pulmonary Disease (COPD) (Goldstein and Webster, 1990). Dust gradually builds up along airways and air passages, and lines the inside of the lungs. Most dust is caught on mucus and is coughed up. However, with constant exposure, the body's ability to efficiently get rid of the dust decreases. Over time, this limits the amount of air the body is able to process. This can lead to diseases such as chronic bronchitis and emphysema.

2.4.4 Impact of community livelihoods

Generally, a livelihood is a means of gaining a living and comprises the capabilities, assets and activities required for a means of living (Mishra, 2009). Mineral resources may play a critical role in fostering economic growth including creation of employment opportunities but may also have negative impacts on local communities' livelihoods (Hota and Behera, 2015). Impacts can arise as a result of a direct decline in availability and quality of natural resources, such as water and land.

Apart from health effects, contamination of soils and water can reduce the productivity of soils and have adverse effects on the viability of crops and health of livestock (Mangena and Brent, 2006). Similar to humans, water that has come into contact with ARD can have serious health issues for cattle and other livestock (Simate and

Ndlovu, 2014). In their study to assess the cost of coal mining on agriculture and human health in Odisha, Hota and Behera (2015) found the cost incurred by the local communities, in terms of loss of agricultural production and increase in medical expenses, to be substantial. Pollution of land and water by ARD arising from coal mining, resulted in a loss in livelihood from both fishing and farming. Locally, a report by the Centre for Environmental Resources (CER, 2016) has claimed that the impact of mining activities is in most cases so severe that farming activities cannot be sustained on the surrounding land.

2.5 Summary

The review in this section indicates that primary metal and coal production results in significant quantities of solid waste. Historically, these wastes have been land-disposed in (often un-engineered) dumps, impoundments or tailings facilities. Whilst the re-processing or beneficiation of defunct mine waste dumps for the recovery of valuable metals such as gold is gaining traction, the bulk of the mined material is usually still viewed as unwanted material and condemned to landfill. Literature shows that deposits of mine waste can give rise to environmental emissions (particularly airborne particulate matter and leachates), which impact on eco-systems and human health, and also result in a loss of natural resources, such as water, mined minerals and land, ultimately impacting on natural, human and economic capital. Deleterious metals contained in the waste material are of particular concern, as these can be mobilised through exposure to the elements and pose significant risks to biodiversity, crop productivity and mammalian health. Mobilisation of metals in seepage and run-off is further enhanced by the generation of acid, formed through the microbially-enhanced weathering of sulphide minerals.

Water that is contaminated by metal-rich acid rock drainage (ARD) is unsuitable for both human and animal consumption; the acidity and toxicity of the water disrupts metabolic functions, leading to adverse health effects and the death of aquatic life. Contamination of soils by ARD may affect fertility and in turn hinder plant growth and crop quality. Although current mine waste management approaches focus largely on limiting the weathering and subsequent release of contaminants from mine waste dumps through the use of covers and revegetation, such techniques have yet to be found effective in removing exposure risks and related impacts in perpetuity.

CHAPTER 3: RELATIONSHIP BETWEEN MINING, ENVIRONMENTAL DEGRADATION AND COMMUNITY QUALITY OF LIFE

3.1 Introduction

The minerals industry is essential to modern living and has the potential to make a significant contribution to the socio-economic development of nations, particularly across the African continent. In South Africa, mineral development dates back to the eighteenth century, when gold was discovered, and has contributed significantly to the economic growth in the country in the past. However, the benefits are not always equitably shared and local communities closest to the source of mineral development can suffer the most (WRI, 2014). Mining activities impose harmful, usually irreversible effects on the terrestrial and aquatic environments and on health and livelihoods on a local and regional scale (CER, 2016; Rybicka, 1996).

The negative environmental and socio-economic impacts of mining have often led to mine company-community conflicts and have received a great level of attention by advocacy organisations and traditional and social media. A study by the International Council on Mining and Metals (ICMM, 2015) revealed that mining-related conflict between communities and companies had increased over the period 2012-2013, with environmental and economic grievances dominating. A study by Davis and Franks (2014) confirmed environmental pollution to be the most common cause of mine-community conflict globally, followed by access to resources and distribution of benefits (Figure 3.1).

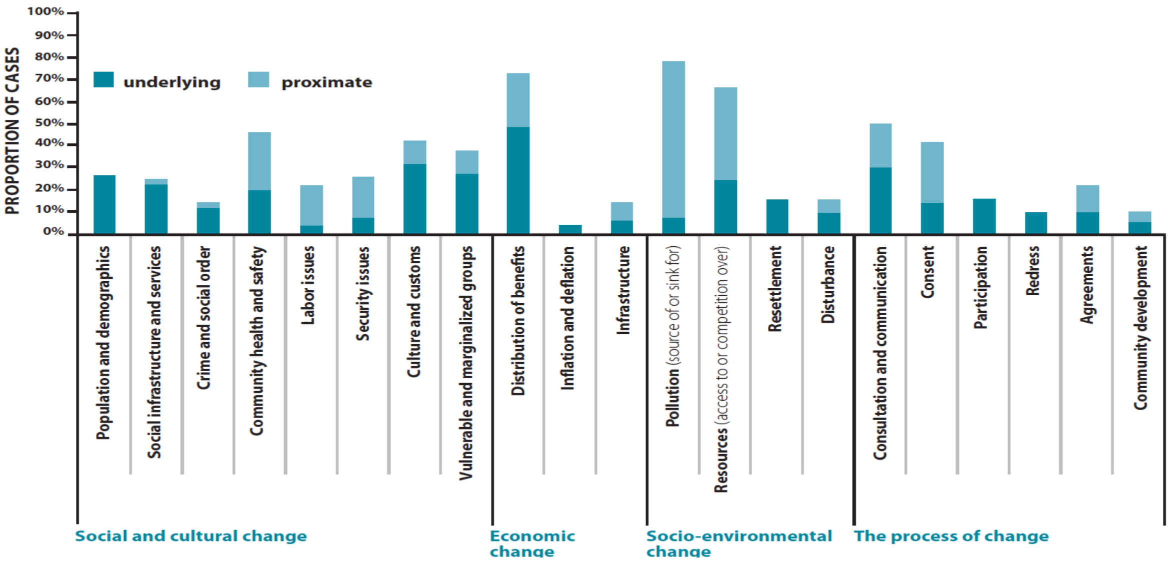


Figure 3-1 Cases of company-community conflicts (Davis and Franks, 2014)

Costs resulting from losses induced by conflicts between the mining company and the community can be significant. For instance, in a study done in 2014, the lost productivity as a result of temporary delays or shutdowns was estimated at approximately US$20 million per week, mostly due to lost sales (Davis and Franks, 2014).

However, despite enhanced industry commitment to improved environmental performance and increasingly stringent legislation, pollution of air, soils and water sources remains a major source of conflict between the mining industry, communities and government, with continuing reports by communities and civil society of associated health issues, cattle and livestock deaths and destruction of livelihoods through subsistence farming and fishing. A number of civil society organisations have been established in South Africa with the purpose of protecting the local environment and communities against “injustices” by mining companies (see Table 3.1), resulting in increased publicity of the impacts of coal mining.

This chapter explores the relationship between mining, environmental degradation and community quality of life through three separate case studies, covering the South African coal (Section 3.2) and gold (Section 3.3) sectors and Zambian copper (Section 3.4) sector. These case studies attempt to unpack the facts, perceptions, concerns and conflicts around mining operations and mine waste in particular, with a specific focus on:

- Historical incidences of environmental pollution from mining; the sources and origins of such pollution; the impacts that this has had on local communities; and the actions taken by various stakeholders to address these incidents.
- Perceptions and understandings amongst communities and community-support organisations with regards to the mine-environment-community cause-effect chain
- Current and emergent responses to these concerns
- The extent to which such concerns and responses are supported by data and factual information
- The gaps and shortcomings with respect to the availability of scientific, quantitative data to address society concerns and perceptions.

3.2 A Coal Case Study: Mpumalanga, South Africa

3.2.1 Background

3.2.1.1 Coal mining in South Africa

Coal mining is a mature industry in South Africa and the economy depends heavily on it; both as a source of foreign income and as a primary source of energy (Bench Marks Foundation, 2015; Reddick et al., 2008). South Africa has the fifth largest coal deposits in the world and is found in 19 coalfields (shown in Figure 3.2) located mainly in Mpumalanga, Limpopo and the Free State, with smaller reserves in KwaZulu-Natal, Gauteng, the North West Province and the Eastern Cape. The South African Coal Roadmap (SACRM, 2011) estimates the coal reserve base at approximately 33Gt. The majority of these reserves and operating mines are currently in the Central Basin, which includes the Witbank, Highveld and Ermelo coalfields located in Mpumalanga and Gauteng Provinces, Limpopo and KwaZulu-Natal where smaller operations are found (Bench Marks Foundation, 2015; Jeffry, 2005). The Waterberg and Soutpansberg coalfields, located in Limpopo Province, have vast resources, mostly unexploited, whilst the Central Basin coalfields are in decline.

Coal mining is one of the key development drivers within the Mpumalanga Province; it supports the growth of the economy and creates jobs. By 2007, there were 73 collieries in the country, and 61 of these were located in Mpumalanga (Pooe and Mathu, 2011). According to the CER, in 2015 there were 239 operating mines and 788 derelict and ownerless mines in Mpumalanga (CER, 2016b). The major coal mining areas are currently in and around the towns of eMalahleni, Middelburg, Ermelo, Standerton and Secunda (Jeffrey, 2005). Witbank (eMalahleni) is considered the supreme coalfield at present. By 1889, four small colliers; namely Brugspruit, Steenkoolspruit, Maggies Mine and Douglas Colliery, were already operating in the Witbank coalfield (Jeffrey, 2005) and by 1920 the Witbank Colliery had acquired a ten-year license to generate electricity for the town with a new power station being established by 1925 (www.sacities.net). The largest industrial companies are located in the Witbank area and include a remarkably high number of coalmines and power stations: there are 22 mines in the area within a radius of no more than 20 km, and 12 coal-fired power stations out of the 16 in the country (ActionAid, 2014; Mining Weekly, 2010).

Table 3-1 Organisation that promote human rights in communities affected by mining operations

Organisation	**Location**	**Objective(s)**	**Activities**
The Benchmarks Foundation	Johannesburg, South Africa	To monitor multinational corporations operating in Southern Africa and the rest of the African continent to ensure that they meet minimum social, environmental and economic standards	Advocacy: Research, media campaigns, community organisation and monitoring
Action Aid	South Africa (Johannesburg), Asia, Europe, America	To work against poverty and injustice worldwide.	Human rights advocacy and support: inequality, youth, HIV/AIDS, democratic governance, education, emergency and conflict, climate change
GroundWork	Pietermaritzburg, KwaZulu-Natal, South Africa	To improve the quality of life of vulnerable people in South Africa who are most affected by environmental justice	Research, Solidarity and Empowerment campaigns: climate and energy justice, coal, waste, environmental health
Centre for Environmental Rights	Cape Town, South Africa	To help communities and civil society realise their constitutional right to a healthy environment	Legal research, advocacy and litigation
Federation for a Sustainable Environment	Johannesburg, South Africa	To promote environmental and social justice in the mining industry	Advocacy and research
Open Society Foundation	Cape Town South Africa, Asia, Europe, Latin America and the Caribbean, Middle East, United States	To promote extractive sector transparency and accountability	Research and advocacy
Greenpeace International	Africa, America, Europe, Asia and the Pacific	To change attitudes and behaviour, to protect and conserve the environment and to promote peace	Global campaigns against environmental degradation
Earth Justice	San Francisco, USA and International partnerships	To promote a healthy environment: wild, communities, healthy climate	Litigation
Earth life Africa	Johannesburg, Pretoria, Durban, Cape Town and Namibia	To encourage and support individuals, businesses and industries to reduce pollution, minimise waste and protect our natural resources.	Campaigns: AMD, Biodiversity and toxins, renewable energy, nuclear energy, climate change
International Council on Mining and Metals	United Kingdom	To enhance mining industry’s social and environmental performance and its contribution to society	Environmental stewardship, role of mining to society, human wellbeing

The air quality of the Province, particularly on the Highveld, is among the worst in the country due to coal mining and other industrial activities such as power generation, coal-to-liquids conversion, metals (steel and ferroalloys) manufacturing, transport and agriculture (Dlamini, 2007; CER, 2016). Not only does the Mpumalanga Province coalfield account for over 84% of South Africa's coal production, it also contains 46.4% of the country's major arable soils and is a major producer of maize.

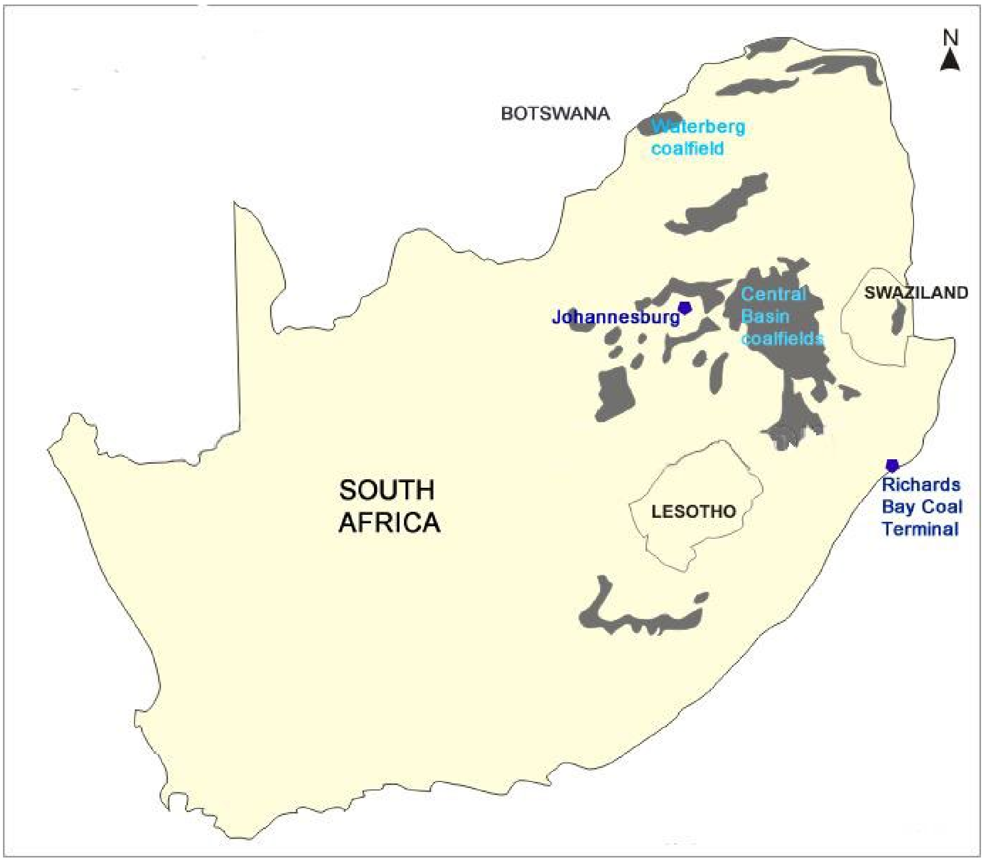


Figure 3-2 Coalfields of South Africa (Bench Marks Foundation, 2015)

Of the coal produced, 85% production comes from the major coal producers, namely Anglo American's Thermal Coal business unit, Exxaro, Sasol Mining, BHP Billiton (now South32) and Xstrata. According to Munnick (2010), approximately 51% of South African coal mines are underground and 49% open cast (or open-pit) in which a large area of the coal deposit is exposed by removing the covering rock (the overburden) from the mined area, before coal extraction, usually using trucks and mechanised shovels or bucket-wheel excavators.

In accordance with available statistics (Prevost, 2010), approximately 60% of the 312 Mta raw coal mined in South Africa in 2007 was beneficiated, resulting in a conversion of ROM coal to washed saleable coal of 41% and to raw (unwashed) saleable coal of 39%. These values indicate a considerable decline in the proportion of washed ROM ore in comparison with 2002/2004 data as reported by de Korte (2004) and Reddick (2006), which indicated that between 80 and 85% of the ROM is washed in some 60 washing plants. Values for overall product yields (typically 76-80% of the ROM coal) and deportment to discards (typically 21-24% of ROM coal) have, however remained relatively consistent over the past decade. Figure 3.3 presents the relative proportions of ROM coal that are screened and washed, and ultimately recovered as saleable coal product (including raw coal and beneficiated product) for 2007 (Prevost, 2010).

The processed coal is used primarily to produce electricity by ESKOM and liquid fuels and chemicals by Sasol (SACRM, 2011) but a large volume of it is exported to other countries mostly Europe, China and India through the Richards Bay Coal Terminal (RBCT). Other users are small sectors including steel, iron, and ferroalloys, industrial and manufacturing.

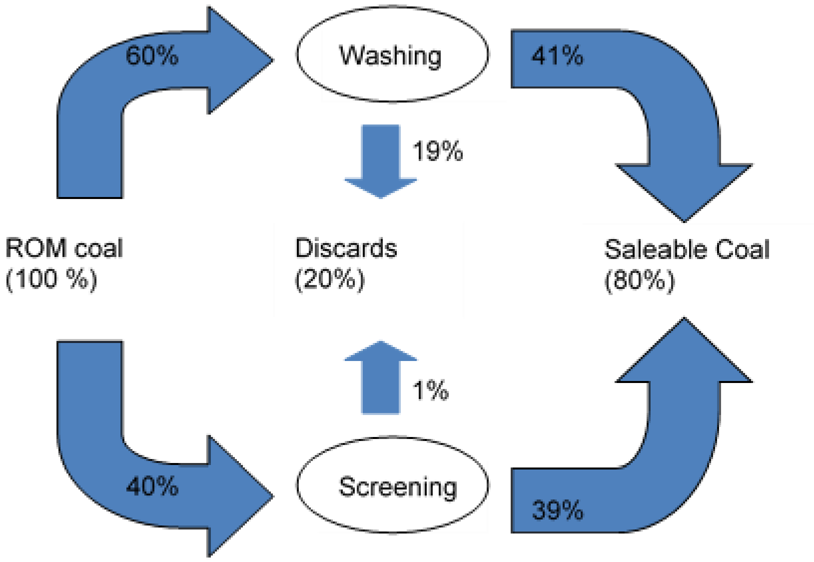


Figure 3-3 South African coal chain showing relative distributions of ROM coal (after Prevost, 2010)

3.2.1.2 *Challenges facing the coal industry*

Whilst coal has historically been one of the world's most used resource, it is currently being increasingly displaced by less carbon intensive energy sources, such as gas, nuclear and renewables, and global patterns of coal consumption are changing dramatically. Some countries in Europe have rendered coal mining as obsolete, with France closing all coal mines in 2004.

Nevertheless, recent reports show that coal production and utilisation remains significant, with coal remaining a dominant source of power in many countries of the world, due largely to its affordability (Morrice and Colagiuri, 2013; SACRM, 2011). China is the lead producer of coal in the world with the United States coming second. Having traded about 74 million tons of coal in 2012, South Africa is ranked the 7th largest global coal producer and sixth largest coal exporter.

South Africa's on-going dependence on coal as a source of power in the face of climate change pressures and declining reserves has been the topic of much debate in the country. Climate change impacts due to greenhouse gas (GHG) emissions are a particular concern to South Africa. Apart from being highly dependent on coal as a source of energy, the good quality coal is generally exported leaving the lower quality to be burned by coal fired power-stations which adds to South Africa's carbon footprint and dirty emissions (Munnick, 2010).

As such, South Africa was declared the largest emitter of carbon dioxide on the African continent. Hartnady (2010) predicted that South Africa's demand for electricity would outstrip coal supply by 2020, whilst highlighting that resource estimates were not adequate for informed projections on the future of the coal industry. Following these reports, the South African Coal Roadmap study (SACRM), a collaborative initiative between the South African government, major coal consumers, coal producers and other stakeholders, was initiated to explore the state of the country's coal industry and the issues it faces, and to develop a clear roadmap of the preferred path for the industry (SACRM, 2011). The SACRM study recognises the benefits from the industry in terms of income, employment, energy and the potential for continued economic benefit and energy security, but also identifies a downside within the coal industry. Many of the critical challenges outlined in the SACRM reports are of an institutional nature. In particular, the resource and reserve information is not up to date, and there is no clarity on the outlook of the coal industry on a national level. Climate change pressures, the availability of infrastructure and resources such as water, access to financial capital investment and the continued adverse impacts of coal mining on the local environment and surrounding communities were also highlighted (SACRM, 2011).

As the reserves of the central coalfields (Witbank, Middelburg and Highveld) become exhausted and focus turns to the richer northern coalfields in Limpopo, these challenges are likely to increase. This is due to a combination of challenges associated with the Limpopo coal reserves and geo-political climate, particularly the low-grade, depth and geological complexity of the deposits; severe water shortages; insufficiently developed infrastructure; and fragile natural environment (Jeffry, 2005). As per the provisions of the National legislation, the issues concerning the long term sustainability of mining communities will also need to be considered in this relatively remote and undeveloped area.

The broader challenges facing the coal sector notwithstanding, this case study is specifically concerned with the environmental and associated community-related impacts associated with coal mining operations with a specific focus on the Mpumalanga coalfield region.

3.2.2 Case study methodology

This case study was qualitative and applied a combination of desktop review and case study field work. The scope of work was conducted in two phases as described in Sections 3.2.2.1 and 3.2.2.2.

3.2.2.1 Review of published literature

A detailed review and assessment of the published literature was conducted with respect the environmental and social impacts of primary coal production in South Africa; associated conflicts between local coal mining companies and communities; and the actions taken by various stakeholders to address these impacts. This theoretical base drew on i) published scholarly opinions on the impacts of coal mining on the environment and community quality of life, and ii) published reports including company reports on cases of pollution, concerns, conflicts and responses pertaining to coal mining communities.

3.2.2.2 Semi-structured interviews

Semi-structured interviews with community representatives, community-support organisations and environmental consultants were conducted with a view to establishing a deeper understanding of local communities' views pertaining to the environmental and social impacts associated with coal mining and processing activities in the Mpumalanga Province; the extent to which such concerns are being/have been reported and addressed; and stakeholder (government, company and NGOs) roles and mitigating actions. For this purpose, a questionnaire was designed consisting of pre-set variables, from which participants rated their responses using a Likert scale, and simple comprehensive open-ended questions. Selected participants included community members (participants 1-2, with participant 2 comprising a group of 3 community activists), representatives of civil society organisations (CSOs, participants 3, 4, 5, 9 and 10) and professional environmental consultants (participants 6, 7 and 8) actively involved in services and programmes relating to environmental and social justice in the context of coal mining within the Mpumalanga Province. Although relatively limited in number (thirteen in total), these participants all have extensive experience and/or expertise of relevance to this study and can thus be considered to provide adequate representation of the general concerns and perceptions amongst the communities and local experts. Further details on the interview process and participants are provided in Appendix A.1

3.2.3 Case study outcomes

This section of the report assimilates the findings of the literature review and stakeholder interviews. Section 3.2.3.1 provides an overview of the reported, experienced and perceived environmental and associated social impacts pertaining to coal mining, whilst Section 3.2.3.2 summarises the stakeholder initiatives, aspirations and expectations.

3.2.3.1 Environmental and related social impacts

Although affordable, reliable and secure, coal is generally considered a dirty source of energy because of its impacts. Apart from the generation of greenhouse gases and other pollutants during combustion, the extraction and production of coal results in land degradation and loss, subsidence, water consumption and pollution, dust, increased traffic, noise and other disturbances such as vibrations and subsidence (Bell et al., 2001; CER, 2016; Moffat and Mulloli, 2003; Morrice and Colagiuri, 2013; SACRM, 2011; Zhengfu et al., 2010). According to a report by ActionAid (2014), there are 22 mines in an area with a radius of no more than 20 km in Mpumalanga, many of which are abandoned, and the area is characterised by severe air, water and soil pollution. A report by van Wyk (2014) on behalf of the Bench Marks Foundation focuses on the impacts of coal mining operations on communities in the Nkangala District including Witbank (eMalahleni) and Middelburg (Steve Tshwete). In accordance with this report coal mining is seriously impacting on the surrounding communities as a result of environmental pollution and reduced access to agricultural land and water. The study also found that many small farmers along the roads to Kendall and Ogies have switched from farming and converted their land into truck stops to service the collieries in the area. Furthermore, farming exports have been affected as farmers have lost European clients due to the effects of poor quality irrigation water on crops. Environmental pollution has also affected livestock fertility and milk production. The recent report by GroundWork (Hallowes and Munnik, 2106) reflects the frustration and concerns over the impacts of coal mining, of many farmers in Mpumalanga.

The survey and semi-structured interviews, conducted with selected community members, non-profit organisation representatives and independent environmental consultants actively involved in the coal mining activities within the Mpumalanga Province of South Africa, reflected considerable concern by all participants over the environmental and social impacts, and the perceptions of the coal mining and processing sector were largely extremely negative. Community activists were particularly negative and considered coal mining to have a significant impact on the local environment and eco-systems, and on human health and activities, such as agriculture and livestock farming. The biggest concerns amongst all participants (see Figure 3.4) related to occupation of land, declining water quality and soil fertility. Land subsidence, destruction of aquatic life, loss of soil fertility and the associated decline in crop productivity were also rated as posing a high to very high risk by most of the participants, followed by air pollution, human health and livestock productivity. Other concerns related to blasting, which cause damage to housing, and the transport of coal, which damages the roads.

Further details on the specific environmental and associated social impacts, concerns and perceptions from coal mining, with particular emphasis on the Mpumalanga coalfield region are provided in Sub-sections i to iii.

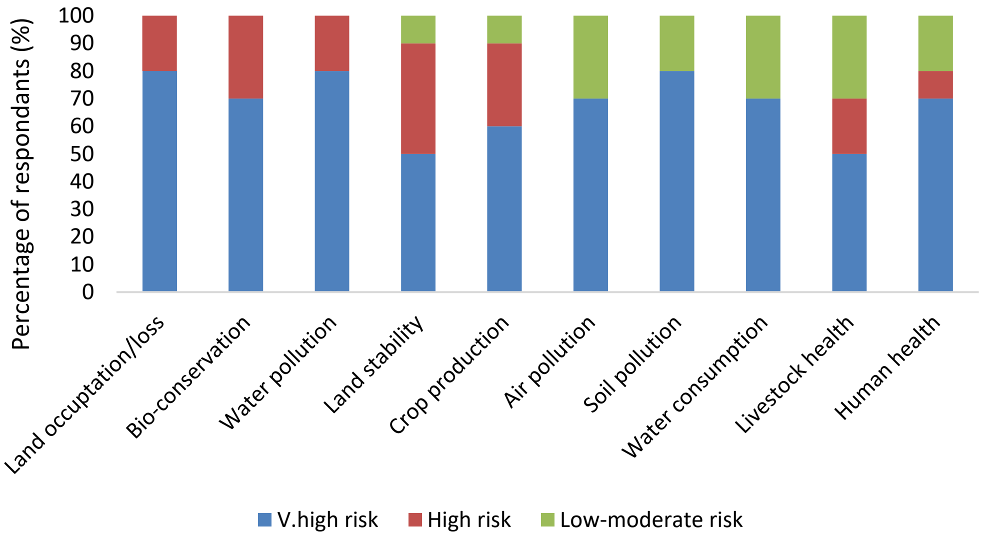


Figure 3-4 Participant concerns and perceptions on environmental and associated social impacts from coal mining

i Land occupation and degradation

A survey of the literature indicates that coal mining is generally associated with extensive displacement of existing land use and dramatic landscape change (as shown in Figure 3.5); land occupation and deforestation mainly occurring as a result of excavations, erection of supporting and processing infrastructure; and the disposal of waste in the form of overburden, discards and slurry (Bell et al., 2001; Sonter et al., 2014; Zhengfu et al., 2010). Land disturbances can also extend beyond the mining site, as a result of land subsidence, commonly associated with underground mining, and the dispersion of dust and contaminated water from operations and waste dumps.

(Source: GDACE, 2008)

Figure 3-5 Aerial view of an open cast coal mine showing the extent of land disruption (GDCA, 2008)

The risks and impacts of coal mining on land occupation and loss, as well as land pollution and erosion, in the Mpumalanga province were rated as very high by 80% of the interviewees. Land subsidence was also rated as high to very high risk by 90% of the participants and was perceived to mostly occur as a result of abandoned mines and lack of proper rehabilitation.

Participant concerns in terms of land centred largely on relocation and resettlement, the loss of productive land, as well as land use change, both during and after mining.

“Very high productive land is taken up by open cast coal mining” – Participant 7
“In any case land is lost because of the scale at which mining occurs in South Africa” – Participant 9
“Mining is always 100% destructive and it will always have a fundamental change in land use before and after mining” – Participant 8.

It was noted that issues of relocation and resettlement were most important to community activists. In terms of land degradation, subsidence was generally considered to be a significant issue in the Mpumalanga Province, particularly with respect to abandoned mines that have not been adequately rehabilitated. Whilst subsidence risk is mainly a function of the depth and type of mining employed, the use of heavily loaded mine machinery and transport and illegal mining were also mentioned as contributing factors. Participants also highlighted the safety risks that land subsidence poses to communities and reported incidents.

“… children had fallen into the sinkholes and old people burnt on their feet” – Participant 10 and “houses disappear into sinkholes, children and livestock fall and if there’s water at the bottom, there can be drowning” – Participant 9.

Whilst some participants felt that the long-term effects of mining on land use and productivity could be avoided through proper rehabilitation, concern was also expressed that soil fertility in mining areas could never be effectively restored, thus affecting the ability of the land to support agricultural and other framing activities post-mining. Participants reported that crops in the Mpumalanga region are stunted, resulting in a decline in crop quality and to rising food prices.

“You cannot farm in co-existence of mining” – Participant 3

Of particular concern was the effect of coal mining on maize production, with a very large area of the Province’s open pit workings situated on the old maize triangle. According to one participant, maize is pH sensitive and when soil acidification takes place, the root tips may stop growing.

“I have a working relationship with the Mpumalanga Agricultural Union, farmers are complaining about the quality of crops, they fail quality tests and as a result they cannot export. They sell locally and that doesn’t make business sense” – Participant 10
Some participants were of the view that the decrease in soil fertility due to coal mining could ultimately have an impact on national food security.
“I would go beyond talking about water quality and quantity and soil fertility and start talking about food and water security” – Participant 9

ii Air pollution

Globally, air pollution from operational and abandoned coal mines is mainly due to the emissions of particulate matter (PM) and gases such as methane, sulphur dioxide (SO_2), hydrogen sulphide (H_2S) and oxides of nitrogen (NO_x) (Zhengfu et al., 2010). In accordance with a report by the Centre for Environmental Resources (CER, 2016), coal mining and coal-based power generation is by far the largest contributors of gaseous emissions on the Highveld, accounting for 89% of PM, 90% NO_X and 99% of SO_2 releases. Of specific concern to coal mining is spontaneous combustion, which occurs as a result of self-heating on exposure coal to air and moisture, which occurs at mine workings and within waste dumps (Pone et al., 2007). The susceptibility of coal to self-heating is dependent on a number of factors including coal rank, exposed surface area, moisture and pyrite content, and is aggravated by land subsidence, which allows free passage of air into mine, creating an ideal situation for spontaneous combustion of the coal (Bell et al., 2001). Apart from hydrocarbons, halocarbons and greenhouse gases (Pone et al., 2007), concerns have also been expressed regarding the possible release of toxic metals, such as arsenic and mercury during spontaneous combustion (Munnick, 2010), although there appears to be little quantitative data to support this. Also of environmental concern are the solid by-products of spontaneous combustion, left on the surfaces of the coal deposits.

According to Pone et al. (2007), these are mostly oxidised sulphur and sulphur-bearing minerals, which may be leached into the surrounding environment on exposure to water. However, reports of spontaneous combustion in underground coal mines in South Africa are now rare and, in accordance with an inventory compiled by the Department of Minerals and Energy (DME, 2001), there has been a marked reduction in fires on coal wastepiles over the past decade (6% of dumps burning and 17% partially burned in 2001). In contrast, a report by Coaltech report (Coaltech, 2011) states that discards from current and future surface mining operations in the Waterberg coalfield are still considered to pose a serious spontaneous combustion problem.

Whilst interviewees considered coal mining to have a significant effect on air pollution in Mpumalanga, overall the participants considered dust or particulate matter emissions from active coal mines to be of more concern than gaseous emissions through spontaneous combustion of waste dumps and mine workings. Dust containing toxic metals were linked to human health issues, and livestock and crop productivity.

Air pollution by coal dust was considered to pose the biggest health risk to local communities in Mpumalanga, with the majority of the participants attributing elevated cases of asthma and chronic illnesses, such as cardiovascular and kidney diseases, to the inhalation of coal dust.

“My whole family has asthma, my father worked at the coal mines for years and he died from kidney failure, a kidney stone was found in his body” – Participant 2

In a study based on household-level data collected from four mining (polluted) villages and two control (non-polluted) villages, Hota & Behera (2015) showed that people residing in coal mining communities are indeed at an increased risk of developing chronic diseases including heart and lung disease, cancer, hypertension and kidney disease. This is also consistent with a report by ActionAid (2014), which claims that members of coal mining communities have a 70% greater risk of developing kidney disease; a 64% greater risk of developing chronic obstructive pulmonary disease (COPD) such as emphysema; and are 30% more likely to report high blood pressure/hypertension. In the United Kingdom (UK), a study by Hendryx (2015) showed a significant increase in medical visits for asthma in conjunction with the opening of a surface mine. Whilst a similar study by Moffat and Mulloli (2003) found no direct link between coal mining and the prevalence of asthma in children, an increase in dust fallout in the vicinity of an opencast coal mine did correlate with an increase in GP consultations for respiratory conditions. A survey of the health and environmental concerns of parents living close to opencast mines in the UK indicated a high degree of uncertainty in terms of health risks, and a need for enhanced dust and air quality monitoring in the vicinity of coal mining operations (Moffat and Mulloli, 2003).

Another form of air pollution threatening the health of mining communities, is due to the direct combustion of low-grade coal, obtained directly from defunct mine dumps for domestic use. This is considered to be a significant cause of human health problems (such as cardiovascular diseases, sinuses, asthma).

“The people there do not have electricity, so they burn the coal and make imbawulas” – Participant 10

Zheng et al. (1999) reported that in Southern-west China, 15 million people suffered from fluorosis; more than 300 had arsenism and 477 people had endemic selenosis due to the use of high fluorine, arsenic and selenium coal in unvented ovens. In South Africa, the informal mining and use of coal for residential purposes appears to be shaping the way of life for people living in proximity to Coronation coal mines in Mpumalanga Province. According to ActionAid (2014), the coal waste piles at an informal settlement at Coronation are being mined by informal miners, including children, for their own energy needs and also as a form of income (see Figure 3.6).

Figure 3-6 A woman standing in a sinkhole while digging for coal and a man firing up an imbawula that will be used at home for heat and cooking (ActionAid, 2014).

This activity entails the use of low-grade coal for domestic purposes at an unregulated level which in turn may present health problems, due to the volatilisation of toxic elements during combustion. Potential health risks posed by elements commonly associated with coal are presented in Table 3.2.

Table 3-2 Possible health impacts of trace elements from coal (Finkelman et al., 2002; Zheng, 1999)

Element	**Health Impact**
Fluorine	*Fluorosis:* mottling of tooth enamel, osteosclerosis, limited movement of joints, knock-knees, bow legs, spinal curvature
Selenium	*Selenosis*: Hair and nail loss, skin discoloration
Arsenic	*Arsenism*: pigmentary skin changes: flushed appearance, hyperkeratosis: freckles, scaly lesions on the skin Bowen's disease: dark, horny lesions of the skin Squamous cell carcinoma
Mercury	Hair loss, loss of vision

Some of the participants (40%) also attributed the decline in soil fertility, and the consequent decline in crop productivity or even failure, to coal dust fallout. Coal dust was also believed to cause a decline in the quality and quantity of milk production, due to contaminated grazing lands and cattle fodder.

"Every crop there is black" – Participant 2

The contribution of other industries, including power generation, to the elevated levels of air pollution in the Mpumalanga province was, however, also acknowledged, whilst it was recognised that the wide-spread dispersion of coal dust from mining activities and waste dumps can be prevented if effective mitigation measures are implemented.

"It is a manageable problem associated with dust from active coal mines or where you have unrehabilitated dumps particularly of carbonated waste that combusts and gets fires – that can be overcome if its rehabilitated" – Participant 9.

iii Water consumption and pollution

Water consumption occurs mainly in underground mining, coal preparation (or beneficiation) and in dust suppression. South African coal preparation plants are reportedly using half a tonne of water per tonne of high grade coal washed (Mangena and Brent, 2006). Consumption may vary according to the operations: low-grade coal preparation plants involving simple crushing and screening use less water whilst plants involved in dust suppression activities and in irrigation of reclaimed land and deposition of large amounts of low-density slurry consume larger quantities. In surface mining operations dust control alone consumes around 22.8 litres of water per ton of coal produced (Mavis, 2003), whilst in underground coal mining, which is generally the more water-intensive method, water is required as a coolant for cutting surfaces and for the prevention of fires and explosions (Mavis, 2003).

Overall, there were mixed responses from interviewees regarding water consumption by the coal mining industry in Mpumalanga. Some participants considered the coal mining sector to be a significant consumer of water, particularly in terms of dust suppression and coal processing.

"Coal mining is an intensive process, coal has to be washed, mined and crushed and that uses a lot of water" – Participant 9

"Mines use a significant amount of water which cannot be re-used for consumption, yet government blames households and farms for using more water and leaves out the mines" – Participant 2

"…they use tonnes and tonnes of water, yet people go for weeks without water, the law says everyone has a right to clean water… government is doing nothing about it" – Participant 1

There were also concerns regarding the impact of water withdrawals by the mining operations on natural water sources, such as rivers, surface pans and groundwater aquifers. Not all the participants, however, considered coal mining to pose a significant risk to the water resource on a provincial level, particularly relative to that posed by the agricultural sector. Professional environmental consultants, in particular, highlighted the efforts by mining companies to minimise water withdrawals by adopting re-use and recycling approaches.

"Modern mines recycle every drop of water, it goes into a tailing facility and back into the plant" – Participant 6

"Mines are generally capable of generating their own water, it is possible to dewater coal seams and use that as part of processing water – the biggest user of water in coal mining is the dust suppression" – Participant 8

It is, however, the impact of coal mining on water quality of local water resources, particularly as a result of ARD emissions in Mpumalanga, which raised the bigger concern amongst interviewees. Poor water quality, particularly in the Witbank Dam, the Olifants River and the Loskop Dam, was mainly linked to ARD emissions from both mine workings and waste piles. Community representatives noted frequent discoloration of local tap water, attributing this to aid rock drainage (ARD) pollution from coal mining:

"The water from the taps is not clean, sometimes it is a brownish coffee-like colour and sometimes too much white, even an uneducated person can tell you" – Participant 1

Impact on water quality is generally considered to be the coal mining industry's most severe environmental impact (McCarthy and Pretorius, 2009; Reddick, 2006), with the main sources of water pollution including: acidic or circum-neutral pH drainage from mine working; sediment runoff from mining site; oil and fuel/workshop effluents; leaching of pollutants from waste dumps; and sewage effluent from site (Tiwary, 2001). Data reported by Annandale et al. (2009) has shown that mine water from collieries in the Mpumalanga, Free State and Limpopo Provinces contains elevated levels of metals and salts, even in cases where the pH is neutral. The generation of ARD from South African opencast and underground coal mines is described extensively in Vermeulen and Bester (2006). Apart from mine workings, seepage and run-off from coal waste deposits can also be a major source of water pollution. Bosman and Kidd (2009) have reported that discard dumps and slurry disposal ponds pose a high groundwater pollution risk. Location of South African coalfields in the sensitive upper reaches of major river systems such as the Vaal, Olifants, Usutu, Komati, Pongola and Tugela rivers are linked directly to extreme pollution and environmental impacts related to water. Elevated salt levels in the Witbank and Middleburg dams over the period 1972-2007 have also been attributed directly to coal mining (McCarthy and Pretorius, 2009).

As discussed in Sections 3.2.2-3.2.4, ARD has the potential to impact significantly on a number of economic sectors such as agriculture (grain farming, stock farming, mushroom farming, food processing, etc.) and tourism (Chamber of Mines, 2014; Naidoo, 2009; Wait, 2010). ARD also carries significant health risk to communities that come into contact with contaminated water, soil or crops. As in the case of coal dust, participants linked ARD pollution to a number of challenges in Mpumalanga, including soil fertility, crop production and the health of humans, livestock and aquatic life. Drinking of water polluted with AMD and ingestion of contaminated crops was also noted as a as a major cause of human and livestock health problems such as impairment in cognitive function, skin lesions, neural defects in foetus development.

"Many of the farmers in Mpumalanga are complaining of their livestock dying from drinking borehole water" – Participant 4
"The livestock there is thin, and their skin is patched off" – Participant 1
"When you have a stomach-ache and go to the clinic, they advise you to drink borehole water instead of tap water. At some point a nurse resigned after revealing that they are trained not to inform us what really it is in the water that is making us ill"
The acidity and toxicity in RMD polluted water decants the water quality was also considered to have a negative, fatal impact on aquatic biota.
"There is nothing living, people are no longer fishing" – Participant 1
"Serious impacts on aquatic life do happen and will continue to happen in that area" – Participant 6

3.2.3.2 Stakeholder initiatives, aspirations and expectations

Coal mining and its impacts on the surrounding environment and the quality of life and livelihoods of local communities is an on-going source of conflict between the various stakeholders (society, government and industry) in many parts of the world. In Australia conflicts are mainly attributed to concerns over water, food security, health, community impacts, local and national economic imbalances, property rights and climate change (Duus, 2013). In particular, local communities and farmers are concerned about the impact of coal mining on surface water quality, livestock health, loss of fertile cropping land and food production potential. These concerns led to the rejection of a number of applications to expand and develop new coal mines over the period 2010-2012. Similarly, there have been a number of conflicts and reported incidents associated with coal mining in many part of South Africa, particularly in Limpopo, KwaZulu-Natal and in Mpumalanga. In the Limpopo Province, mine company-community-government conflict has been evident between Coal of Africa Limited (CoAL) and a local community (Prinsloo, 2014), with two of its mines, the Vele and Makhado projects, having received strong opposition from community members, NGOs and some government departments. Opposition relates to inadequate consultation as well as environmental impacts and human rights violations. Of particular concern in the case of the Vele mine was the potential of the mine to consume high amounts of water, ground water pollution, dust pollution from mining transport and destruction of agricultural and tourism activities and jobs. In Northern KwaZulu-Natal, strong resistance to the proposed Ibutho Coal Mine by residents from Fuleni, at Mtubatuba, has been going on for two years (EJA, 2016). The Fuleni community is against the mine mainly due to its possible impacts on the Mfolozi Wilderness area (particularly the Hluhluwe Game Reserve), livelihoods through crop and livestock farming, water and health. The proposed mine will be on the boundary of the reserve and about 500 metres from the local settlements. The Mfolozi Community Environmental Committee Justice Organisation (MCJE) are also advocating for the communities, linking the impacts from the coal mine on the local communities with wider climate change and governance issues. In particular, the Mpumalanga Province, where the majority of coal mining activity takes place in South Africa, has been at the centre of considerable dispute between coal mining companies and local farmers who complain about the effects of water contamination and mine dust on their crops (Biyase, 2015a). At the centre of controversy in Ermelo, is the Imbabala open pit coal mine which was closed by the DMR in 2011 following environmental compliance offences. The mine currently lies abandoned and unrehabilitated (Biyase, 2015b). Conflicts between communities and the government over the granting of mining rights in Mpumalanga continue to this day. Indian-owned Atha-Africa was granted a mining right by the Minister of Mineral Resources in 2015, shortly after the declaration of the environmentally protected area by the Mpumalanga MEC. Since then, Atha has received licences and approvals from the Mpumalanga Environment Department, the Department of Water

& Sanitation, and the Minister of Environmental Affairs. All these approvals have been challenged by a coalition of eight civil society and community organisations through internal appeals, and a High Court judicial review of the original mining right granted (https://cer.org.za/news/speaking-truth-to-power-cers-2017-in-review)

The environmental and associated community-related impacts outlined in Section 3.3.1 thus not only affect local communities, but they also pose management challenges for mining companies and regulatory agencies (Sonter et al., 2014). This study also sought to establish current and emergent responses to these impacts by industry (sub-section i) and government, (sub-section ii), as well as the initiatives, aspirations and expectations of communities (sub-section iii).

i Coal mining industry initiatives

With greater awareness and stricter environmental laws, mining companies have paid more attention to their environmental practices and strategies and community projects, including the development of technologies for air quality management (including the reduction of dust and methane emissions), water and waste management, and strategies for rehabilitation and closure.

- Mine waste management

The South African Coal Road Map (SACRM, 2011) provides details on how the management of waste has evolved in the years, mostly in response to the growing concerns on the impacts from coal mining. To reduce chances of spontaneous combustion on dumps, discards are now mostly spread and compacted to eliminate airflow into the dump (SACRM, 2011). In a method called integrated disposal, dewatered ultra-fine mine waste is co-disposed with the discards, thus simultaneously reducing water losses and creating a waste matrix that is stable and non-oxidising. Discard facilities are also now being clad with soil and vegetated to prevent all forms of atmospheric pollution and dumps are now being constructed with run-off paddocks and borehole collection systems to control and collect run-off and seepage (SACRM, 2011).

- Water management

Paradoxically, whilst civil society in Mpumalanga struggle with water-scarcity above ground, the mines in the Province, some of which have reached the end of their working life and others which are still operating, are constantly having to deal with an excess of ingress groundwater. This mine ingress water poses a challenge to both operating and closed mines as it is contaminated by elevated levels of salts and metals, and is often highly acidic. It is thus unfit for human consumption or use and, without adequate management and resources, can lead to pro-longed pollution of groundwater and, ultimately, surface waters. It was against this background, that Anglo American’s coal division (Anglo Coal), BHP Billiton Energy Coal South Africa (now owned by South32), and the eMalahleni Municipality embarked on a joint initiative to install the first commercial plant in the world for recovering potable water from acid rock drainage (ARD) in 2007 (Gunther et al., 2006). The operational eMalahleni Water Reclamation Plant (EWRP) uses a combination of lime neutralization (HDS process), reverse osmosis (HiPRO process) and ultrafiltration treats contaminated mine water from operating and defunct coal mines in the province for the past 10 years, and has recently undergone an upgrade and modification to extend capacity to 50 ML/day. On the back of the success of the EWRP, a mine water reclamation demonstration plant was commissioned at Optimum opencast coal mine (Cogho, 2009), followed by a second full-scale plant at Glencore’s Tweefontein Colliery in 2016. The Tweefontein plant also uses the HiPRO desalination process to treat excess mine to drinking water standard, producing 15-20 ML/day potable water, a portion of which is to be supplied to the local municipality at municipal tariffs.

Building on the success of these initiatives, the collaborative Mine Water Coordinating Body (MWCB), which was established as an outcome of the broader Strategic Water Partnership Network (SWPN) in 2017, has recently instituted a number of cross-sectoral and multi-stakeholder projects to promote integrated use of mine owned land and water and energy infrastructure to foster regional development in the Mpumalanga coal fields.

- Land rehabilitation

Despite the challenges involved, many mining companies have made concerted efforts to improve their rehabilitation efforts, in line with guidelines published by the Chamber of Mines and Coaltech (Chamber of Mines and CoalTech, 2007). For instance, Glencore Coal South Africa took the initiative to rehabilitate Voorslag Farm section of the Spitzkop Mine whose operations had ceased in 1984 and had been poorly rehabilitated (*http://www.glencore.com*). The site had gone derelict with poor water quality, eroded infertile soils and limited vegetation. In early 2000s, efforts were made to restore the soil fertility, land capability and water quality at the site. A biodiversity management plan that included alien plant control and wildlife management was also developed. The water quality was improved to a neutral pH status and reduced levels of sulphate runoff through developing a water improvement system and long-term water management strategy (*http://www.glencore.com*). Anglo American recently embarked on a post-mining land-use project, as part of its rehabilitation work at Kriel Coal Colliery in Mpumalanga. Initially as a trial, maize was planted on 400 hectares of rehabilitated land with a successful harvest after which soya beans were also successfully planted and harvested on the same land. The decision to plant soya was based on the view that this can improve the soil's nitrate concentration, which means that fertilizers would not be used in the next stage of the crop rotation cycle. The next phase of the mine's study will look into assessing and addressing soil nutrient deficiencies and any other factors that could impact crop yields (*http://www.angloamerican.com*).

- Community health

As indicated in Section 3.2.3.1, the domestic use of coal, particularly low-grade coal waste, has significant health implications. Anglo Coal initiated a funded project to make the domestic use of coal safer and less harmful to individuals and the environment in the Vosman Township near Witbank in Mpumalanga, South Africa (Balmer, 2007). Anglo Coal appointed a private research and consulting firm to implement a demonstration and training programme on an alternative fire lighting method called " Basa Njengo Magogo" also known as "top-lit up-draft stoves" to 10 000 households. The method involves stacking a coal fire differently and lighting from the top (Balmer, 2007). According to Balmer (2007), this method has the potential to eliminate more than 80% of smoke and this not only has an impact on health but when implemented on a wide scale can result in coal and monetary savings for low-income households.

ii Government initiatives

Over the past two decades, there have been several legislative reforms and regulations have become more stringent placing social and environmental well-being as much a priority as that of the economic benefit of mining. The Minerals and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002) administered by the DMR succeeded the Minerals Act No. 50 of 1991 which provided a basis for environmental management for the first time in South Africa (Limpitlaw et al., 2005). Specifically, the Act requires that rehabilitation be sustainable and support environmental, social and economic development. Another recent example of regulatory reform designed to protect the environment, is the Waste Amendment Act 26 of 2014.

In addition, the DMR recently completed an extensive legislative review that resulted in the removal of environmental authorisation legislation from the MPRDA into the National Environmental Management Act (NEMA) effective as at 25 November 2015 (http://institutionalimpact.co.za). This change was done to create one environmental system of laws that govern the mining industry's rehabilitation obligations. According to Mining Review Africa (2016), NEMA now requires three closure plans: an operational rehabilitation plan, a final rehabilitation plan and a post-closure rehabilitation plan. Mining companies that do not comply will be subject to fines of up to R10 million, 10-year prison sentences or both (Mining Review Africa, 2016). Legislative and regulatory reforms are also aimed at improving social equity and protecting the socio-economic well-being of local mining communities. These aspects were emphasised in the amended Mining Charter, released in June 2017. Although there is no denying the need for socio-economic transformation, the contents of the new Charter have received strong criticism from the Chamber of Mines, mining analysts and mining companies (Brown, 2016). Objections include the lack of stakeholder engagement in developing the charter and the practicality of new regulations, pertaining to ownership and procurement (Peyper, 2017; Brown, 2016).

Operation Phakisa, a South African government initiative administered through the Department of Planning, Monitoring and Evaluation and launched in July 2014, aims to fast track the implementation of development issues by economic sectors, including the mining sector. The Mining Phakisa which took place for 5 weeks in late 2015 was intended to address issues undermining the competitiveness of the sector (Mining Weekly, 2015). Implementation strategies for the long term development and transformation of the mining sector were designed through a laboratory process in which key stakeholders from the public and private sectors, academia as well as civil society organisations collaborated (http://www.operationphakisa.gov.za). Within the sector, the initiative targeted promoting investment into the sector, greater exploration activities, participation of emerging miners, jobs and skills development, infrastructure, social and community development and research, development and innovation (DPME, 2017; Mining Weekly, 2015). Mine rehabilitation interventions is also an area of focus within Mining Phakisa. The effectiveness of this initiative in addressing the challenges and issues facing the sector is still to be proven.

The revitalisation of distressed mining communities programme is another government initiative aimed at improving socio-economic challenges in mining towns and their labour sending areas. The programme forms part of the Special Presidential Package (SPP) Social Accord signed between government, business and labour in October 2012 (DPME, 2017). Nineteen mining areas in 6 provinces namely the Northern Cape, Free State, Gauteng, Limpopo, Mpumalanga and North West and their associated labour sending areas have been prioritised for the programme. In the KwaZulu-Natal and Eastern Cape Provinces, 12 labour sending areas have also been prioritised (DPME, 2017). The programme focuses on integrated and sustainable human settlements, improved working and living conditions of mine workers, and meaningful contribution to the development trajectory of mining towns and labour sending areas. Another objective of this programme is to evaluate the relevance and effectiveness of the environmental governance legislation in mining and the implementation of the Mining Charter in order to strengthen the realization of the objectives within the Charter). Since its inception in 2012, several surveys have been conducted and interventions implemented. This include the development of a state supported mine worker housing model, infrastructure provision and public sector housing projects, and a number of large and small scale industrial projects aimed at creating businesses and employment opportunities in coordination with municipal economic development plans (DPME, 2017).

iii Community initiatives, aspirations and expectations

- Reporting of concerns and incidents

As per the discussions above, public protest has historically been one of the main responses to community concerns over environmental and social injustices by the coal mining sector. With the growing number of community support organisations, community concerns and grievances have been increasingly communicated to the general public by means of written reports by civil society organisations (see for example reports by the Centre for Environmental Rights (CER, 2016), GroundWorks (Hallowes and Munnik, 2016) and Bench Marks Foundation (van Wyk, 2016)); written and verbal media reports; meetings with mining companies and communities; as well as academic papers and other written outputs. Community and community support organisations in Mpumalanga also indicated that the concerns and incidents have been reported to various government departments and civil society organisations, as well as to local leadership and the management of mining companies and their local operations.

"We have done a number of documentaries, especially on the impact of water"-Participant 4
"Mostly have been reported to mine management where we could" – Participant 7
"Communities raise concerns, they protest from time to time"-Participant 3
"We have reported to the respective departments and to local leadership – Participant 10

However, despite these efforts, most respondents felt that the communities lacked the capability and capacity (both in terms of human and financial resources) to communicate their concerns effectively.

"Communities are not taken seriously, and they do not have the resources and capacity to raise issues in a systematic manner" – Participant 3

“In terms of capacity we are limited, we try as much as we can, everything is documented” – Participant 10

There was also a general perception that the reports were not always being received by the responsible persons and key decision-makers (in mining houses and government).

“Problem is that some of these companies are multinationals, so the word does not get up the ranks” – Participant 7.

This, together with the lack of adequate response from government and mining houses, had served to discourage communities from prioritising reporting. In some instances, this has given rise to what participant 8 termed *‘vigilante activism’*, with certain community activists taking it upon themselves to act in an enforcement role.

- Community perceptions on mining company and government initiatives

Despite the efforts by communities and communities support organisations to report their concerns and incidents of environmental and social injustices, as well as the initiatives implemented by mining companies and government bodies, the general impression amongst interviewees is that community concerns in Mpumalanga are not being taken sufficiently seriously or receiving adequate response from government, mining companies or the general media.

Community activists in particular felt that there has been no response or any plans to mitigate or address the impacts and risks presented by coal mining.

“Nothing has been done, everything has been said verbally” – Participant 1
“The responsible people are never seen; our government doesn’t help one bit; it fails to manage the law and regulations” – Participant 3
“No, they have never been attended to” – Participant 2

Other participants felt that, whilst there had been some response to concerns, these had been insufficient and did not match the severity of the impacts.

“We have had a lot of public response and not had sufficient responses from government and mining companies. Responses have not been satisfactory, and we are worried that government and mining companies are responding appropriately” – Participant 4
“Some of them (i.e. impacts) have been dealt with, some partially and some not at all”-Participant 6
“Response is not sufficient they just appear for a meeting and that’s it”-Participant 10
“Quite a lot has been done – water treatment plants, relocation of people and better, alternative livelihoods…rehabilitation should be much better done and there are a lot of technologies that can be applied”-Participant 7.
“There have been some successes; we have influenced amendments to some policies and regulations although they came at a cost. For example, water use licence and compliance reports are now made available and mining companies (upon application for a mining right) have to make financial provision for the impacts (pumping and treatment of mine waste) throughout the life of the mine and post closure” – Participant 5

According to these participants, some of these interventions had already reduced impacts while others may be expected to do so in the future.

Overall, participants were impressed by the work done by civil society organisations (although more was suggested) in terms of supporting communities but were less impressed by the efforts of the mining corporations and, particularly, the government in addressing community concerns in the context of coal mining impacts.

“…. we have seen it is not a responsible industry although it paints itself as a highly responsible industry”-Participant 9.

The lack of adequate intervention was, furthermore, attributed largely to the political influence and the unethical arrangements between government representatives and mining companies. Thirty percent of the participants expressed concern that the mining companies were not complying with regulations, as they were being unduly favoured by government due to these arrangements.

"We do not have any regulators checking to see that rehabilitation is properly done which means mining companies are left at their own devices…"– Participant 9
"Government is not doing its role, we cannot trust government on their own because senior employees in government are all mine managers" – Participant 3
"Government should enforce its mandate, our worst enemy at the moment is Government more than the mining companies – there is political interference and that often results in no enforcement" – Participant 5

The continuing conflict between communities, government and mining houses is reflected by the number of current class actions in progress.

"We have lots of pending cases, litigation is a long term battle"-Participant 9

- Future expectations for coal mining

Expectations with regards to the coal mining sector in the future were also interrogated. As indicated in Figure 3.7, more than half the participants felt that coal mining should no longer be practiced at all.

"There's no future for mining, they have done enough damage" – Participant 1

Of these six, four participants felt that a move away from coal mining was necessary for investment in alternative sources which are less destructive to the environment.

"We need to reduce coal mining and increase energy generation from alternatives such as wind and sun energy" – Participant 4
"I would hope that government and the nation start realising that we need to stop extracting fossil fuels from the earth and start looking at alternatives forms of energy because we cannot afford to keep doing what we doing from a climate change point of view and death rate as a direct result of air pollution" – Participant 9
"Government should move to renewable energy where the economy is supported without inflicting pain in the health and lives of people" – Participant 10

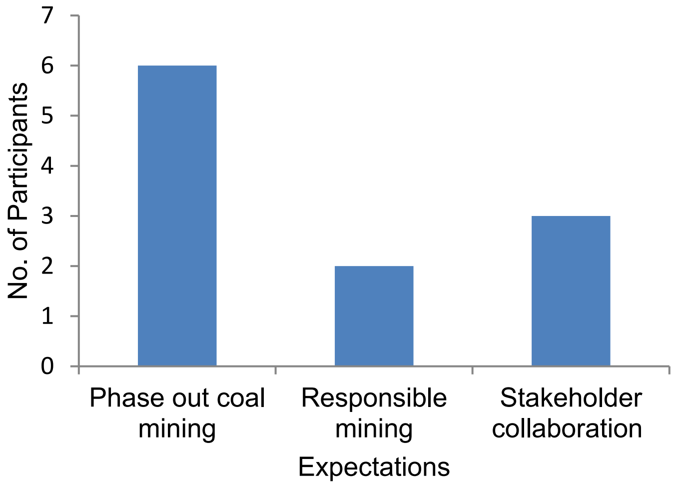


Figure 3-7 Participants Future Expectations for Coal Mining

Whilst the majority of the participants were anti-mining, other participants still felt that coal mining is essential in terms of providing affordable energy and should not be phased out altogether. In saying that, two participants mentioned that the coal mining industry ought to operate in a more environmentally and socially responsible manner, particularly in terms of its waste management and rehabilitation of closed and abandoned mines.

"We need mining companies that are proactive with community needs and with AMD and that will focus on sustainable future land use" – Participant 5

As long as coal mining continued to take place, mining companies were generally expected to comply with Government laws and regulations and requirements, relating in particular to the acquisition of the necessary licences and adherence to the licensing conditions, and to the general principals of good governance in terms of their social and environmental obligations.

"They should adhere to social and labour plans; and integrate them with IDP Municipalities even though that has been highly politicised to address the needs of politicians" – Participant 5

"Mining companies should be good corporate citizens, apply working codes and comply with licences and ensure that they are not violating environmental rights, particularly the right to water – currently they are not complying because they are not monitored" – Participate 9

The need to apply measures to ensure that there was effective rehabilitation of mining areas was emphasised.

"The environment should be adequately and sustainably rehabilitated" – Participant 4

In general, participants believed that government should be playing a more prominent role in regulation and enforcement (Figure 3.8). Participants felt that it was government's responsibility to improve policies and regulations, and to enforce and monitor compliance. They also considered it the responsibility of the government to ensure adequate rehabilitation of abandoned and ownerless mine sites. In general, the participants expressed dissatisfaction with the government's performance in terms of the above-mentioned roles, attributing this to political interference.

"In a normal society, government would be the regulator, mining corporations would be regulated and get their licences and civil society would play an oversight role – South Africa is not a normal society and will not be with a government made up of a political party having an investment arm" – Participant 8

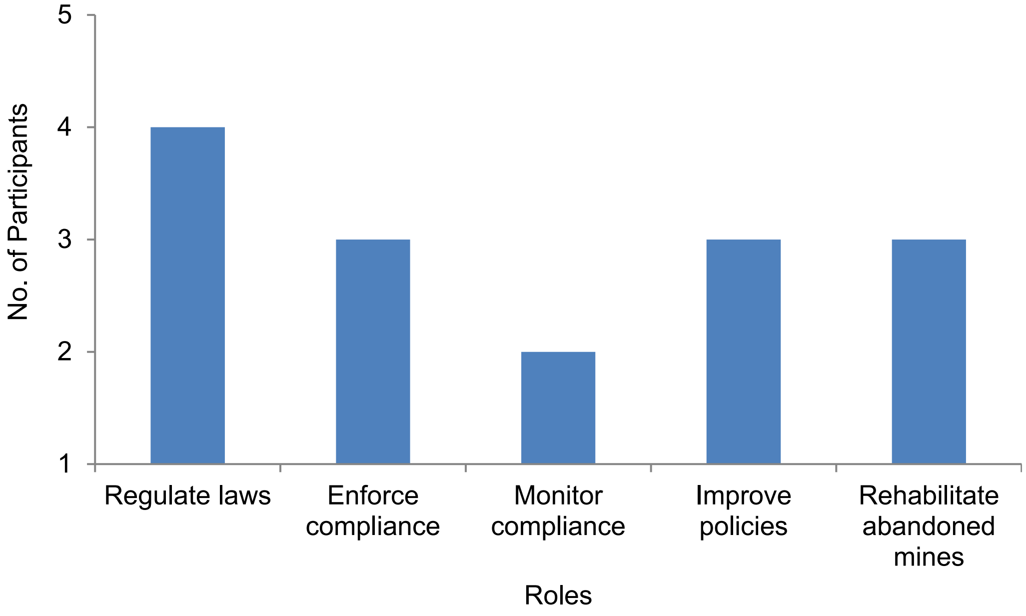


Figure 3-8 Perceived government roles in terms of addressing the community concerns on the impact of coal mining in Mpumalanga.

It was proposed that CSOs are given more recognition in order to enable them to play a more *“sophisticated role”* in managing and engaging government and mining corporations.

“Civil society is doing enough but the problem is that they are not the ones to take action against the mining companies, their roles is just to capacitate communities” – Participant 2
“They should join government in holding mining accountable” – Participant 7

Participants also called for more meaningful engagement between the different stakeholders to mutual benefit. The majority of participants suggested a joint initiative between civil society, mining corporations and government in order to address, and effectively mitigate, the environmental and social impacts of coal mining in the Mpumalanga Province.

“I would expect a high road scenario where we have meaningful co-operations between government and mining corporations” – Participant 6
“I hope there will be more cooperation between the different companies for systems like water treatment, rehabilitation, agricultural cooperatives, etc.” – Participant 7
“It is possible to have a relationship between the three, to help and support each other” – participant 9

Companies were also expected to involve mining communities in decision-making and to develop more effective community grievance mechanisms.

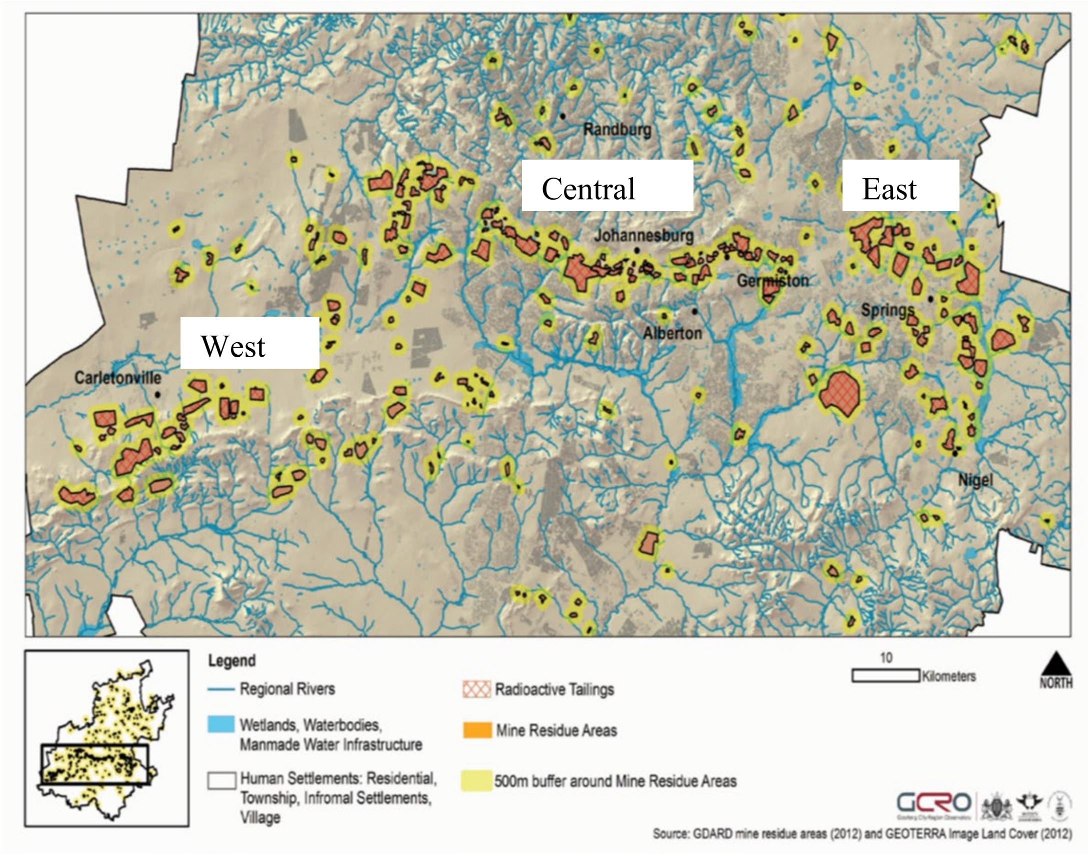
“Mining companies must consult with communities, they do not consult right now” – Participant 2

3.3 A Case study of gold mine tailings in South Africa

3.3.1 Background

For nearly 150 years, the mining industry in South Africa has been the driving force behind the economic growth and social development, particularly in terms of foreign exchange earnings, employment and other economic activities. During this gold mining period, infrastructural, recreational and community developments occurred alongside cities, towns and inner city slums in some of the mining complexes such as the Witwatersrand goldfields (Naicker et al., 2003, Ojelede, 2012), and has also led to the development of cities such as Johannesburg (also known as eGoli, the city of gold). Gold mining did not only shape the economy, but also the socio-political and cultural development of South Africa (Smith, 2013).

However, apart from a thriving economy, the gold mining industry has also left a legacy of derelict and ownerless mines and abandoned tailings storage facilities (TSFs), most of which occur in the Witwatersrand basin, comprising the West, Central and East Rand (Figure 3.9). Since the beginning of gold mining in the Witwatersrand basin, more than 270 mine tailing facilities have been erected covering approximately 180 km^2 in surface area. Most of the defunct gold tailings are not vegetated or are characterised by sparse vegetation (Ojelede et al., 2012). The dumps typically contain significant quantities of sulphide minerals, and elevated concentrations of metals and nuclides, including lead (Pb), copper (Cu), nickel (Ni), cobalt (Co), zinc (Zn) and uranium (U) and Radium (Ra). Figure 3.9 provides an indication of the vast number of tailings storage facilities that have been classified as radioactive (Bobbins, 2015).



Source: GDARD mine residue areas (2012) and GEOTERRA Image Land Cover (2012)

Figure 3-9 Distribution of tailings storage facilities in the Witwatersrand Goldfields, South Africa (after Bobbins, 2015)

A study by Maseki et al. (2016) indicated that tailings deposits in the Central and Extern Basins are frequently enriched in Cr, Ni, As, U, Pb and Au relative to average crustal abundances, and occasionally in Fe, Zn and Cd (Table 3.3)

Table 3-3 Measured mean concentration of metals in four gold mine tailings storage facilities in the Central and Eastern Basins compared to Earth crustal averages (After Maseki et al., 2016)

Element	Mean Concentrations in Tailings (ppm)				Mean Concentrations across the Four TSFs (ppms)	Concentration in the Continental Crust
	ERSP[1]	ERBK[2]	CWJB[3]	CWRD[4]		
Fe	40500	42200	44800	21300	37100	43200
K	19700	21000	10670	2200	11700	21400
Mn	205	220	325	160	240	716
Cr	410	550	230	120	290	126
Zn	40	30	70	30	46	65
Ni	106	60	76	16	60	56
As	150	140	90	110	116	1.7
U	8	7	16	16	13	1.7
Pb	16	11	27	24	21	14.8
Cd	0.10	0.08	1.52	5.67	2.42	0.10
Au	0.52	0.72	3.91	1.30	2.09	0.0025

1. ERSP: Eastern Witwatersrand Springs;
2. ERBK: Eastern Witwatersrand Boksburg;
3. CWJB: Central Witwatersrand Johannesburg;

This case study investigates the environmental and related community impacts associated with gold tailings facilities in the Witwatersrand basin of South Africa.

3.3.2 Case study methodology

As in the coal case study, this case study entailed both a review of the literature and semi-structured interviews with selected stakeholders. The published literature was reviewed with respect to the environmental and associated community impacts associated with gold tailings facilities in the broader Witwatersrand Basin, as well as in specific communities in the region; namely Davidsonville, Tudor Shaft and Riverlea. Semi-structured interviews were then conducted with selected stakeholders to gain a more in-depth understanding of the experiences and perceptions with respect to the impacts arising from the defunct Princess gold tailings facility in Davidsonville. A total of seven participants were selected for these interviews, including three Davidsonville community members (participants 1-3), 2 representatives from community-support organisations (CSOs) (participants 4 and 5), and 2 environmental consultants operating in the area (participants 6 and 7). Further details on the interview process for this case study are detailed in Appendix A.2.

3.3.3 Case study outcomes

3.3.3.1 Environmental pollution and associated social impacts: Witwatersrand basin

A number of published reports bear testimony to gold tailings as a source of extensive air, soil and water pollution in the Witwatersrand area (see for example Bobbins, 2015, Durand, 2012,Naicker et al., 2003, (2005), Pulles, 1992, Rösner and van Schalkwyk, 2000; Rösner et al., 2001; Tutu et al., 2003; Winde and van der Walt, 2004). Metals, metalloids, acid and salts contained in the gold mine TSFs are dispersed to surrounding environments through numerous pathways and spread to various ecological receptors such as the flora and fauna, water resources, and the atmosphere (Rösner, 1999; Bobbins, 2015). This, in turn, impacts on the quality of life and livelihoods of local communities.

i Wind erosion

As indicated in Section 3.3.1, most of the gold tailings facilities (TSFs) in the Witwatersrand region are not vegetated or only partly vegetated, such that significant distribution of contaminates occurs as a result of wind-blown dust. (Figure 3.10). According to a report by the international Human Rights Clinic (IHRC, 2016), the areas in close proximity to the gold tailings dumps in the West Rand and Central Rand become white with dust when it is windy, particularly in August and September. In accordance with this report, local inhabitants complain that they cannot escape the dust as it is everywhere; in their homes, lungs and food. In severe cases, visibility becomes completely impaired. Studies have found that sporadic dust events produce particulate matter in the PM 10 range that exceeds the 24-hour limit set by South African Department of Environmental Affairs (18 $\mu g.m^3$), with PM10 particles containing crystalline silica being recorded up to 2 km downwind of the tailings facilities (Ojelede et al., 2012; Kneen et al., 2015).

ii Seepage and run-off

Sulphide minerals in the TSFs are susceptible to acid rock drainage generation, with concomitant release of sulphate salts and metals (Durand, 2012; Duruibe et al., 2007; Moore and Noller, 2000). Whilst much of the acid rock drainage in the region can be attributed to discharge from defunct mine workings, seepage from the TSFs is reported to account for about 20% of acid drainage pollution (Naicker et al., 2003).

Figure 3-10 Dust visible from the tailings storage facilities (Photographer: Nwaila, PC).

iii Contamination of soils and crops

In accordance with the report by the IHRC (2016), soils in the proximity to the gold tailings facilities are contaminated and this affects the growth and quality of vegetables and other crops. When the plants do survive, they might not be suitable for consumption due to the elevated metal content and radioactivity of the soil (IHRC, 2016). A study by Kootbodien et al. (2012) found that the soil in a school vegetable garden situated near a tailings facility contained high levels of arsenic (30.5 ppm), whilst the levels of lead, zinc and mercury in vegetables from three different sights in the vicinity of tailings facilities in the Witwatersrand basin exceeded recommended limits in all cases. Lead levels were highest in the fruiting vegetables, decreasing in the order: tomatoes (1.91 mg/kg) > peppers (1.85 mg/kg) > butternut (1.09 mg/kg) > pumpkin (0.47 mg/kg). Zinc concentrations were particularly high in in rooting and leafy vegetables, with the highest concentration found in carrots (143 mg/kg). Mercury levels decreased in the order: peppers (0.99 mg/kg) > tomatoes (0.76 mg/kg) > butternut (0.21 mg/kg) > pumpkin (0.12 mg/kg).

iv Impacts on community health and quality of life

Previous discussions have highlighted the potential health risks due to exposure to carcinogenic, mutagenic and teratogenic elements such as uranium, arsenic, radon, nickel, zinc and other radioactive materials that are found in gold TSFs. These risks are aggravated by the fact that these facilities are often located near to human settlements. Whilst local mining regulations and international practice prohibits or avoids locating residential areas closer to 500 m from a tailings dump or mining operations (Kneen et al., 2015), these buffer zones have clearly not been adhered to or enforced in the Witwatersrand area (Table 3.4) . On the contrary, aerial photographic images indicate that housing developments continue to expand into the buffer zone, and even the building of government-financed housing developments (also known as RDP houses) encroach on the tailings dumps buffer zones (Kneen et al., 2015).

The unrestricted encroachment of residential houses onto land close to TSFs increases the risk of human exposure to windblown dust and metal pollution from the TSFs. Even where townships and informal settlements lie outside of the buffer zones, they often occur directly downwind and downstream from defunct mines and waste dumps. Whilst a risk assessment by Maseki et al. (2016) has indicated that the concentrations of metals (As, Au, U, Pb, Cd and Cr) in ambient particles of < 20 μm are unlikely to exceed thresholds for public health, nevertheless argue for the continued monitoring and mitigation of airborne dust exposure. Health problems, particularly amongst children, due to contact with contaminated soil and consumption of food grown in local vegetable gardens, remains a matter of concern (IHRC, 2016).

Table 3-4 Households and residential areas around tailings storage facilities during 2001 and 2011 with estimates of population for the City of Johannesburg (Kneen et al., 2015)

Buffer Distance (m)	Number of Households (2001)	Population Estimate (2001)	Number of Households (2011)	Population Estimate (2011)
500	26 232	80 700	22 370	71 600
500-1000	24 809	82 600	39 524	126 500
1000-1500	21 597	69 300	36 192	115 800
1500-2000	16 575	52 000	31 510	100 800
2000-2500	16 144	51 700	28 445	91 000
2500-3000	16 489	53 900	24 952	79 800
Grand total	*121 846*	*390 200*	*182 993*	*585 500*

Whilst these impacts have not been limited to disadvantaged communities alone, a recent study of the area completed by the International Human Rights Clinic at the Harvard Law School (IHRC, 2016) has highlighted the fact that poor and disempowered communities more often than not bear the brunt of the pollution impacts. These residents have few options to relocate or means to protect themselves from the effects of pollution. Residents of these areas are often not aware of the dire health risks they are exposed to daily (Manungufala et al., 2005). If they are aware of the health issues arising from adjacent TSFs, they are often reluctant to raise the issue (Bobbins, 2015). The IHRC (2016) furthermore comments that, by not effectively addressing and mitigating these impacts, the government has failed to defend and protect the needs of those communities who face the greatest threat. This, coupled with the exclusion of community members in decision-making, has resulted in significant tensions between the government and communities, and increased the distrust for mining companies.

3.3.3.2 Specific community case studies: Tudor Shaft, Riverlea and Davidsonville

Whilst a number of communities have suffered the adverse impacts of gold mining in the West and Central Rand (see Figure 3.11), three of the most prominent cases include Tudor Shaft, Riverlea and Davidsonville.

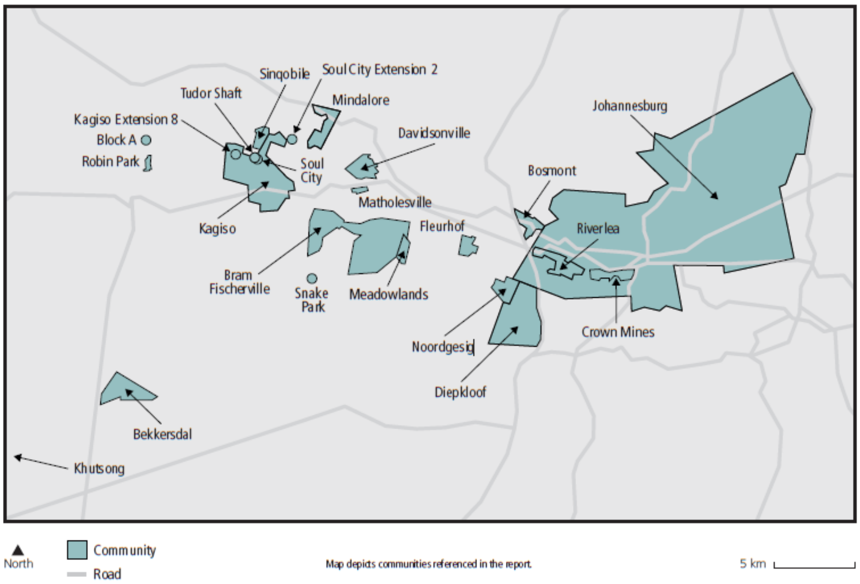


Figure 3-11 Map depicting communities affected by gold mining operations

v Tudor Shaft

The Tudor Shaft community (Figure 3.12) is an informal settlement that is located on and around an old radioactive gold tailings dump in Krugersdorp.

Figure 3-12 Tudor Shaft Informal Settlement (source: http://earthlife.org.za)

The Tudor Shaft community is said to consist of about 2000 residents that continue to live in shacks on the gold mine tailings dump (Figure 3.13). The informal settlement was created when the local government was relocating hundreds of people from another informal settlement a few kilometres away in 1996. According to the analysis conducted by the Federation for a Sustainable Environment, a local NGO, the soil in this area contains elevated levels of aluminium, arsenic, cadmium, cobalt, copper, mercury, manganese, nickel, zinc and uranium (Cairncross et al., 2013). In 2011, the National Nuclear Regulator of South Africa confirmed that the radiation levels were 15 times higher than the regulated levels (Cairncross et al., 2013). It was recommended that the community should be relocated with immediate effect. However, although families directly on top of the dump were re-located, those living at the foot of the dump were not. Despite reports that the government was building new homes for the remaining members of the community, as of July 2016 there had been no further re-locations. Community members believe that their health problems are related mainly to exposure to the gold mine tailings. In a study conducted by Cairncross et al. (2013), residents state that they have been residing in the area for up to 10 years and their children are sick from respiratory tract infections and chest pains since from their birth.

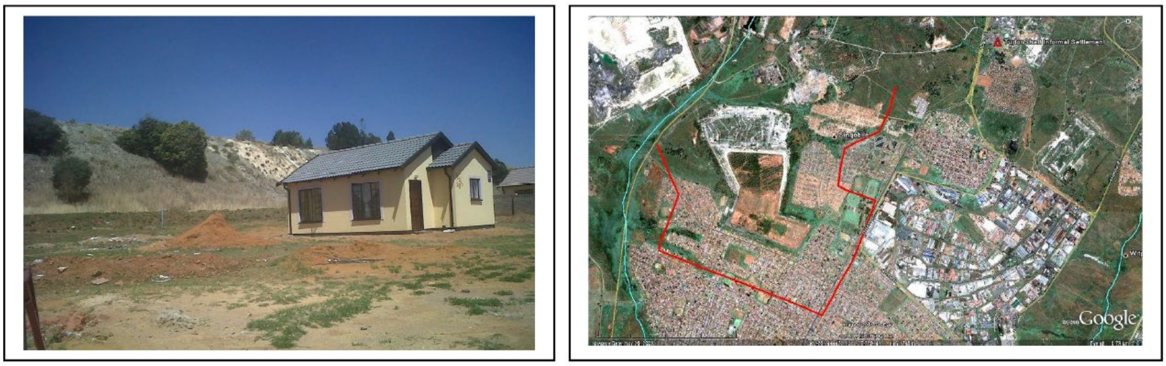


Figure 3-13 Houses at the edge of the gold tailings dump (source: Turton, 2015)

vi Riverlea

Another case is that of Riverlea, a suburb situated south-west of Johannesburg. This suburb is in the centre downwind of gold tailings dumps (Figure 3.14). The community has been objecting to dust emissions arising from the DRD Gold mine reclamation project that is reprocessing the local tailings dump. Since the beginning of this project in 2010, the residents of Riverlea have been complaining about health issues that are related to the increased dust fallout. DRD Gold has been confronted by the community regarding increased dust levels and the health issues that they are experiencing. As there is no scientific evidence linking the health issues to the dust from the tailings dump, DRD has not taken any responsibility for this (Bobbins, 2015). In an attempt to prove that the dust is the cause of local health issues, Earthlife Africa, an NGO, was approached by the community of Riverlea to gain information on mining impacts on the community. However, Earthlife Africa was unable to access relevant information from the government despite the Promotion of Access to Information Act (PAIA) (Bobbins, 2015). The residents have planned to take the legal action in order for them to attain the required information (Bobbins, 2015; Kings, 2013; Kings, 2013a).

Figure 3-14 Riverlea suburb on the Central Rand

vii Davidsonville

Davidsonville is a suburb located in Gauteng Province, in Roodepoort town in the City of Johannesburg Local Municipality (Figure 3.15).

It is predominantly a coloured community area. This suburb is situated in close proximity to the historic “L” shaped Princess tailings dump and has been severely impacted and contaminated by it. The Princess gold tailing dump was created by various gold mining companies which have since ceased to exist. As a result of rehabilitation efforts in 2010, the Princess tailings dump is partially covered at the base but the uncovered slopes provide a serious pollution threat through the erosion of the tailings which are continually being transported to nearby waterways and wetlands (Ngigi, 2009). Princess tailings dump has a long history of contaminated run-off that leads to acid rock drainage, slime spillage, and dust emissions, ultimately impacting on the community residing near the dump (Ngigi, 2009; Oelofse et al., 2007). Access to the site from existing roads is easy since there is no fencing.

Figure 3-15 Davidsonville community on the West Rand

In October 2006 the community of Davidsonville approached the High Court of South Africa to compel the owner of the dump (City of Johannesburg) to address the associated environmental damage. A court order ruled in favour of the community members. Semi-structured interviews conducted as part of this study are, however, indicative of on-going concerns around pollution arising from the Princess tailings dump, and the impacts that this is having on the local communities in Davidsonville.

Six out of seven of the participants (86%) considered the dump to pose a high to very high risk with respect to air pollution. The unprotected slopes are susceptible to wind erosion. Dust and erosion are aggravated by various activities, such as recreational trail riding and the brick making industry located on site.

“I have the right to breathe fresh air. When there is dust blowing and eating you can taste the sand. It’s like sand in your mouth” – Participant 3
“There is no fresh air, we breathe air with sand” – Participant 1
“The particles from the dump pollute the air. During the month of August it is worse.” – Participant 2
“Dust and air pollution is a manageable problem.” – Participant 6

Figure 3.16 shows the street of Davidsonville that has tailings material that has been eroded from the tailings dump.

Figure 3-16 Tailings dump material eroded to the streets.

Five of the seven (71%) participants also rated water quality to be a high to very risk associated with the dump. This is consistent with a study conducted by Ngigi (2009), who found that pollution resulting from the Princess Dump is seriously impacting the water quality and the environment around the site, with concentration of pollutants exceeding the Target Water Quality Ranges (TWQR) as stipulated by the local government. A more recent study by Taylor and Maphorogo (2015), also revealed that the soil and surface water in Davidsonville are contaminated with metals, with soil pH values of 3.04 and water pH of 3.24 being reported. In a separate study by Dlamini et al. (2016), water sample results show that As, Cd, Hg, Pb and Al exceeded the World Health Organisation's guidelines. Moreover, Davidsonville has also gained media attention following natural erosion and mine water runoff that continuously floods the Davidsonville community settlement area, making it muddy and unpleasant. The seepage of acidic waters from the dump floods residents' yards and leaves stagnant pools during the wet season. The Princess tailing dump is also situated across the road from a local public school, man-made wetland called Davidsonville Dam, and Manuel Street Park (Figure 3.17), which further place strain to human health. Participants in this study noted that water in the nearby wetland and park is polluted and is void of aquatic life.

"About 2 years ago, the water came down to people's houses from the dump" – Participant 3
"The kids can't play here, it is wet all-over. This is from the water that comes from the dump." – Participant 3

Figure 3-17 Water running through the park

3.4 A Zambian Copperbelt Study

The copper mining industry in Zambia is the economic mainstay, dating as far back as independence (1964). It is also recognised as a force that has fostered urban development on the Copperbelt Province, producing the largest quantity of copper and cobalt in Africa.

Although being affected by low copper prices in the late 1990s, copper production has increased since 2000 and Zambia continues to be the second largest copper producer in the world (ZDA, 2015). However, despite the economic successes of the mining industry in the recent past, a majority of Zambians continue to suffer in extreme poverty. By December of 2005 around 67% of the population was surviving on less than a dollar a day (Cronje et al., 2008). Furthermore, environmental legacies from the mining and beneficiation operations have led to conflicts between mining houses and the community emanating from reported associated health issues, cattle and livestock demises, and loss of livelihood through infertile agricultural land for subsistence farming and fishing (SGU, 2014).

This case study explores the impacts and conflicts associated with copper mining in the Zambian Copperbelt Province.

3.4.1 Background

The Copperbelt Province is a province in Zambia which covers the mineral-rich Copperbelt, and farming and bush areas to the south. The province adjoins Katanga province of the Democratic Republic of the Congo, which is similarly mineral-rich. The main cities of the Copperbelt are Kitwe, Ndola, Mufulira, Luanshya, Chingola and Chililabombwe (Figure 3.18).

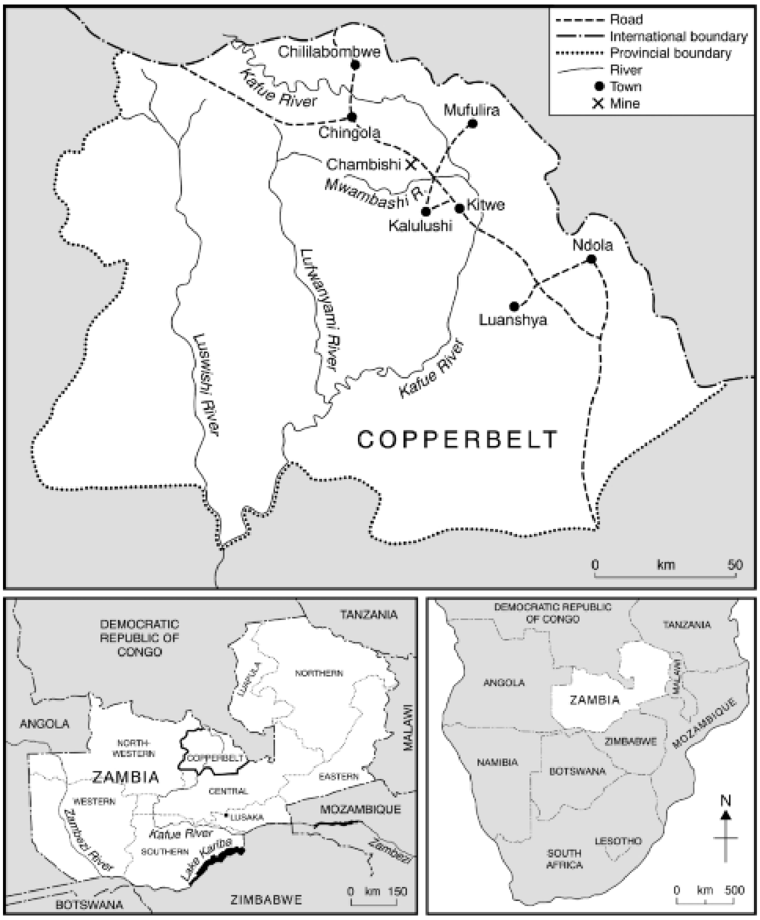


Figure 3-18 Zambian Copperbelt region (von der Heyden and New, 2005)

Deposits in the Copperbelt were discovered by modern prospectors around the turn of the last century but most were not exploited on a large scale until the 1930s (Limpitlaw, 2001). The first claims were pegged at Chambishi, just north of Kitwe, in 1903. Shortly after this, the Nkana deposit was discovered in 1910, followed by further discoveries at Nkana, Mufulira and Kirila Bombwe in 1923 and 1924 (Limpitlaw, 2001). Large-scale mining operations and metallurgical plants were commissioned between 1929 and 1932 at Nkana and Mufulira, followed closely by Nchanga and later by Konkola (at Kirila Bombwe) in 1957. Kirila Bombwe is now the site of the town of Chililabombwe. These operations were managed privately until after Zambia gained independence in 1964. They were nationalized by the government of Kenneth Kaunda in 1969. In 1982, the nationalized mines were amalgamated into Zambia Consolidated Copper Mines (ZCCM). ZCCM was privatized at the close of the last decade (1998-2000) after protracted negotiations. This brought about reinvestment in the Copperbelt by multinational companies and coincided with improvements in the level of environmental management required under Zambian Law (Limpitlaw, 2001).

3.4.1.1

In 2012, 86% of the foreign direct investment that came into Zambia was due to the mining industry. In addition, 80% of the country's export earnings came from the mining industry, as well as over 25% of all revenues collected by government (Sikamo et al., 2016). Figure 3.18 shows the production of copper in Zambia in relation to global production.

Figure 3-19 Zambia's share of copper production globally (Sikamo, 2006).

The Zambian Copperbelt is arguably the most significantly mineralized Neoproterozoic basin on Earth, preserving a truly spectacular scale of mineralization. In excess of 1,000,000,000 tons of ore at 2.7% copper has been extracted to date, and there are also major cobalt accumulations. The origin of these deposits has been hotly debated for more than six decades, yet the driving forces that generated this system are poorly understood, particularly the relationships between tectonics, paleo-fluid circulation, and ore deposition (McGowan et al., 2003). Most recoverable copper deposits (90-95%) are in the form of disseminated sulphide minerals, such as chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), bornite (Cu_5FeS_4) and carrollite ($CuCo_2S_4$) in association with pyrite (FeS_2) (Zientek et al., 2014). Sulphide ores are conventionally recovered by means of by flotation (in the ore concentrator plants), smelting and refining. A further 5%-10% of copper output is extracted from weathered products of sulphide minerals which preferentially concentrate copper and cobalt. These so-called "oxide ores" are treated by acid leaching followed by solvent extraction and electrowinning (SX-EW).

The two major copper mining companies operating in the Copperbelt Province are Konkola Copper Mines (KCM) and Mopani Copper Mines. Konkola Copper Mines (KCM) is the largest copper mining company in the country, and is a subsidiary of London-listed Vedanta Resources Plc. It has three operations called integrated business units (IBU), manley Nkana (smelter, refinery and acid plant) in Kitwe, Nchanga in Chingola and Konkola in Chililabombwe. The Nkana Smelter is the largest primary copper production plant in Zambia and treats concentrates from the KCM Nchanga, and Konkola mines, as well as the Mopani-owned Nkana mine, producing up to 150,000 tons of new copper. Mopani Copper Mines Plc (Mopani) is a joint venture company based in Kitwe, comprising Glencore International AG (73.1%), First Quantum Minerals Ltd. (16.9%) and Zambian Consolidated Copper Mines Limited (10%). Mopani operates the Mufulira mine, smelter, concentrator and copper refinery and the Nkana mine, concentrator and cobalt plan

3.4.2 Case study methodology

As in the previous case studies, this case study entailed two main tasks. Firstly, the published literature was reviewed with respect to environmental and community impacts, as well as initiatives implemented to govern and mitigate these impacts. Semi-structured interviews were then conducted with various stakeholders in terms of (i) their concerns and perceptions regarding environmental and associated community impacts of copper mining; (ii) sources of conflicts between communities and mining operations; and (iii) community expectations of the mining sector and local operations. A total of 14 participants were selected for these interviews, including community members, community-support organisations (CSOs), mining representatives and consultants to develop a deeper understanding of their concerns and points of conflict, as well as their expectations in terms of the mining sector in Zambia. The selected participants included eight representatives from the community (participants 5-4), one representative from a community support organizations (CSO) (participant 1), environmental consultants working in the area (participant 3 and 4), and one representative from the Konkola Copper Mines (participant 2). Further details on the interview process for this case study are outlined in Appendix A.3

3.4.3 Case study outcomes

The findings of the literature review and stakeholder interviews are presented in this section. Section 3.4.3.1 provides an overview of the reported, experienced and perceived environmental and social impacts; Section 3.4.3.2 provides an overview of the interventions taken to mitigate and govern these risks on the basis of published literature and documentation, whilst Section 3.2.3.3 provides insights into community-mine conflicts and community expectations, as derived from the stakeholder interviews.

3.4.3.1 Environmental and associated community impacts

Pollution in the vicinity of mining operations in the Zambian Copperbelt ranges from high to severe (see Figures 3.20 and 3.21).

Reports from various environmental impact assessment studies over the past two decades include references to high levels of TDS, sulphate, copper, cobalt, iron, aluminium, nickel, TSS, pH in effluent waters, high levels of copper, cobalt, sulphur and sulphate in stream sediments, widespread contamination of soils and localized groundwater contamination. Many of the problems to do with mining and the environmental impacts originate from the Zambia Consolidated Copper Mines (ZCCM) era between 1970 and 2000 (Lindahl, 2014), a time when concerns about the environment were not closely monitored, either locally or internationally. Whilst mining is the dominant cause, pollution in the area is aggravated by other industries, settlements, farms, markets, leaking sewer lines, poor sanitation (Ntengwe, 2006). The main impacts of concern relate to air, soil and water pollution (Lindahl, 2014; Lungu and Fraser, 2007).These direct impacts and the subsequent effects on eco-systems and communities in the surrounding area are discussed in further detail in points (i) to (v).

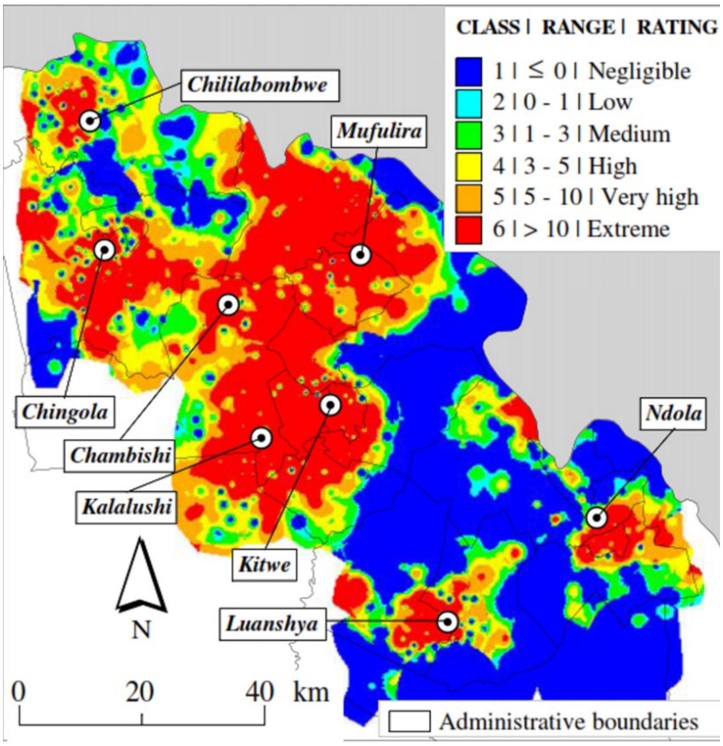
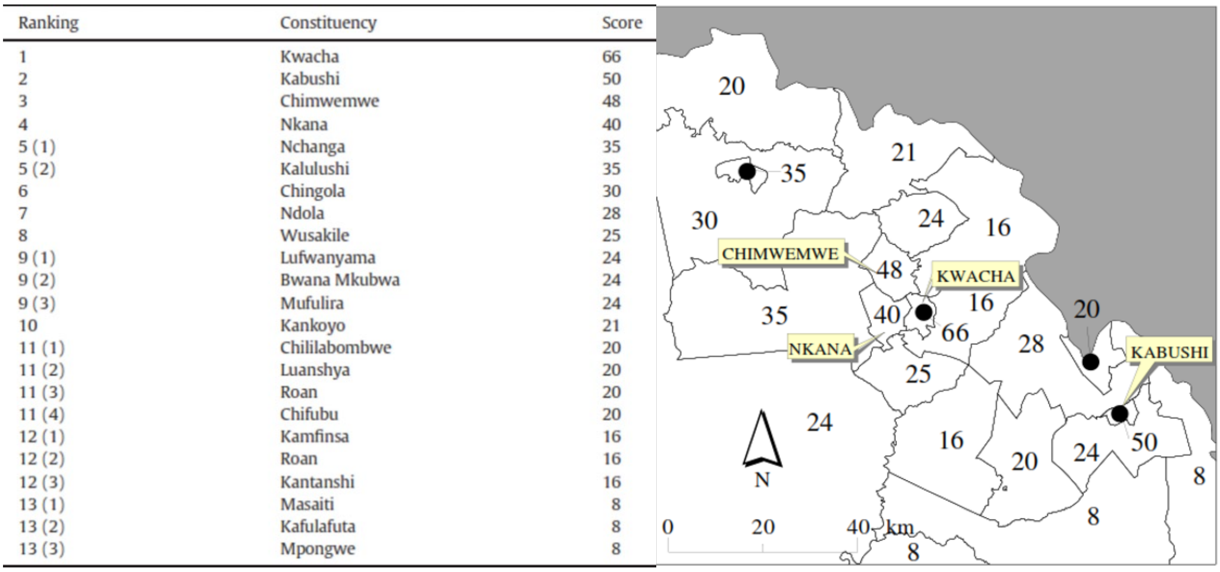


Figure 3-20 Degree of contamination on the Zambian Copperbelt (Albanese et al., 2014)



Ranking	Constituency	Score
1	Kwacha	66
2	Kabushi	50
3	Chimwemwe	48
4	Nkana	40
5 (1)	Nchanga	35
5 (2)	Kalulushi	35
6	Chingola	30
7	Ndola	28
8	Wusakile	25
9 (1)	Lufwanyama	24
9 (2)	Bwana Mkubwa	24
9 (3)	Mufulira	24
10	Kankoyo	21
11 (1)	Chililabombwe	20
11 (2)	Luanshya	20
11 (3)	Roan	20
11 (4)	Chifubu	20
12 (1)	Kamfinsa	16
12 (2)	Roan	16
12 (3)	Kantanshi	16
13 (1)	Masaiti	8
13 (2)	Kafulafuta	8
13 (3)	Mpongwe	8

Figure 3-21 Ranking of constituencies in accordance with pollution score (Albanese et al., 2014)

i Air pollution

Of the participants interviewed, 69% rated air pollution risks as high to very high, and the remaining 31% rated air pollution as a critical risk. A survey of the literature indicates that while small sized particles (PM10) come from smelters and dusting of unpaved roads and tailings dams, the largest contribution to air pollution comes from smelters fumes, containing elevated levels of sulphur dioxide (SO_2), and often enriched with volatile metals such as Pb, Zn, As and Cd (Lindahl, 2014). According to air quality data monitored by a private mining company for the period from July-December 2010, the SO_2 concentration in ambient air in one location was 100% above the World Health Organization guideline limit, and in another location was more than 83% above the guideline limit (Lacey and Pittman, 2011). The Mopani smelter at Mufulira (Figure 3.22) was closed in early

2012 because of its high SO_2 emissions, and continued facing accusations for its high sulphur dioxide emissions in 2014.

Figure 3-22 Sulphur dioxide being released in the atmosphere at Mopani Copper Mines in Mufulira

As a result of weather characteristics such as wind speed and direction, the most affected areas with poor air quality occur in the northwest and west of the respective large smelters at Nkana (Kitwe) and Mufulira (Lindahl, 2014). In their study of emissions from the Nkana Smelter, Ettler et al. (2011) also found that the spatial distribution of As, Co, Cu, Pb and Zn was mostly affected by the prevailing wind direction, with the highest concentrations being detected downwind (NW) of the smelter.

Most of the companies currently operating in the Copperbelt recognise the air pollution problems and have undertaken to reduce emission by up to 80%, through the installation of technologies to capture sulphur dioxide and converts it into sulphuric acid, which the company can then use in mineral processing operations. Despite these commitments and interventions, air pollution, particularly from sulphur dioxide emissions, continue to be a major concern for surrounding communities, with representatives from both the environmental consultancies and mining companies in the area indicating that current interventions are not fully effective.

“At the KCM smelter we are trying to convert 99.9% of the sulphur but when you look at the concentrations as per regulations, we are not doing fine.” – Participant 2

Dust from tailings dams is also considered a major source of air pollution. These tailings are normally finely milled (75% passing 150 µm) and are a major source of air pollution.

“To focus purely on acid plants and SO_2 if one is talking about air pollution would not be fair, because then you are oversimplifying an issue that is more complicated than that. There are other sources of air pollution that come from mining operations and significant among those are the tailing dumps” – Participant 3.

ii Soil pollution

In accordance with reports by Ettler et al. (2014) and Lindhal (2014), soil contamination by metals is mainly as a result of wind-blown dust from dry tailings dams and smelter emissions. These reports indicate that metal values in soils around operating mines and smelters are high relative to natural background values, particularly with respect to copper. A study by Ettler et al. (2014) found, furthermore, that copper contamination levels around the Mufulira smelter increased with increasing proximity to the operations (Figure 3.23), with concentrations of up to 8980 mg kg^{-1} being reported in the top soil close to the smelter.

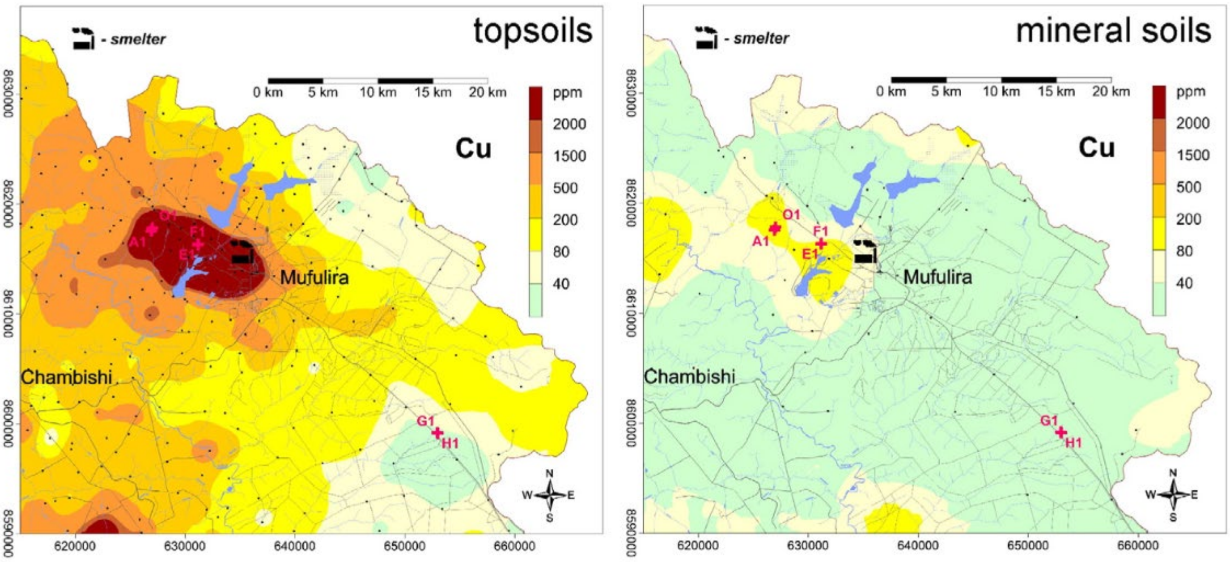
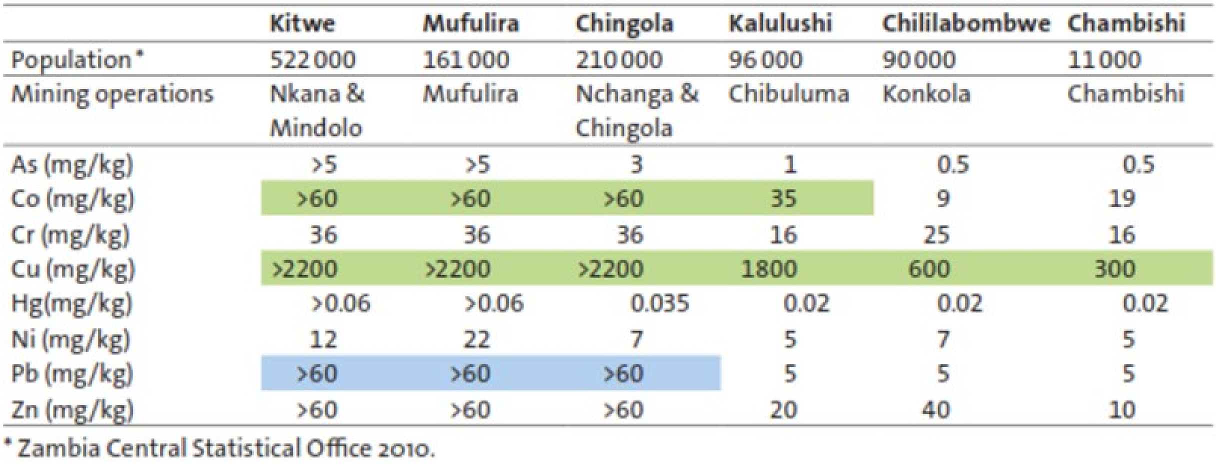


Figure 3-23 Spatial distribution of Cu in the top and mineral (80cm) soils in the vicinity of the 2afulira copper smelter (Ettler et al., 2014)

Other metals, reported to occur at elevated concentrations in the soils around mining and mineral beneficiation operations, include Co and Pb (see Table 3.5), with the districts of Chingola, Kitwe, and Mufulira having the highest concentration levels (Lindahl, 2014).

Table 3-5 Average soil concentrations in Zambia Copperbelt (Lindhal, 2014)
(Concentrations marked in green are higher than the international guidelines for soils for residential and agricultural applications, and concentrations in blue are likely to be higher)



	Kitwe	Mufulira	Chingola	Kalulushi	Chililabombwe	Chambishi
Population*	522 000	161 000	210 000	96 000	90 000	11 000
Mining operations	Nkana & Mindolo	Mufulira	Nchanga & Chingola	Chibuluma	Konkola	Chambishi
As (mg/kg)	>5	>5	3	1	0.5	0.5
Co (mg/kg)	>60	>60	>60	35	9	19
Cr (mg/kg)	36	36	36	16	25	16
Cu (mg/kg)	>2200	>2200	>2200	1800	600	300
Hg(mg/kg)	>0.06	>0.06	0.035	0.02	0.02	0.02
Ni (mg/kg)	12	22	7	5	7	5
Pb (mg/kg)	>60	>60	>60	5	5	5
Zn (mg/kg)	>60	>60	>60	20	40	10

* Zambia Central Statistical Office 2010.

Stakeholder interviews indicated that soil pollution is a major concern, with 92% of interviewers considering copper mining to pose a high to very high risk, and the remaining 7% a critical risk to the quality and productivity of soils in the surrounding areas.

iii River pollution

Mining operations in the Copperbelt are in the catchment area for the Kafue River (Figure 3.24), which is a major source of agricultural and residential water in the region.

Figure 3-24 Kufue river flow through the Zambian Copperbelt (Sracek et al., 2012)

A number of studies (Lindhal, 2014; Limpitlaw, 2001; Sracek et al., 2012) have indicated that, despite high air and soil pollution levels, dissolved metal concentrations in the Kafue River are generally relatively low. This has been attributed mainly to the high acid neutralizing capacity of the mining wastes and local geology, which results in the rapid precipitation of iron oxides and hydroxides and adsorption and/or co-precipitation of other metals and semi-metals. This phenomenon is also consistent with the relatively high levels of metals and metalloids reported in the sediments of the Kafue River (see Table 3.6). The high neutralising capacity of the local geology and mine gangue material means that generation of acid rock drainage is rare (Lindhal, 2014, Srareck et al., 2012).

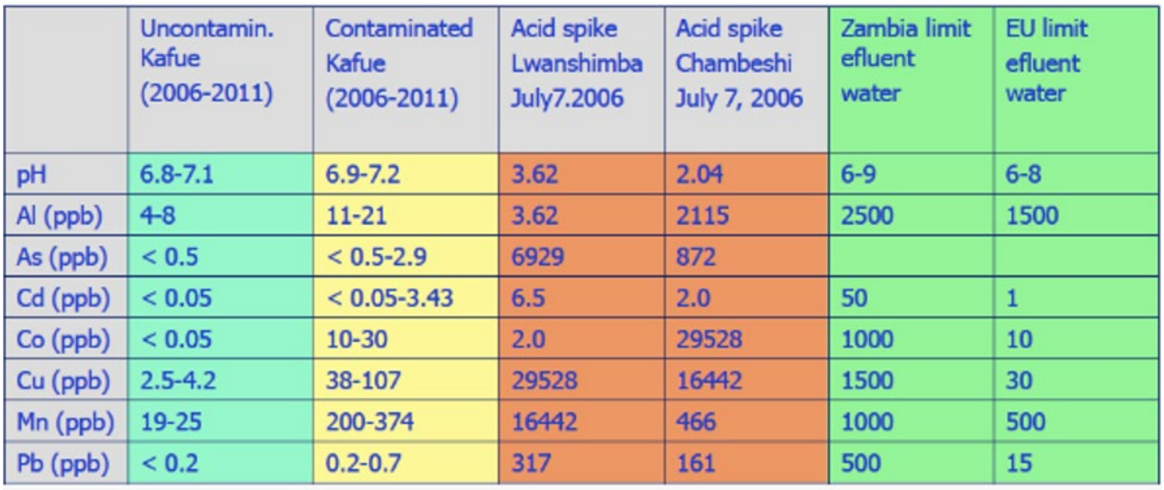
Table 3-6 Comparison of Kafue river sediment values with Canadian guidelines (Das and Rose, 2014)

Element (ppm)	ISQG (concentration above which adverse biological effects are occasionally observed)	% of samples exceeding ISQG values	PEL (concentration above which adverse biological effects are frequently observed)	% of samples exceeding PEL values
Arsenic	5.9	8.2%	17	2%
Cadmium	0.6	0%	3.5	0%
Cobalt	37.3	22.9%	90	2%
Copper	35.7	98.4%	197	55.7%
Silver	0.17	8.2%	0.49	0%
Lead	35	6.6%	91.3	2%
Zinc	123	0%	315	0%

Elevated concentrations of suspended or soluble metals and acidic pH values are thus mainly as a result of direct discharge into surface waters, whether intentional or through accidental spills. For example, in 2006 Konkola Copper Mines (KCM) released acidic sludge containing elevate levels of Cu, Mn and Co into the river

Kafue over several days, turning the river in the vicinity of the spill green (Das and Rose, 2014). The quality of contaminated and uncontaminated river water (Table 3.7) shows the effects of spills in 2006 (Das and Rose, 2014). In 2008, 13 people were hospitalized as a result of a similar spill this time from Mufulira leaching plant. (Lindahl, 2014). Similarly, a 2010 judgement in the Zambian High Court, following another major spill, found KCM guilty of four counts of illegally polluting the environment and wilfully failing to report the incident (Das and Rose, 2014).

Table 3-7 pH value and concentration of chemical elements in uncontaminated and contaminated waters in the Kafue river and tributaries (Das and Rose, 2014)



	Uncontamin. Kafue (2006-2011)	Contaminated Kafue (2006-2011)	Acid spike Lwanshimba July7.2006	Acid spike Chambeshi July 7, 2006	Zambia limit effluent water	EU limit effluent water
pH	6.8-7.1	6.9-7.2	3.62	2.04	6-9	6-8
Al (ppb)	4-8	11-21	3.62	2115	2500	1500
As (ppb)	< 0.5	< 0.5-2.9	6929	872		
Cd (ppb)	< 0.05	< 0.05-3.43	6.5	2.0	50	1
Co (ppb)	< 0.05	10-30	2.0	29528	1000	10
Cu (ppb)	2.5-4.2	38-107	29528	16442	1500	30
Mn (ppb)	19-25	200-374	16442	466	1000	500
Pb (ppb)	< 0.2	0.2-0.7	317	161	500	15

Stakeholder interviews indicated that water pollution is another major concern, along with air and soil pollution. Of the participants interviewed, 54% considered copper mining to pose a high to very high water pollution risk, and 46% a critical risk. Environmental consultants operating in the area confirmed that pollution of rivers through discharges by mining operations is on-going.

> “… experience will show that KCM has existed in a higher risk level because of the reported frequencies of water contamination arising out of KCM operations; whether those operations are related to their tailing leach plant, where you have suspended solids coming out of there, PCD, or indeed their Acid Plant operations (and) spillages from their leaching activities ending up in the Chingola stream and so on” – Participant 1

KCM was ordered to replace the 40 year old tailings leach plant tanks (see Figure 3.25) by September 2011, but by 2014 this had not been done. In accordance with Foil Vedanta, a NGO operating in the area, negligent contamination of the Mushishima stream and Kafue River by the KCM mine was ongoing @ August 2015, and continues to cause conflicts with local communities (see Figure 3.26).

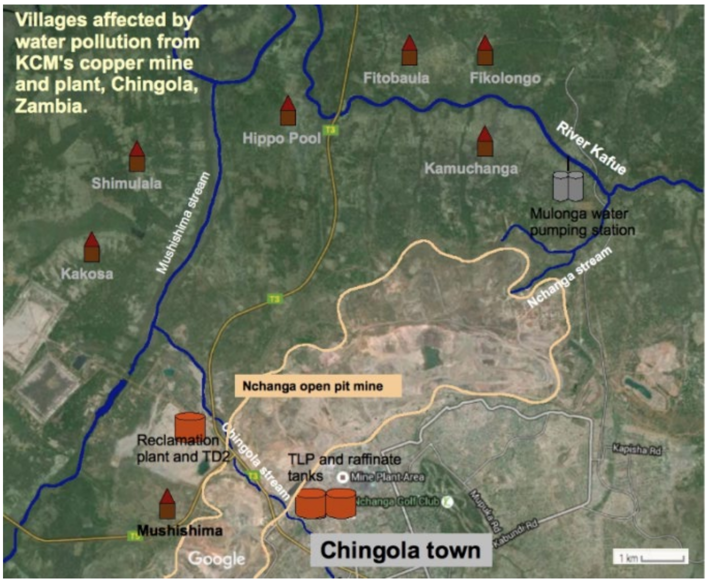


Figure 3-25 Villages and rivers in proximity to the Nchanga open pit mine (Das and Rose, 2014)

Figure 3-26 Protests against Kafue River pollution by Konkola Copper Mines Plc

Discharge of slurry wastes (Figure 3.27), such as tailings, from existing operations and erosion of waste dumps and tailing dams also gives rise to siltation of local rivers (Lindahl, 2014). Older tailings impoundments have been reported to be particularly susceptible to erosion, resulting in high concentrations of suspended solids in local rivers (Limpitlaw, 2001). A survey amongst the participants interviewed showed that 94% consider copper mining to pose a high to very high siltation risk.

Figure 3-27 Siltation caused by mine slurry discharge (Lungu and Fraser, 2007)

iv Effect on bio-diversity and crops

A study by Mwitwa et al. (2012) indicated that there is extensive deforestation around Copperbelt mining towns due to both direct and indirect impacts of mining. Direct causes stemmed from “green site development” and heavy pressure on selected tree species, while indirect causes were associated with the population “pull” and economic growth of mining towns. “Green site development”– the delineation and establishment of a new mining site – causes deforestation through establishment of the open pit or deep mining sites, large tailing dams to store effluent, and mining waste dumps for solid waste storage. The mining industry is also a direct consumer of timber for use in smelting (largely in the past).

Apart from deforestation, local vegetation is also affected by pollution of air, soils and water. According to van der Ent and Erskine (2015), the Copperbelt has the richest metallophyte (plants endemic to metal-enriched soils) location in the world. These metallophytes occur on isolated copper-mineralized hills spread throughout the Copper-Cobalt Belt and accumulate extraordinarily high concentrations (up to 2%) of Cu and Co metal in their living tissues. Van der Ent and Erskine, 2015), in their study of the remediation of the contaminated soil using copper-cobalt hyper accumulator plants on the Copperbelt discovered that the original flora on natural copper-cobalt mineralized sites have been impaired in almost all places that have been vulnerable to mining. This is attributed to both pollution and deforestation.

Metal pollution of rivers, soils and sediments also has an effect on crops and aquatic life. Studies around the Copperbelt province regarding metal uptake by crops have indicated that sweet potatoes and cassava accumulate metals in their leaves rather than on the roots. In contrast the maize grains do not appear to be affected by industrial metal contamination (Lindahl, 2014). Ntengwe and Maseka (2006) attributed the absence of abundant aquatic life in the Chambishi tream to elevated zinc and nickel levels. Furthermore, a number of fish species in both tailing dams and the Kafue River have indicated relatively high concentrations of metals, such as copper and cobalt, in comparison to areas not affected by mining (Lindahl, 2014). Siltation has also been linked to biodiversity destruction and depletion of fish stocks around KCM’s plant near Chingola town (Das and Rose, 2014).

Two of the participants (Participant 1 and Participant 4) alluded to the effect of soil pollution on crop productivity, with participant 1 being of the view that crops grown in the vicinity of mining operations are highly contaminated, and participant 4 claiming that crop productivity is low due to soil acidity from sulphur dioxide emissions.

v Human health effects

As indicated in the sub-sections above, communities in areas surrounding mining and ore beneficiation operations may be exposed to noxious gases and elevated metal pollutants through inhalation (particulates and fumes), skin contact (contaminated soils, water and dust) and ingestion (water, contaminated fish and crops).

Historically, the primary environmental health issue in the Copperbelt mining area has been exposure to sulphur dioxide and particulate emissions in Mufulira, Kitwe, and Chambishi (CEP, 2002). This is partly due to the close proximity of these residential areas to the mines and smelters. In August 2014, protests broke out at the Mafulira plant due to claims that seven people had been hospitalized from the sulphur dioxide emissions from the smelter (Das and Rose, 2014). Earlier measurements (March 2014) showed pollutant values that exceeded the WHO´s limits by up to 30 times (Das and Rose, 2014). A survey amongst participants interviewed indicated that 69% considered copper mining to pose a very high risk and 31% a critical risk to the health of surrounding communities.

> “excessive SO_2 pollution in the past still has so many health and land issues which are not to (the) fullest of our knowledge handled in the right manner. If you look at our children, most of them have chronic coughs that have not been seen in other generations in our lineage. We strongly suspect that this is owed to the fact that they had too much exposure to SO_2 and other air pollutants from the concentrator” – Participants 5-9

Apart from air pollution, the majority of towns on the Copperbelt province depend on the Kafue for domestic water, raising concerns about potential contamination from mining activities (Lindahl, 2014). Although the concentrations of suspended metals in the Kafue river are generally relatively low, the local water supplier to Chingola, Mulonga Water, is reported to be forced to repeatedly shut off water supply to the town due to untreatable levels of pollution in the River Kafue, as a result of direct discharge from the nearby KCM operations (Das and Rose, 2014). Residents in Chingola have reported that the piped water often smells of sulphur and sometimes causes itching after washing (Das and Rose, 2014). The Nchanga South residents have also expressed concern about the suitability of piped water for domestic use (Figure 3.28). In 2015 an eight year long legal battle by 2000 contaminated residents finally ended when the Supreme Court of Zambia confirmed the High Court's opinion that KCM was guilty of 'gross recklessness' and damaging villagers' health.

Figure 3-28 Chingola community members displaying the quality of water coming out of the tap as a result of the pollution in Kafue River (Das and Rose, 2014).

Though the majority of Chingola town is affected when the piped water is contaminated, the most affected people are the villagers living alongside the contaminated streams and the river Kafue downstream of KCM's plant (Das and Rose, 2014). Unlike the townspeople who may have access to cleaner boreholes, these communities have no access to clean water as the groundwater is polluted over a wide area either side of the streams (Lindhal, 2014). Where poor communities have no access to piped water, they draw their drinking and washing water directly from rivers. The tributaries of the Kafue River have also been utilis9d for fishing and irrigation activities.

Ndilila et al. (2014) conducted a study on the non-occupational long-term metal exposure within a community in the Copperbelt mining region of Zambia (Kitwe), and compared this to a non-mining community (Livingstone). The results of the study (Figure 3.29 and Table 3.8) indicated that, in general, concentrations of metals and semi-metals in residential soils, dusts and drinking water in mining areas of the Copperbelt are higher than those in non-mining area. This pertained in particular to cadmium, cobalt, copper, lead and zinc in soil and dust, and arsenic, cobalt, copper, lead and nickel in drinking water. The results in Figure 3.28 and Table 3.8 also indicate that metals concentrations in the toenails of residents in mining communities and towns were significantly elevated in comparison to residents from non-mining areas, particularly with regards to cadmium, lead, copper and cobalt exposures. Ndilila et al. (2014) emphasised that this exposure posed a specific risk the health of children, pregnant women and the immune-compromised residents.

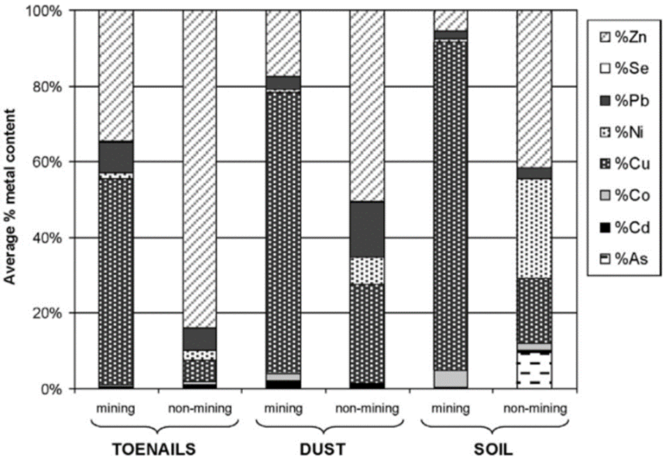
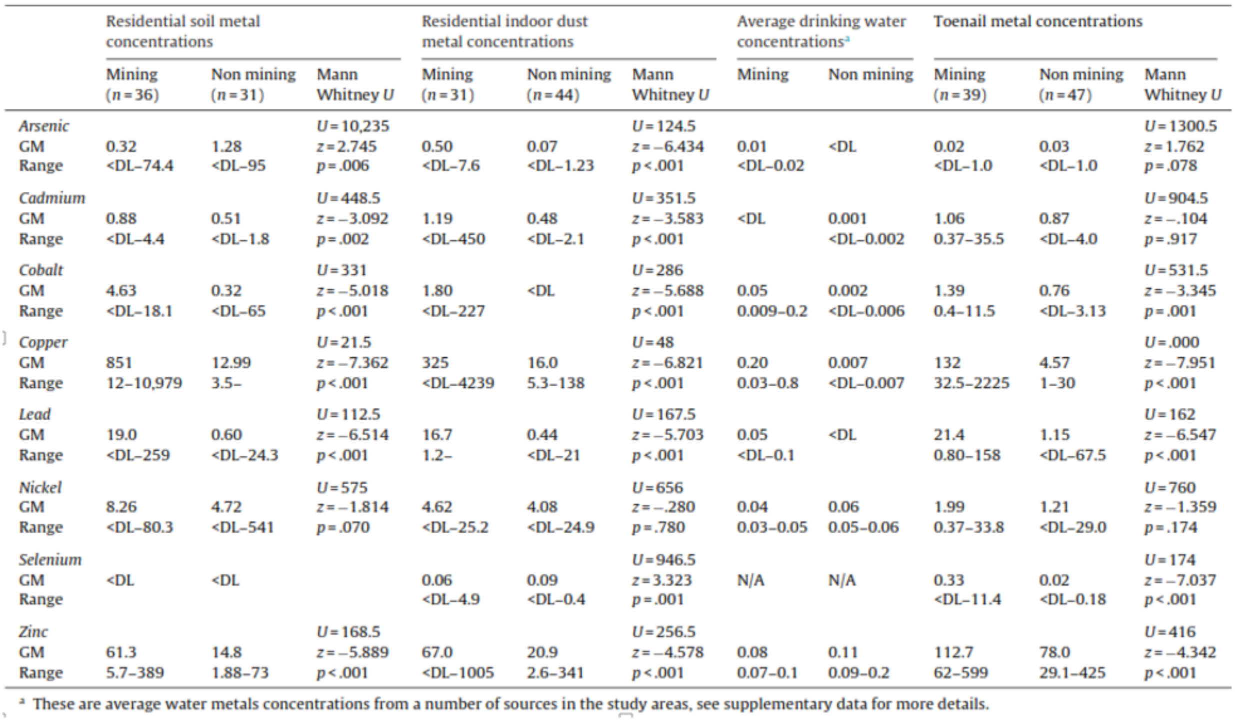


Figure 3-29 Average percentage metal concentrations in dust, soil and toenail samples for residents of Kitwe (mining) and Livingstone (non-mining) (Ndilila et al., 2014)

Table 3-8 Summary of residential soil, dust, toenail and drinking water metal concentrations (mg/kg) in the mining and non-mining areas in the Copperbelt (where GM is the geometric mean) (Ndilila et al., 2014)

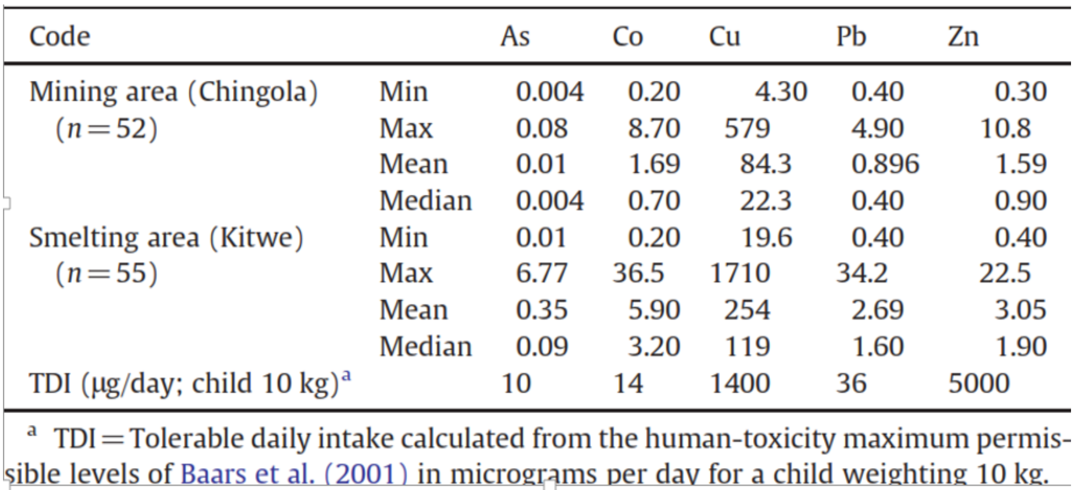


	Residential soil metal concentrations			Residential indoor dust metal concentrations			Average drinking water concentrations[a]		Toenail metal concentrations		
	Mining ($n=36$)	Non mining ($n=31$)	Mann Whitney U	Mining ($n=31$)	Non mining ($n=44$)	Mann Whitney U	Mining	Non mining	Mining ($n=39$)	Non mining ($n=47$)	Mann Whitney U
Arsenic			$U=10{,}235$			$U=124.5$					$U=1300.5$
GM	0.32	1.28	$z=2.745$	0.50	0.07	$z=-6.434$	0.01	<DL	0.02	0.03	$z=1.762$
Range	<DL–74.4	<DL–95	$p=.006$	<DL–7.6	<DL–1.23	$p<.001$	<DL–0.02		<DL–1.0	<DL–1.0	$p=.078$
Cadmium			$U=448.5$			$U=351.5$					$U=904.5$
GM	0.88	0.51	$z=-3.092$	1.19	0.48	$z=-3.583$	<DL	0.001	1.06	0.87	$z=-.104$
Range	<DL–4.4	<DL–1.8	$p=.002$	<DL–450	<DL–2.1	$p<.001$		<DL–0.002	0.37–35.5	<DL–4.0	$p=.917$
Cobalt			$U=331$			$U=286$					$U=531.5$
GM	4.63	0.32	$z=-5.018$	1.80	<DL	$z=-5.688$	0.05	0.002	1.39	0.76	$z=-3.345$
Range	<DL–18.1	<DL–65	$p<.001$	<DL–227		$p<.001$	0.009–0.2	<DL–0.006	0.4–11.5	<DL–3.13	$p=.001$
Copper			$U=21.5$			$U=48$					$U=.000$
GM	851	12.99	$z=-7.362$	325	16.0	$z=-6.821$	0.20	0.007	132	4.57	$z=-7.951$
Range	12–10,979	3.5–	$p<.001$	<DL–4239	5.3–138	$p<.001$	0.03–0.8	<DL–0.007	32.5–2225	1–30	$p<.001$
Lead			$U=112.5$			$U=167.5$					$U=162$
GM	19.0	0.60	$z=-6.514$	16.7	0.44	$z=-5.703$	0.05	<DL	21.4	1.15	$z=-6.547$
Range	<DL–259	<DL–24.3	$p<.001$	1.2–	<DL–21	$p<.001$	<DL–0.1		0.80–158	<DL–67.5	$p<.001$
Nickel			$U=575$			$U=656$					$U=760$
GM	8.26	4.72	$z=-1.814$	4.62	4.08	$z=-.280$	0.04	0.06	1.99	1.21	$z=-1.359$
Range	<DL–80.3	<DL–541	$p=.070$	<DL–25.2	<DL–24.9	$p=.780$	0.03–0.05	0.05–0.06	0.37–33.8	<DL–29.0	$p=.174$
Selenium						$U=946.5$					$U=174$
GM	<DL	<DL		0.06	0.09	$z=3.323$	N/A	N/A	0.33	0.02	$z=-7.037$
Range				<DL–4.9	<DL–0.4	$p=.001$			<DL–11.4	<DL–0.18	$p<.001$
Zinc			$U=168.5$			$U=256.5$					$U=416$
GM	61.3	14.8	$z=-5.889$	67.0	20.9	$z=-4.578$	0.08	0.11	112.7	78.0	$z=-4.342$
Range	5.7–389	1.88–73	$p<.001$	<DL–1005	2.6–341	$p<.001$	0.07–0.1	0.09–0.2	62–599	29.1–425	$p<.001$

[a] These are average water metals concentrations from a number of sources in the study areas, see supplementary data for more details.

Ettler et al. (2014) evaluated the potential intake of metals by children through soil ingestion, on the basis of metal bioaccessibility of metals in residential areas around mining and smelting operations on the Copperbelt. The results, summarised in Table 3.9, showed that a soil intake of only 100 mg per day daily could result in excessive doses of Cu and Co in the Kitwe region. Otherwise the risk of metal intake through soil ingestion was generally relatively low

Table 3-9 Calculated amount of contaminant ingested (µg) assuming a soil ingestion rate of 100 mg /day (Ettler et al., 2014)



Code		As	Co	Cu	Pb	Zn
Mining area (Chingola)	Min	0.004	0.20	4.30	0.40	0.30
($n = 52$)	Max	0.08	8.70	579	4.90	10.8
	Mean	0.01	1.69	84.3	0.896	1.59
	Median	0.004	0.70	22.3	0.40	0.90
Smelting area (Kitwe)	Min	0.01	0.20	19.6	0.40	0.40
($n = 55$)	Max	6.77	36.5	1710	34.2	22.5
	Mean	0.35	5.90	254	2.69	3.05
	Median	0.09	3.20	119	1.60	1.90
TDI (µg/day; child 10 kg)[a]		10	14	1400	36	5000

[a] TDI = Tolerable daily intake calculated from the human-toxicity maximum permissible levels of Baars et al. (2001) in micrograms per day for a child weighting 10 kg.

3.4.3.2 Governance of mining activities and impacts

i Legislation

In Zambia, minerals in the ground are vested in the President on behalf of the state. Current Government policy is not to participate in exploration or other mining activities or any shareholding other than its regulatory and promotional role. Prior to 1995, depressed copper prices on the international market, plus the under-capitalization of the copper mines, resulted in severe constraints on the country's economy. To address this problem, and in order to ensure that the mining industry continues to play a crucial role in national development, the Zambian government changed their mineral and mining policy in 1995 (Grant and Haslett, 2007). In line with Government's stated Mining Policy, the 1995 Act greatly simplified licensing procedures, placing minimum and reasonable constraints on prospecting and mining activities, creating a very favourable investment environment, whilst allowing for international arbitration to be written into development agreements should it be deemed necessary. Mining operations in Zambia are currently regulated by the Mines and Minerals Act (No. 11) of 2015. This is a latest revision from the 1995 and 2008 revisions (Parliament, 2015). Mineral sector legislation and the fiscal regime have changed in recent years. The fiscal regime has been altered several times to increase some mineral taxes and royalties. However, this has increased commercial risks for mining companies in Zambia and potential investors (ICMM, 2014). The Government encourages private development and diversification of the mining sector and promotes small-scale mining.

The Environmental Protection and Pollution Control Act (No. 12) of 1990, the Mines and Minerals Environmental Regulations of 1997 and the Environmental Protection and Pollution Control (Environmental Impact Assessment) Regulations, 1997, provide a framework for environmentally responsible development of mines (Figure 3.30).

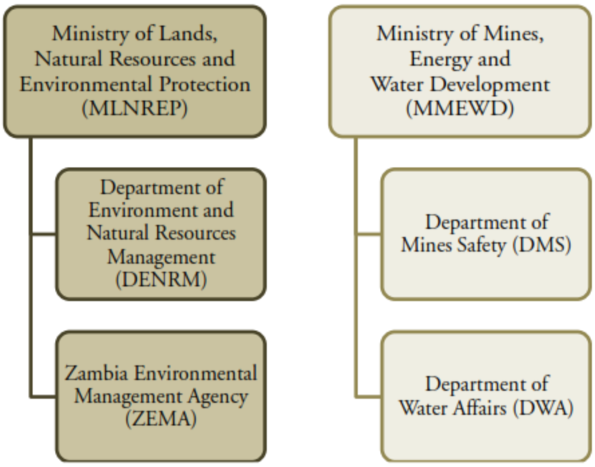


Figure 3-30 Framework for environmentally responsible mining in Zambia (Lindahl, 2014).

Zambia Environmental Management Agency (ZEMA) was established in the 1992 under the former name Environmental Council of Zambia. ZEMA is the major environmental institution in Zambia and the lead agency with a mandate by law to; “*do all things necessary to ensure the sustainable management of natural resources and protection of the environment and the prevention and control of pollution*”. ZEMA´s functions include:

- authorising or inhibit industrial projects,
- issuing permits and licenses,
- auditing and monitoring the compliance of operating industries, and
- Publicizing information regarding environmental management and pollution control.
- developing and enforcing measures to prevent and control pollution,
- developing guidelines and standards related to environmental quality,
- promoting research and studies,
- Advising the government on policy work,
- coordinating the implementation of environmental management in all ministries,
- controlling the Environmental Impact Assessment process

Bilateral development agreements (DAs) were entered into by the Zambian Government with each company at privatization. However, these were revoked in 2008 and all mining companies now operate under a common legislative framework.

ii The Zambian Extractive Industries Transparency Initiative

Zambia joined the Extractive Industries Transparency Initiative (EITI) as a candidate in May 2009 and was fully compliant in September 2012 (Moore, 2012 and 2013). EITI is an international organization that promotes transparency in the declaration of earnings and revenues arising from the extractive industries, as well as its compliance with the environmental financial disclosure by mining companies (Sequeira et al., 2016). EITI was launched at the World Summit for Sustainable Development in Johannesburg by Tony Blair, United Kingdom's Prime Minister at the time, as the future global transparency standard. It was established through a partnership of governments, industry, civil society and investors. The ultimate goal of the EITI is to lead to improved sustainable development outcomes through public debate over the effective allocation of resource revenues and public finance (Sequeira et al., 2016).

In Zambia, the local organization is called Zambia Extractive Industries Transparency Initiative (ZEITI) and it monitors what the mining companies say they have paid into government and government agencies and what government acknowledges as having received. The overall objectives of the reconciliation exercise are to assist the government of Zambia in identifying the positive contribution that mineral resources are making to the economic and social development of the country, and to realise their potential through improved resource governance that encompasses and fully implements the principles and criteria of the EITI (Sikamo et al., 2016)

ZEITI has so far released six reports for 2008 to 2013. These reports show remarkable agreement between what governments acknowledges as having received and what the mining companies say they have paid. From the reports (Table 3.10), it is clear that the mining industry has been contributing revenues to the treasury on an increasing basis in line with increasing production and copper price fluctuations (Moore, 2013).

Table 3-10 Zambian Kwacha Exchange rate Vs US $ between 2008-2013 (ICMM, 2014)

Year	GDP (Kw billion)	Total taxes collected (Kw billion)	Mining taxes collected (Kw billion)	Mining taxes (% GDP)	Mining taxes (% total tax)
2008	54,839	9,670	1,541	2.81%	16%
2012	111,049	20,723	6,619	5.96%	32%

According to research conducted by (Sequeira et al., 2016) in Zambia, EITI does not improve voluntary disclosure by companies, even when industry, government and civil society make consensual decisions about the type of information that should be disclosed. The current level of information disclosure in the Zambian minerals sector as an EITI compliant country is, furthermore, not sufficiently transparent to allow funders to determine level of compliance. This research further suggests that it is currently impossible to de-couple financial payments from environmental impacts. To achieve true transparency in the mining sector, the ultimate value of a mining activity to a society would be expressed as the financial value minus the full costs (including environmental rehabilitation liabilities). In contrast with, for example taxes and royalties, the financial payments from companies to governments associated with mining securities are a unique transaction.

iii Environmental initiatives

The Zambian Copperbelt is one of the most contaminated areas in southern Africa because of the extensive long-term mining and processing of Cu and Co ores (Ettler et al., 2014). To address the concerns raised, many initiatives have been launched to monitor the impacts and improve their governance made to study the impacts of mining on the environment of the Copperbelt Province. Some of them are;

- The *Australian Agency for International Development (AusAid) project*. AusAid's project in Zambia aimed to build capacity through training of key stakeholders around water and sanitation and use of natural resources in a sustainable manner. This project ran from 2013 to 2014 and was executed by the International Mining for Development Centre (IM4DC) (IM4DC, 2014).
- The *Czech Republic Development Cooperation* conducted a study between 2004 and 2006 on the assessment of mining and processing of copper on the environment and human health in the Copperbelt between 2008 and 2010
- The *Danish International Development Agency (DANIDA)* focused on the water and sanitation sector. The program ran between 2009 and 2013 and was aimed primarily at strengthening the capacity of the Ministry of Lands, Environment and Natural Resources by providing policy and legislative frameworks to mainstream environmental management.
- In the late 1990s, the *Swedish International Development Cooperation Agency* (Sida), together with Luleå University of Technology, funded an extensive research study on the geochemistry of the Kafue River. The results of the study generated valuable knowledge on the natural behaviour of the river as well as the extent of the impacts from mining. Sida has also funded an environmental monitoring programme for the Zambezi River through the Zambezi River Authority with technical support from Stockholm Environment Institute (SEI).

The most extensive study was the *Copperbelt Environmental Project (CEP)* funded by the World Bank. This project, conducted over the period 2002-2007, was initiated to address the liabilities of the ZCCM operations following the privatization of the majority of the copper mines on the Copperbelt. Following an initial environmental assessment (EA) of mining hazards in the Copperbelt area and Kabwe from a risk-based perspective, the CEP set out to achieve set out to establish an Environmental Management Facility (EMF) and strengthen the environmental regulatory framework. The EMF was established to finance the costs of priority environmental and social mitigation measures required as a result of ZCCM's past operations, as well as ongoing activities on properties that remained with ZCCM-Investment Holdings. This was in addition to funding mitigation measures agreed upon with the investors who bought the ZCCM mining assets. The Environmental Regulatory Framework was designed to strengthen the institutional framework that requires the Mine Safety Department (MSD), ZEMA and ZCCM to monitor the Environmental Management Plans agreed upon by the various private investors as well as by ZCCM. The framework also assisted in building capacity within national institutions to monitor the implementation of the environmental mitigation commitments made by the investors and ZCCM. The CEP offered an opportunity for a concerted and more holistic approach to addressing historical environmental problems, particularly the environmental liabilities that arose as a result of mining sector reform. During the implementation of the project, the environmental regulatory framework was reviewed and environmental management plans were prepared by individual mining units. Other achievements of the project include:

- Establishment of a monitoring system for the implementation of environmental management plans and their compliance with environmental regulations
- Regular monitoring of pollution flows and loads resulting from mining operations
- Improvement of the MSD and ZEMA's capacity to enforce regulations and performance
- Enhancement of civil society capacity for active participation in environmental management
- Enhanced co-ordination and partnership among authorizing agencies and collaborating institutions so that they effectively participate in the regulatory framework
- Increased environmental awareness and public participation

3.4.3.3 Stakeholder relationships and expectations

This section of the report provides insights into community-mine conflicts and community expectations, as derived from the stakeholder interviews.

i Factors contributing to mine-community conflicts

Semi-structured interviews indicated that poor governance and enforcement of regulations is considered to be the major cause of mine-community conflicts by the majority of the stakeholders. In contrast, only two of the participants considered environmental pollution to be a major cause of conflict, despite the stakeholder concerns relating to pollution and associated health risks.

- Governance and regulation of the mining industry

The lack of effective governance and regulation of the mining industry by the government was a serious concern for most of the respondents.

> "The government is failing in their duties. They have to be in the forefront in bringing us together, which they are not doing at all" – Participants 10-14
> "Government does not seem to be doing what it is supposed to be doing protecting these people, they complain daily about SO_2,, they are not heard, the complain about houses being cracked, they don't get compensated. So what do you expect? People will react in anger!!" – Participant 4
> "We the communities close to the mine suffer the impacts because there is no proper legislation let alone implementation" – Participants 10-14

Whilst the legislation itself was largely considered to be adequate, implementation was seen as generally problematic.

> "I will be honest with you Zambia has one of the best environmental legislations in the region. Actually, the mining law is one of the most altered and repealed to make it suitable for our place. I am confident that we do not even need extra legislation in Zambia. What we need is the implementation of those laws" – Participant 4

"The legislation is in place but has room to be adjusted further. The weakness lies in implementation. It is in place though can be further aligned and then enforcement of course" – Participant 4
"Yeah it is sufficient but not implemented. That's the issue" – Participant 2

Some respondents believe that poor implementation of regulations and legislation is due to institutional inefficiency and lack of capacity, particularly in terms of environmental monitoring.

"ZEMA don't have enough man power, equipment and vehicles, even resources to be in many places and they rely on the reports generated by these same mining houses using either themselves or other consultants and those are the things they make decisions on" – Participant 4
"We have a regulator, mine regulator apart from ZEMA we also have mine safety department who are mandated to ensure that these mines operate with a certain set of rules and guidelines, but these are handicapped institutions" – Participant 4

However, most of the respondent believed that the failure of the government to effectively implement laws is due to political interference.

"There is a very strong political hand when it comes to mining in Zambia. These mining companies speak directly to the head of state, they don't even bother talking to these "small boys", so whilst one can have a compelling reason for example to close a mine as an environmental agency the challenge is that the politicians will come and override your decision" – Participant 4
"What we are trying to say is that there is serious political interference on the mining operations in Zambia such that the agency mandated to monitor and regulate the environmental affairs around mining are just a frame and absolutely toothless!" – Participants 5-9
"Little action takes place to correct the situation and it is because of this kind of political pressure that is on regulators when it comes to dealing with mining companies" – Participant 4
"Whenever there is a serious matter to deal with, the politicians will interfere. That's now we have seen a rise in the local copper thieves popularly known as JERABOS" – Participants 5-9

In fact 54% of the participants considered poor governance and political interference to be the main cause of conflict between mining houses and local communities.

"I think it is **the law**, the government not fully playing its role of regulator and governor. Regulator in the sense that the government being the enforcer of the law. Making sure that the mining operators are in accordance with the law and that at many levels" – Participant 3.

One of the respondents referred to the controversial "development agreements" entered into between the government and the mining companies during the mining sector privatization in the year 2000, some of which are in conflict with recent government regulations.

"These agreements have more or less rendered our laws irrelevant because the contract itself is a legally binding document" – Participant 4

- Environmental impacts

In general, the perception amongst respondents is that incidents relating to safety, environmental pollution and community impacts are poorly reported, and conflicts over such incidents are minimal. Whilst environmental pollution was generally recognised as an issue, only two interviewees considered this to be a major point of conflict.

"The major cause of conflicts, I think it is the access to water, quality water" – Participant 2
"I think pollution is one of the major causes" – Participant 4

One of the reasons for the low level of reporting appears to be related to the economic dependency of local communities on mining activities, and fears over the loss of livelihoods should the mines be forced to close as a result of environmental infringements.

“We must say that only 30% of the incidents are really reported because the community themselves fear the mining houses. We are talking about cities the solely depend on mining. If anything went wrong they locals are the first ones that suffer the consequences” – Participants 5-9 (group)
“So the communities as I speak now, they perceive the mines as more of their “god”. We cannot close this mine because of pollution, otherwise if we close them we die, this is a huge challenge” – Participant 4

Another concern linked to poor reporting and action on the part of communities, was a lack of adequate knowledge and understanding, both in terms of the impacts from mining and the legal rights of the community to a healthy environment.

“We the community are not well informed, we are not considered to be anything apart from a source of casual workers who cannot reason with the mine at a top level” – Participants 10-14
“We the community are not fully aware of the procedures that the mines work with for example, we don’t even get a chance to know how much air pollution and water have been reduced over time” – Participants 5-9
“We are working in an environment where these big mining companies have taken advantage of the poverty and the lack of knowledge within the community and understanding of what is going on and have pushed the agenda without remorse, without caring for the people that live around those communities” – Participant 4
“The rate of the conflicts we have as very minimal even when they are supposed to be very high. It’s just that people are not properly sensitized about the rights though we had sporadic cases where the local community has sued the mines. But I was expecting more of these conflicts!” – Participant 4

There was also a perception from the community that these reports do not solicit adequate response.

“What is reported is not traced though. As a community now we even feel discouraged to report these matters” – Participants 10-14

Communities thus tend to rely on Government and community-support organisations (CSOs) to play the role of “environmental watchdogs”.

“The community and dependent on the government agencies to be there environmental Watch Dogs rather than taking it upon themselves to be responsible for reporting an incidence on the environment that affects the community’’ – Participant 1
“Government must take a lead because their sole responsibility is to protect the interest of the citizenry” – Participant 4

Whilst CSOs, in particular, are considered to be the “*voice for the community*”, only 10% of the respondents felt that they were effective.

“The CBOs (Community-based organisations or CSOs) also lack the enthusiasm to stand for the community in as much as they are well informed most of them are there because they want to make money! In the absence of motivation financially, they shun being proactive” – Participants 5-9
“At the center of all this, the referees are the CBOs but most of them are so quiet. We had CBO which is still there but not as vibrant as it was because the leader has taken up a new role. So we need someone to fill up that. Even the Church must be on board” – Participant 4

Responses from the interviews indicate that the CSOs currently play a less active role than they have in the past.

“I had a project back in 2012 which was called Community Based Environmental Project which was aimed at sensitizing the community of the new act, their right and how they could address issues of pollution and confront the mining houses. We were able to prosecute these mining companies like Konkola Copper Mines and Mopani and also Chibuluma mine. Most of the cases, we won and people were compensated" – Participant 4

ii Stakeholder expectations

In general, the majority of the interviewees considered the copper industry sector to have the potential to play a more positive role in the socio-economic development of the country. Specific expectations in terms of realising this potential pertained mainly to the development of stronger economic linkages, improved governance and regulation on the part of the national government, and enhanced stakeholder engagement and communication.

- Economic linkages

Two of the respondents stressed the need for better upstream and downstream linkages, in order to realise the full potential of the copper sector in terms of socio-economic development.

"We are not clever in transferring our mineral assets into more sustainable forms of resource" he added that "If we are not clever, our mineral resources will be exhausted and we would not have industrialized. For me that is the biggest problem" – Participant 3
"I would like to see a mine in Zambia where the suppliers and contractors are predominantly Zambian. So that we can have that socio-economic impact being growth development localized" – Participant 2
"Beneficiation should happen right here in Zambia. I want to see a full life cycle in terms of product beneficiation right here in Zambia" – Participant 2

- Governance and regulation

The general consensus was that the national Zambian government should play a more active role in enforcing environmental regulations and protecting communities against environmental and social injustices.

"Government should make sure that the regulations up to date and that the mining houses are complying with the set rules and regulations". Government are the key player in adhering to set regulations and ensuring that when you are meant to impacts that mining causes on the local community are curbed and reduced because government has the power" I'm looking forward to seeing the environmental liabilities not been transferred to the local people that do not have the ability to contain them" – Participant 1
"Government is meant to ensure that the policies the regulations that have been formulated are followed to the latter" – Participant 2
"They (the government) are responsible for the main infrastructural development and health care of their countrymen and women, education and providing the necessary amenities for the community to be resilient" – Participant 3
"We are not fully aware of the legislation but we feel that it must be changed to suit the needs of the community as well. We are the ones that suffer these impacts. They must seriously consider our plight too. The legislation must be more inclusive" – Participants 5-9

Participant 1 however highlights that even if the role of cannot be played in Isolation:

"This role cannot be played independently or in isolation. It must be played in consultation with these other stakeholders".

- Stakeholder engagement and communication

The general consensus amongst respondents is that there needs to be more effective and inclusive engagement and communication between all stakeholders (government, industry, communities and community-based organisations).

"We want to see a mining operation that respects the community, a mine that will involve the community even in decision making with regard to processes that affect the community environmental wise and socially" – Participants 5-9
"I would like to see a mine that is inclusive" – Participant 2
"The major challenge which I find is that communities are not partners with the mining houses; there is little stakeholder engagement" – Participant 1
"We (the community) want to see a mining industry in which we are included even in decision making – participants" – Participants 10-14
"What I look forward to is situations where people will sit down, we start planning life after mining. Little is being talked about regarding life after mining" – Participant 4

There is also a call for the communities themselves to be more proactive in terms of communicating their concerns and reporting incidents of environmental pollution or social injustices.

"The local community must also be sensitized, they must know of their rights and take up this challenge, fight it for themselves"

One respondent (participant 3) called for forums and mechanisms that would promote engagement between mines and local communities, as well as between government and communities.

"There should be a deliberate liaison arrangement that should exist between the community and the mine. So that people on a regular basis interact with the mine managers or the mine owners and are able to express themselves about issues that concern them – both positive and negative."
"The government through ZEMA for example has obligations in the mining industry to control and listen to the community, address them give feedback. But unfortunately we don't usually get that. So the deficiency really lies in the government reporting system"

These engagement and communication platforms would also serve to educate and inform local communities about their rights and obligations, thus enabling them to take ownership of their own well-being and future.

"… there is need to physically sensitize the local community and the ones to create a platform for such sensitization is not only the government but also the mines and the CBOs (community-based organisations) but most importantly the government must the willingness to push this agenda" – Participants 5-9
"People in the communities must be educated about life after mining"– Participant 4
"A change in attitude (is required) from government, the community, the community-based organisations and other stakeholders. These must work together to make profits and make sure that there's a better future for the generations to come" – Participant 1

3.5 Summary

Whilst there are a number of inter-related factors affecting specific concerns and experiences, including the nature of the ore, the local geography and the socio-political, economic and regulatory climate, all three case studies emphasised the adverse effects of mining activities on the surrounding environment and the associated impacts on the quality of lives and livelihoods of surrounding communities. Environmental impacts reported to be of concern by local communities, community-support organisations and environmental experts include water pollution, physical and chemical land degradation, and air pollution through emissions of particulate matter (PM) and toxic gases. This environmental pollution was reported to have a significant effect on local eco-systems, as well as on community health and livelihoods, particularly through crop and livestock farming. In each case, mine waste deposits were considered a significant source of environmental and associated social impacts, particularly in terms of metal-rich acid rock drainage and wind-blown dust emissions. Of particular relevance to defunct coal waste dumps, are the additional human health issues associated with the release of gaseous emissions as a result of combustion of coal wastes, whether spontaneously or as a result of domestic consumption. The gold tailings case study in the Witwatersrand basin, in particular, illustrated how defunct mine waste dumps can continue to impact on the local environment and surrounding communities for decades after mining operations in an area have ceased, and how difficult it is to keep such dumps isolated from human settlement developments over the long-term. Whilst there appears to be very few detailed site-specific data and source-response or cause-effect case studies to support reported incidents of pollution and related impacts from mining operations and waste deposits, the concerns and experiences of local communities and environmental experts are largely consistent with reports in the published literature pertaining to the environmental and associated social impacts of coal, gold and copper mining, both in the context of the case study regions, and more broadly.

There is also evidence that the environmental impacts of mining are recognised, and being responded to, by the Government and by mining companies, particularly the larger multi-national companies, in both South Africa and Zambia. These responses include significant legislative and regulatory reforms, as well as the rehabilitation of degraded lands, the implementation of more modern and cleaner processing technologies, improved waste management practices, and the treatment of contaminated mine water. In Zambia, in particular, a number of projects have been funded by international organisations to investigate and mitigate environmental impacts associated with copper mining. However, reports in the open literature and stakeholder interviews also reflect doubts about the ability of government to implement and enforce regulations in a consistent and fair manner, and on the effectiveness of interventions by mining company. Furthermore, for the most part, local environments remain polluted and mining communities continue to suffer, resulting in a highly politicised scenario and on-going (and possibly escalating) conflicts between communities, mining companies and local government. This is particularly the case in South Africa, where there are a relatively large number of active community support organisations, and a high level of public knowledge and awareness of these impacts. In contrast, the Zambian Copperbelt study indicated that conflicts over environmental impacts from mining in Zambia appear to be minimal, despite the concerns expressed by community stakeholders and consultants. This was attributed to a combination of inter-related factors, the most significant being fears over potential repercussions in terms of loss of jobs and livelihoods, and a general lack of community awareness and support.

In general, all three case studies indicated that communities and community-support organisations feel that are not been taken seriously, and that government and industry are failing to alleviate the environmental degradation and human suffering in the mining regions. The lack of adequate intervention on the part of both the government and industry in South Africa and Zambia is, furthermore, attributed largely to the unethical arrangements between government officials and/or community leaders with mining corporations. The general consensus appears to be that governments are failing to enforce regulations due to their close relationship with the mining industry, a situation that the mining companies are exploiting. In terms of the expectations and aspirations of communities regarding actions and responses going forward, the coal and copper case studies both indicated that effective rehabilitation is considered a key requirement in terms of mitigating the environmental impacts and associated risks pertaining to human and livestock health and crop productivity. Conversely poor rehabilitation is seen to be contributor to environmental pollution and associated risks. This pertains not only to current operations but also to abandoned mines, the rehabilitation of which is seen to be the responsibility of the government. The coal and copper case studies also stressed the need for more effective and consistent implementation and enforcement of regulations designed to protect the environment and society, and the need for different stakeholders (government, mining companies and civil society organisations) to collaborate and co-operate.

CHAPTER 4: MINE WASTE VALORISATION IN SOUTH AFRICA: OPPORTUNITIES, BARRIERS AND ENABLERS

4.1 Introduction

As indicated in Chapter 2, a potential alternative to land disposal of large-volume wastes is to re-use or re-purpose the mine waste for other applications, ultimately resulting in a zero or minimal waste scenario. This so-called "valorisation" approach considers waste as a secondary resource which can used as feedstock for other uses and purposes, as opposed to unwanted or displaced material, and is consistent with the principals of the circular economy and of resource efficiency as defined by the European Union: "*using the earth's limited resources in a sustainable manner while minimising the impacts on the environment"*. This approach is currently gaining increasing momentum across the world and is now widely applied to household and electronic wastes.

The valorisation of industrial and mining waste has a number of potential advantages. Apart from reducing the waste burden on the environment and society, both through reduced waste footprint and a lower potential for environmental pollution, the re-purposing of waste creates opportunities to reduce resource consumption, by recovering resources from a material that has already been mined and processed. The re-use of mine wastes can also reduce the occupation of land, making it available for other uses, whilst contributing to the local economy by creating additional business and employment opportunities. For example, Sasol Mining, in collaboration with the Mpumalanga Economic Development Department and the Govan Mbeki municipality, embarked on a construction project that uses coal fly ash to make bricks. The brick factory buys 1000 tons of fly ash from Sasol and mixes it with cement and water to produce hollow-block and maxi bricks. Not only has this project reduced the waste output and its effects on the environment and local community, but it has further created job opportunities in the area (Yende, 2016).

Despite these apparent benefits, rigorous development and commercial application of mine waste valorisation approaches remains constrained. A premise of this study it is that a comprehensive understanding of the opportunities available, as well as the associated barriers and enablers, is required to overcome these constraints and develop a defensible business case for the application of waste valorisation approaches.

It is these requirements that this chapter addresses, through the application of two case studies in the context of South Africa, one on gold tailings and one on coal processing wastes. Each of these case studies entailed a detailed review and analysis of the current literature, combined with a series of interviews with relevant stakeholders. Detailed case study methodologies are provided in Appendix C. This chapter presents the synthesised results derived from these case studies. More specifically, Section 4.2 identifies and summarises the valorisation opportunities for gold tailings and coal processing wastes; Section 4.3 outlines the barriers and enablers for the commercial valorisation of mine waste in South Africa; Section 4.4 discusses potential stakeholder roles in the transfer of such technologies; whilst the findings are summarised in Section 4.5.

4.2 Identification of potential valorisation options for mine wastes

Options for the utilisation of benign and sulphide-rich coal waste have been identified and discussed in a previous WRC report, (Harrison et al., 2013), with work on utilisation of coal wastes continuing as part of the WRC-funded project K5/2231: *An Industrial Ecology Approach to Sulphide-containing Mineral Wastes to Minimise ARD Formation*, and K5/2761: *Preventing acid rock drainage (ARD) generation from coal interburden waste rock – comparing long-term efficacy and techno-economic considerations*

This particular WRC-funded project extends previous and current work through a review and analysis of the status quo in terms of the valorisation or re-purposing of large volume mine wastes from the primary processing of different commodities both locally and internationally, with a particular focus on gold tailings (Section 4.2.1) and coal (Section 4.2.2) in the South African context.

4.2.1 Potential re-purposing options for gold tailings

It is quite evident that the waste generated during the gold beneficiation process is significant. In total, waste from gold mining accounts for approximately 42% of all waste generated in South Africa (Oelofse et al., 2007).

In recent years, utilization of mine waste has gained momentum and several studies have been undertaken to investigate the re-use of mine waste worldwide. The most common use of mine waste is as a construction material. Over the past 20 years, the construction of use for roadways, railways, rivers and dams using mine waste instead of natural soil has increased steadily (Yellishetty et al., 2008). Whilst the use of mine waste as a construction material for roads is perhaps the most common application, the findings of the various studies suggest that mine waste can be used for various purposes based on the chemical and physical properties of the waste in question (Van Heerden, 2002). Mine waste, and tailings in particular, have been used for construction of wetlands and roads, production of ceramic products such as tiles and as a cement additive (Harrison et al., 2013). Incorporation of tailings in the making of building materials such as bricks and concrete blocks, as road aggregate, in agricultural applications, landfills and manufactured fillers has also been investigated (Vogeli et al., 2011; Yellishetty et al., 2008). A more detailed review of reported options for the re-purposing of gold tailings is presented in Sections 4.3.1.1 to 4.3.1.5. This review has been based on literature available in the public domain and interviews with local experts.

4.2.1.1 Bricks

In the last decade, South Africa has seen a boom in the property development sector that has resulted in increased demand for construction materials. In addition, increasing population has resulted in an increasing demand for housing thereby placing severe strain on the natural resources that are typically used as construction materials (Malatse and Ndlovu, 2015). Conventional commercial bricks are produced from either ordinary Portland cement (OPC), concrete or clay which is fired in high-temperature kilns (Malatse and Ndlovu, 2015). The clay is typically mined in quarries resulting in adverse landscape alterations and high waste (Malatse & Ndlovu, 2015). Similarly, the production of cement is energy intensive and has a high carbon footprint.

i Brickmaking technologies

Research on the available technologies that have been used to produce bricks from mine waste include geo-polymerization, cementing and firing (Malatse and Ndlovu, 2015):

Geo-polymerization is a process in which solid alumino-silicates materials are dissolved in a concentrated alkali solution in order to form a stable inorganic polymer (Duxson et al., 2007; Zhang and Ahmari, 2014). Geo-polymerization consists of 1) dissolving solid alumino-silicates in a highly concentrated alkali or silicate solution; 2) forming a silica-alumina oligomer as a gel followed by poly-condensation of the oligomer; 3) forming a stable inorganic material; 4) reorganization; and 5) forming a strong bond with any undissolved solid materials in the polymeric structure (Kuranchie, 2015). The geo-polymerisation technology utilises industrial by-products including, but not limited to, kiln-dusts, slags and fly-ash (Klauber et al., 2009). Some of the advantages of geo-polymers over established ordinary Portland cement based concrete technology include excellent mechanical properties, an 80% reduction in overall CO_2 emissions intensity and superior capabilities of immobilising toxic metals (Klauber et al., 2009).

In the firing method, bricks are produced by mixing the virgin resources to form the bricks which are dried and then fired in high temperature kilns (Shakir and Mohammed, 2013). This technology has resulted in environmental contamination due to the high greenhouse gas (GHG) emissions which subsequently results in climatic variations, global warming, smog and acid rain (Shakir and Mohammed, 2013). In addition, the firing stage consumes a lot of the energy, making it very expensive. Modifications to the conventional kiln-firing method have focused on the reduction of energy consumption and the environmental impacts of brick production through using waste materials to partially or entirely substitute the clay, and follows the traditional method of kiln-firing (Malatse and Ndlovu, 2015; Shakir and Mohammed, 2013). Shakir and Mohammed (2013) reviewed published literature on the greenhouse gas emissions associated with brick making. According to this investigation the energy consumption of the clay, sand lime and concrete bricks was approximately 6.5382, 1.16498 and 2.91483 GJ/tonne respectively (Shakir and Mohammed, 2013). The study also revealed that other pollutant gases were emitted and these included fluorine (0.7-4ppm), hydrogen, sulphur dioxide (SO_2) and carbon dioxide (CO_2) (Shakir and Mohammed, 2013). Another study evaluated the energy consumption and associated GHG emissions of clay brick manufacture in the United States using fossil fuels. According to their findings, fired clay bricks have an embodied energy of about 9.3MJ/brick and associated GHG emissions of around 0.6 kg of CO_2 per brick. Concrete bricks on the other hand emitted approximately 0.3 kg of CO_2 per brick (Shakir and Mohammed, 2013). The emissions include carbon monoxide (CO), nitrogen oxides (N_2O), and methane (CH_4) and carbon dioxide (CO_2) emissions. A Sudanese case study investigated the GHG emissions and the linkages between deforestation and the clay brick industry. The findings of the study indicated that the clay industry had annual emissions of approximately 378 028 tonne of CO_2, 15 554 tonne of CO, 1 778 tone of CH_4, 442 tonne of NO_X, 288 tonne of NO and 12 tonne of N_2O (Shakir and Mohammed, 2013). In addition, the fired clay brick making industry resulted in the annual deforestation and loss of 508.4×10^3 m^3 of wood biomass, 267.6×10^3 m^3 round wood and 240.8×10^3 m^3 branches and small tree (Shakir and Mohammed, 2013).

ii Investigations on the use of mine tailings in brickmaking

The use of alternative fuel sources and raw materials offers massive opportunities for improving the sustainability of the bricks industry. In particular, the use of alternative aggregates would reduce the extraction of virgin materials thereby conserving clay, sand and shale resources used in brickmaking (Shakir and Mohammed, 2013). The use of mineral waste aggregate has the added advantage of dealing with the associated environmental impacts of conventional tailings disposal (Shakir and Mohammed, 2013). A significant amount of research has been conducted worldwide on using waste material in brick making (Malatse and Ndlovu, 2015; Roy et al., 2007). In South Africa, a study was recently conducted by Malatse and Ndlovu (2015) which evaluated the use of gold mining tailings from the old gold mines in Johannesburg. The study explored the viability, from both a technical and economic point, of using gold mine tailings in making bricks (Malatse and Ndlovu, 2015). In their research, different ratios of gold tailings from the Witwatersrand basin, water and cement were used to make bricks. The bricks were cured in different environments and tested for compressive strength, water absorption rates and weight loss tests against commercial bricks. Their findings suggest that the tailings exhibit similar chemical compositions to the clay material used for commercial brickmaking and therefore could be a potential substitute material in brickmaking (Malatse and Ndlovu, 2015). However, the bricks used more cement than conventional bricks, making them relatively expensive which could be a significant disadvantage. In addition, the uranium content in the tailings could be another barrier to using gold tailings in brickmaking and thus the mineralogical and chemical compositions of gold tailings would need to be evaluated first before utilization (Roy et al., 2007). The study also compared the compressive strengths of the bricks with the tailings to that of commercially produced bricks. The strongest brick was found to have a compressive strength of 530 kN while is less than the 750 kN of commercial bricks (Malatse and Ndlovu, 2015). This means that the tailings bricks currently do not meet the South African masonry benchmarks for brickmaking and testing.

A study has also been conducted by Mintek to investigate the feasibility of brick making from gold tailings. According to one participant interviewed, samples were taken from different tailings dams in the Free State. The samples first underwent acid leaching to remove the uranium in the samples and approximately 85% of the uranium was removed. After the leaching, brick specimens were made with different quantities of cement. From these bricks, the brick specimen that comprised of 65% cement and the fine tailings was the most competent brick. However, the cost of cement made this brick too expensive and this necessitated the need to explore other alternatives. The alternative brick specimens contained a mix of clay, tailings and cement. Out of all the samples, the bricks that were made from clay and tailings (in a ratio of 1:1) were compliant with SABS standards. The other specimen bricks that were comparable to the conventional bricks contained at least 50% clay with varying proportions of tailings and cement.

In India, Roy et al. (2007) investigated the likelihood of making bricks from a mix of gold mill tailings and different additives. The study followed previous research that had shown that tailings alone were not suitable for making bricks due to their low plasticity. As such, the researchers mixed the tailings with additives, which included ordinary Portland cement, black cotton soils and red soils. These were mixed in different proportions with water to form bricks. The cement-tailings brick consisted of 20% cement while the soil-tailings bricks contained between 45% and 75% tailings (Roy et al., 2007), To cure the bricks, the cement-tailings bricks were immersed in water while the soil-tailings bricks were first sun dried and then fired at high temperatures of between 750 and 950 °C (Roy et al., 2007; Zhang and Ahmari, 2014). After curing, the bricks were then assessed for water absorption, compressive strength and linear shrinkage (Roy et al., 2007). The study revealed that the tailings alone were not a suitable raw material for brick making due to their low plasticity. However, bricks that contained ordinary Portland cement as an additive met the required standards in terms of compressive strength, linear shrinkage and water absorption. However, the cost analysis indicates that bricks with cement as an additive would be very uneconomical due to the cost of cement (Roy et al., 2007). An in-depth cost analysis indicated that the cement-tailings bricks were approximately 2.4 times more expensive than conventional clay bricks. The bricks that had a mixture of soil and tailings were more cost effective, with cost varying to be between 72% and 85% of that of traditional bricks made from clay (Roy et al., 2007).

An investigation conducted by Zhang and Ahmari (2014) investigated the feasibility of using copper mine tailings in the production of geo-polymer bricks. In their study, sodium hydroxide (NaOH) solution was used as an alkali activator and the different brick specimens had different NaOH concentrations, water content, forming pressure and curing temperatures. Their findings suggest that the tailings-brick geo-polymers had comparable performance to conventional cementitious binders such as OPC in terms of water absorption, low shrinkage, density, high compressive strength, low thermal conductivity, fire and high acid resistance (Duxson et al., 2007; Malatse and Ndlovu, 2015; Zhang and Ahmari, 2014). In addition to this, geo-polymers have a significantly lower greenhouse gas emissions, excellent adherence to aggregates and are able to immobilize hazardous and toxic materials (Zhang & Ahmari, 2014). A more recent study was conducted by (Kiventerä et al., 2016) which looked at the geo-polymerization of sulphidic gold mine tailings. In this study, the tailings were activated with an alkaline NaOH solution, and commercial ground granulated blast furnace slag (GGBFS) was added as a co-binder (Kiventerä et al., 2016). Different specimens with varying NaOH concentrations and quantities of co-binder materials were produced and tested for porosity and compressive strength. According to their findings, the specimens made from pure mine tailings had an unconfined compressive strength that ranged from 1.3-3.5 Mpa (Kiventerä et al., 2016). The addition of the co-binder increased the compressive strength of the specimens which ranged from 1.8 MPa to 25 Mpa. The alkali-activation of the tailings allows binders with sufficient compressive strength to be produced and these can be used as either backfill in mining sites or a raw material input for construction materials (Kiventerä et al., 2016).

iii South African applications

In the media, a few cases of brick making from tailings has been documented. Some of these are controversial. One such case is of a brick manufacturing company that is located next to Lancaster dam in Krugersdorp (Balch, 2015). The company makes bricks using tailings from the nearby tailings dump. However, this project received significant negative publicity with environmental activists pushing to have the project shut down. This was mainly due to the fact that the tailings contained radioactive and toxic metals. Radiometric surveys conducted by the Department of Mineral Resources revealed that the tailings had elevated levels of radioactivity. As such, the production of such bricks were seen by various environmental groups as inappropriate and risking the health and safety of both the brick manufacturers and end users of the bricks (Balch, 2015). Another such case occurred in the West Rand where allegations were levelled against a brick manufacturing company operating within the area. The company was accused of using radioactive tailings to make bricks and for selling these bricks at a premium. However, interviews conducted by the International Human Rights Clinic (IHRC) with the Department of Environmental Affairs suggest that these allegations were not true (IHRC, 2016). This is despite the fact that other sources and residents of Mindalore contend that the production of bricks from radioactive tailings is still an ongoing practice (IHRC, 2016).

An alternative and more viable option to brick making in South Africa is making concrete blocks using gold tailings. A study conducted in the United States of America investigated this possibility and found that concrete blocks made from a combination of fly ash, gold tailings and minimal cement resulted in higher compressive strength when compared to conventional concrete blocks (Yellishetty et al., 2008). According to the findings, tailings are often too fine and as such require slower, intermediate technology methods that are more ideal in making concrete blocks (Yellishetty et al., 2008).

In general, most studies on using tailings in brickmaking have been conducted on a laboratory scale and limited scaling up has been done. Zhang (2013) states that limited commercialization of bricks from waste is "*related to the methods for producing bricks from waste materials, the potential contamination from the waste materials used, the absence of relevant standards, and the slow acceptance of waste materials-based bricks by industry and public*" (p. 643).

4.2.1.2 Ceramics

The production of ceramic materials from gold mine tailings is a feasible option and numerous studies have been conducted to investigate this option. One such exploratory research was conducted by Liu et al. (2015) and assessed the technical viability of using gold mine tailings in making ceramics. The chemical and the mineralogical compositions were first determined and based on their attributes; the tailings were mixed with clay and water in varying proportions to prepare ceramic blank material and to improve their performance. The different samples were dried and sintered in an electric kiln. The results revealed that the ceramic samples met the required technical standards of ceramic materials in terms of surface hardness, water absorption and modulus of rupture, and as such the gold tailings can be made into ceramic tiles and various types of ceramic bodies for domestic, industrial and commercial use (Liu et al., 2015). While the researchers acknowledge that the mineral composition and particle size distribution affect the feasibility of re-use, they state that gold mine tailings can also be modified with clay to further ameliorate their composition, particle gradation, and shaping property should they not meet the requirements of ceramic bodies such as ceramic tiles and household ceramics (Liu et al., 2015). This use of gold tailings in ceramics production offers a cheap resource to the ceramic industry whilst simultaneously dealing with a waste issue.

Another recent study, by Yassine et al. (2016), explored the feasibility of using tailings as an alternative material in the production of ceramic products. In the study, treated and untreated calamine tailings were first characterised before being mixed with water, and compressed using a hydraulic press. The samples were air dried and then oven dried at 600^{O}C for 24 hours. The dried samples were then fired in an electric furnace which ranges from between 950 to 1050^{O}C before being tested for compressive strength, porosity, water absorption and bulk density. The mineralogical characterisation of the tailings showed that the tailings consisted of mainly quartz, calcite and gypsum. The findings suggested that both treated and untreated tailings could be used for making ceramic products. However, the treated samples had higher flexural strength and decreased water absorption and open porosity when compared to the untreated tailings at high firing temperatures of 1050^{O}C (Yassine et al., 2016). The leaching test results indicated that metals such as arsenic (As), lead (Pb) and zinc (Zn) were mobile after the firing process and as such present a safety risk when using the tailings to produce ceramic materials. However, the addition of adsorbents such as magnetite on a zeolite and/or perlite matrix with the raw materials could potentially stabilize the metals thereby reducing the risks associated with leaching (Yassine et al., 2016).

Information on the economics of making ceramics from tailings is limited. In the interviews conducted, two of the respondents mentioned that, while they were aware of the production of ceramics using gold tailings in the United States of America, they didn't think this opportunity had been explored within the South African context.

The respondent felt that there was unlikely to be a business case for the use of tailings in ceramics production, as silica (the major ingredient for ceramic making) is available in abundance. In addition, the toxicity of the gold tailings could pose a significant challenge.

4.2.1.3 Mine tailings as a cement additive

Globally, there is increasing pressure for the construction industry to adopt practices and measures that ensure a drastic reduction in CO_2 emissions (Obonyo et al., 2011). The production of cement is the major contributing sector to the country's large carbon footprint. This is largely due to the fact that existing technologies emit hazardous pollutants such as CO_2, NO_x, and SO_x (Sobolev, 2003). In addition, the current method is expensive and consumes a lot of energy (Sobolev, 2003). Cement production therefore provides an opportunity for the construction sector to reduce its environmental impact. This can be achieved through a variety of initiatives such as developing and implementing low-temperature technologies during cement manufacturing, which would result in significant energy consumption and reduced dust and pollutant emissions per unit of cement manufactured (Sobolev, 2003). Schmidt (2016) suggests a combination of different concepts that can also lead to significantly reduced carbon emissions. These include improved efficiency of kilns, increased use of secondary fuels and the reduction of ordinary Portland in concrete production (Schmidt, 2016). An initiative that is gaining momentum is the development and application of alternative binders and the production of blended cements using either industrial by-products and/or mineral additives (Sobolev, 2003).

Çelik et al. (2006) investigated the feasibility of using gold mine tailings as an additive material to produce Portland cement. The tailings underwent treatment to remove free cyanide and to stabilize the metals present within the tailings. After treatment, the tailings were characterized in order to determine the tailings microstructure, mineralogical composition, particle size distribution as well as to ascertain the physical and chemical properties of the specific tailings (Çelik et al., 2006). After characterization, cement mortars were prepared by mixing different ratios of cement, tailings, fly ash and silica fumes. The resulting mortars were tested for compressive strength values and compared to conventional additives. The results indicated that up to 25% gold tailings within the clinker mix produced cement of the required standard. Based on their findings, the researchers concluded that gold tailings are a viable additive in the production of Portland cement, and the addition of fly ash and silica fume improves the quality of the cement and results in mortars with a higher compressive strength values (Çelik et al., 2006).

Another study was conducted by Sobolev and Arikan (2002) to explore the production of High Volume Mineral Additive (HVMA) cement. The HVMA cement is made from a mixture of Portland cement clinker, gypsum, cement clinker, mineral additive and a supersilica admixture (Sobolev, 2003). These materials are ground together in a ball mill and the resulting cement can be used for a range of concrete products. The mineral additives that were selected for the study and successfully applied in HVMA cement manufacturing included natural sand, pozzolanic materials, blast furnace slag, limestone, ceramic waste and fly ash (Sobolev and Arikan, 2002). The findings of the research demonstrated that the HP Cement technology could be successfully applied to produce HVMA cement with high strength properties using selected industrial by-products and waste. Although their study did not include gold tailings, the researchers recognised the role of mineral tailings and state that tailings can be used to produce high strength eco-cement at a reduced cost and with low overall emissions, energy consumption and natural resource use (Sobolev, 2003). The admixtures increase the compressive strength of ordinary cement radically while simultaneously dealing with the challenge of mineral waste (Sobolev & Arikan, 2002). An analysis conducted by Sobolev (2003) showed the production of high volume mineral additive cement can be done in the existing facilities with one minor modification. This modification entails upgrading the grinding unit, which can result in an increase in production capacity of between 30 to 50% without a further increase in clinker output (Sobolev, 2003; Sobolev and Arikan, 2002). A cost comparison was done which evaluated a conventional cement plant with a slightly modified plant that would produce HVMA cement (Table 4.1).

Table 4-1 Existing cement plant expansion for HVMA cement (Sobolev, 2003)

Performance Parameters	Existing Plant	+20% Scenario	+40% Scenario
Mineral additive content (%)	30	50	70
Capacity, mil. tons per year	1.0	1.4	2.3
Required Investments, mil. $	-	4.3	13.9
Unit price	45	45	45
Income, mil. $	45.0	63.0	103.4
Production Cost, mil. $	39.4	53.1	83.5
Gross Profit, mil. $	5.6	9.9	20.0
Extra Profit, mil. $	-	4.3	14.4
Extra Net Profit, mil. $	-	3.4	11.5
Pay Back Period, year	-	1.4	1.3

4.2.1.4 Backfill – Paste and thickened tailings

Worldwide, mine backfill is practiced in many modern mining operations and offers an alternative mine waste management method that results in reduced environmental impacts while also reducing mine waste volumes (Yilmaz, 2011). There are 3 main types of backfill commonly used and these are namely rock, hydraulic and paste (Amaratunga and Yaschyshyn, 1997; Yilmaz, 2011). Rock fill has been used largely to provide underground support and can be used in either a cemented or un-cemented form (Yilmaz, 2011). Rock filling improves bulk-mining activities such as void-filling operations as well as pillar recovery. Rock fills are made up of coarse aggregate and typically consists of blend of waste rock, sand, tailings and in some cases cement (Amaratunga and Yaschyshyn, 1997; Yilmaz, 2011). The hydraulic fill placement method consists of mixing appropriate-sized granular material (i.e. coarse tailings, grainy sand and binder) with water to produce a slurry mixture (Amaratunga and Yaschyshyn, 1997). The slurry mixture typically has a pulp density that ranges between 65-75% solids by weight and the high water content ensures that the slurry can be transported and distributed underground by either gravity, or pumping through boreholes and pipelines (Amaratunga and Yaschyshyn, 1997; Yilmaz, 2011). The use of coarse tailings improves the flow characteristics and strength of the hydraulic fill, and results in better consolidation of the hydraulic fill and consequently water drainage (Amaratunga and Yaschyshyn, 1997). The addition of the binder increases the strength properties of the hydraulic fill with high dosages resulting in greater strength (Amaratunga and Yaschyshyn, 1997). However, this has the disadvantage of being expensive due to the costs of binder.

The paste backfill consists of dewatered mine tailings, a binding agent (commonly cement) and water mixed to the desired consistency (Edraki et al., 2014). Typically, paste fill has a high solids content with a pulp density of between 75 and 85% solids (Amaratunga and Yaschyshyn, 1997). A mix of both fine and coarse tailings is used for making paste fills and, in certain instances, large sized aggregates can be added. Paste backfill is popular worldwide due to the lower rehabilitation costs and improved environmental performance due to a reduction in the amount of tailings stored on the surface (Yilmaz, 2011). Paste fills that have comparative strengths to rock fills can be produced, using less cement than hydraulic fills. In addition, paste fills have a reduced porosity compared to hydraulic fills and as such water decantation from the fill is required (Amaratunga and Yaschyshyn, 1997).

i Research and development

Amaratunga and Yaschyshyn (1997) evaluated the use of gold tailings in paste fill. In their study, paste fill specimens were made with agglomerated tailings pellets, unclassified tailings and binder. Different pellet to tailings ratios, binder dosages and curing times were studied. The resulting specimens were examined for pulp density, moisture content, elasticity and compressive strength. The results indicated that it was possible to produce agglomerated tailings paste fill with superior strength and stiffness characteristics that is suitable to be used as backfill material (Amaratunga and Yaschyshyn, 1997). An investigation was undertaken by

Benzaazoua et al. (2008) which aimed at improving the management of tailings at Doyon mine in Québec, Canada. The study combined environmental desulphurisation of the tailings with cemented paste backfill technology (CPB). The tailings were first desulphurised and then characterized to determine the chemical and mineralogical compositions (Benzaazoua et al., 2008). An assessment of the acid generation potential of the sulphide concentrate and low sulphide tailings was undertaken. Various CPB samples were made using the sulphide concentrate with a binder that consisted of Portland cement (30%) and blast furnace slag (70%). The samples were cured for 14, 28 and 90 days under controlled humidity and temperature conditions. After curing, the samples were assessed for uniaxial compressive strength and leachability. The study results showed that the desulphurised tailings were non-acid generating, and the sulphide concentrate contained about 45% of pyrite, making it suitable to produce a cemented paste backfill (Benzaazoua et al., 2008).

An in-depth analysis was conducted by Fourie (2012) to assess whether the economic benefits of technology used for paste and thickened tailings had been realised. The findings of the analysis suggest that there is limited data on the economics of paste technology. From the case studies evaluated, Fourie (2012) suggested that conflicting experiences regarding the capital expenditure have been documented in literature about the most cost effective technology. In terms of the operating expenditure required, thickened tailings facilities had considerably lower costs than convention tailings due to simpler operation requirements and a reduction in the volumes of material required for wall-building (Fourie, 2012). In terms of mine closure, the thickened paste tailings have lower closure costs and have other added benefits such as reduced water consumption.

ii South African case studies

In South Africa, backfill is being used in the gold mining industry to alleviate problems such as rock falls and rock bursts in mines (Squelch, 1994). One such example where backfill is being used is at Harmony's Target Mine which is situated about 270 km south-west of Johannesburg. Previously the mine utilized a batching wetcrete underground system where the wetcrete material was made from a mix of conventional materials like river sand, cement and chemical additives (Le Roux and du Plooy, 2007). Approximately 108 m^3 of wetcrete material was required monthly which was then transported to the working areas of the mine. The long distances necessitated the need for an alternative wetcrete mix design that could be prepared on the surface and then pumped to the various working areas (Le Roux and du Plooy, 2007). The alternative was a surface batching plant that prepares a wetcrete mix from cyclone tailings, cement and additives. To investigate the feasibility of using the tailings as an alternative aggregate material to river sand, different mixes were created and tested to determine the most appropriate mix design. Different fibre types were then added to the mix design to establish the optimum composition that would attain the required strengths. The findings revealed that the optimum design mix when applied to the rock walls had a uniaxial compressive strength of 38 MPa. This exceeded the design criteria of 30 MPa (Le Roux and du Plooy, 2007).

Another application of backfill within South Africa is being undertaken at AngloGold Ashanti. The mining company, through their Technology Innovation Consortium, have developed a ultra-high strength backfill (UHSB) product and system (AuRa, 2013). The use of UHSB enables mining to be carried out at depths of about 5 km by reducing seismic risks and improving safety underground (AuRa, 2013). It is predicted to replace the pillars thereby increasing the extraction percentage. This ultra-high strength backfill was first tested at TauTona mine using a batch mixing system and was applied by placing it behind a reef boring machine that drilled the reef out (AuRa, 2013). Backfill operations at Gold Fields' South Deep Mine commenced in 1993 when twin shafts of about 3 km were sunk. Because of the location of the shafts, the main shaft pillar was mined out and had to be backfilled at a depth of 2.5 km (Mining Weekly, 2012). The narrow tabular slopes required the use of a high strength backfill and a crushed waste/cyclone classified tailings (CW/CCT) backfill was utilized. However, high strength CW/CCT backfill proved too costly and financially unsustainable. This resulted in the use of a cyclone classified tailings (CCT) hydraulic backfill (Mining Weekly, 2012). The CCT hydraulic backfill was utilized mostly for the long-hole stopes and destressed stopes (Gold Fields, 2012). As mining operations intensified, additional backfill was required and a cemented full plant tailings (FPT) backfill plant was commissioned. This was considered a more cost effective backfill production methodology for the mine and the product is used mainly for the backfill of general mining voids (Gold Fields, 2012). Tailings from the gold plant are stored temporarily in four storage takes and then pumped to the backfill plant, with excess tailings diverted to the tailings dump. The FPT was designed to produce approximately 148 000 m3 backfill monthly. According to the Mining Review (2015), as of the June 2015, backfill production was approximately 80 000tpm and this is expected to increase with the conversion to hydraulic mining of surface tailings.

4.2.1.5 Stone paper

The use of tailings in the making of stone paper is seen as one of the latest and most innovative re-use option that has been undertaken in the past few years. Stone paper is a blend of crushed stones and/or tailings and polymers in a ratio of 80%:20% (Pauli, 2014a). The use of tailings is more cost-effective compare to rock and is an opportunity to turn the liabilities of the mining industry into assets. The production of stone paper can be done in conjunction with extracting further amounts of gold and other materials such as sulphur, uranium and chrome (Pauli, 2014a).

According to research conducted by the ZERI foundation, the investment costs for the equipment required in making stone paper is estimated at US$150 million which is 40% less than the costs of production the same volume of paper in a conventional paper plant (Pauli, 2014). This option has the added benefit of freeing up vast expanses of land that are used for growing trees. This can then be can be agricultural purposes or other alternative uses. This option also uses less water and more energy (Pauli, 2014)

4.2.2 Potential re-purposing options for coal processing waste

Much of the work done on reusing coal mining waste originates from China and Russia, owing to the wealth of coal resources in these countries and China's dependence on this source of energy. The work on the re-use and reprocessing of mine waste in coal mining closely follows that done on mine waste in general (Lemeshev et al., 2004; Li and Han, 2006; Modarres and Ayar, 2014; Modarres and Rahmanzadeh, 2014; Vigil de la Villa et al., 2014; Zhang et al., 2014). This includes the use of relatively benign coal waste in the production of ceramics, building materials and backfill (Skarzynska, 1995; Lemeshev et al., 2004; Modarres and Rahmanzadeh, 2014). While some ideas for alternative uses of materials present in mining wastes have been considered, such as using pyritic waste heaps as a source of heat (Lottermoser, 2011), a thorough and broad ranging approach for using components in mining waste is yet to be developed.

In this regard, UCT has been working of the identification, evaluation and development of a number of potential options for using both sulphide-lean and sulphide-rich coal tailings, mainly through the Water Research Commission (Broadhurst et al., 2018; Harrison et al., 2013). On the basis of this work, a matrix of potentially feasible options has been drawn up and is presented in Figure 4.1.

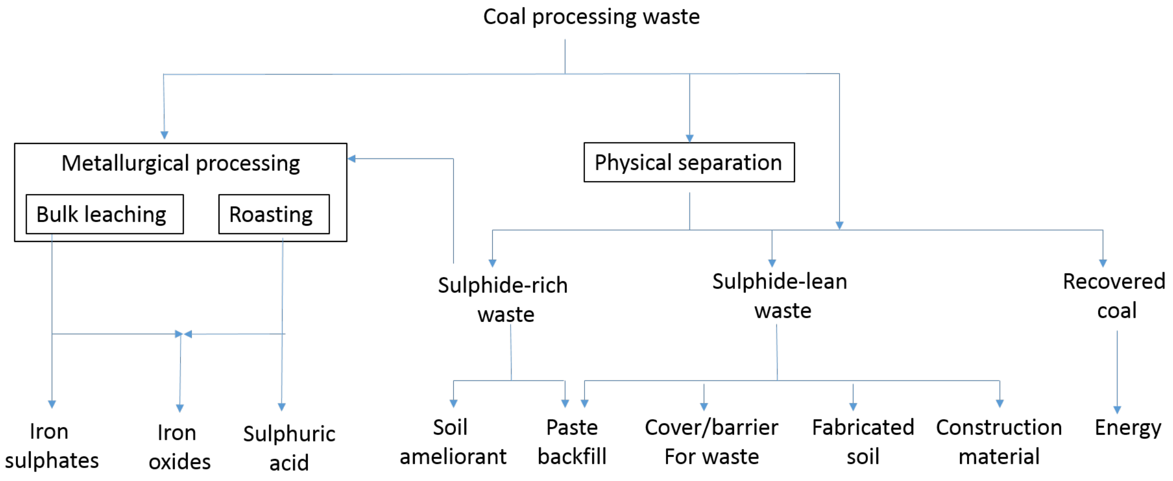


Figure 4-1 Matrix of options for the re-purposing of coal processing waste

As indicated in the Chapter 2 (Section 2.3.2, Figure 2.2), the physical separation of coal waste offers the opportunity to recover a saleable coal product with reduced ash and sulphur, which can be used for energy production using conventional combustion technologies. The recovery of coal from fine coal wastes has been the subject of previous Water Research Commission reports (Harrison et al., 2010; Harrison et al., 2013). The discussions here focus on the potential uses of the bulk coal wastes, enriched in mineral (ash-forming) matter and depleted in coal.

i Direct utilisation of sulphide-lean coal waste fractions

A number of options have been identified for the downstream use of sulphide-lean or non-acid generating fine coal waste, either generated directly in conventional coal beneficiation processes or after application of a further desulphurisation step, using physical separation techniques such as flotation.

One of the reported uses of benign coal slurry waste is as a cover or barrier in the disposal of ARD producing wastes, such as overburden and coarse wastes. In a co-disposal scenario, low sulphur, non-acid generating fine coal fractions act as permeable reactive barriers, limiting the infiltration of oxidants to the sulphide mineral surface and further restricting transport through porous ore channels (Bussiere, et al., 2004; Demers, et al., 2008; Maddocks, et al., 2009; Gautama, et al., 2010). In a previous study at UCT, laboratory-scale tests were conducted to investigate the efficacy of co-disposing benign desulphurised tailings with interburden waste rock as either layered covers or blends (Kotsiopoulos and Harrison, 2015, 2017 and 2018). The results of these tests were consistent with those reported by Erguler, et al. (2014) and show that, in addition to the neutralising efficiency of the benign tailings, the effectiveness of the preventative measure is largely dependent on the restriction of flow, which is related to the degree of compactness of the ore bed (and maintenance thereof) in the test columns, irrespective of the severity of the oxidising conditions. Larger-scale testwork will be continued, as part of a current Water Research Commission project (WRC K5/2761).

Another re-purposing option for non-acid generating fine coal wastes involves application of the separated waste fractions in soils as a main substratum for fabricated soils (Amaral Filho et al., 2016 and 2018; Firpo et al., 2014, Weiler et al., 2018). To use mine waste as the main substratum for fabricated soils, the addition of amendments is required to construct the chemical, physical and biological aspects of a good soil. Key issues for soils derived from mine wastes include soil acidity and neutralisation reactions, macro and micronutrient availability, organic matter content, microbial communities' deportment, metals and phytotoxic compounds mobility, and physical structure. Weiler et al. (2018) demonstrated the feasibility of growing Megathyrsus maximus var. maximus (Guinea grass) in a soil-like substrate composed of desulfurised coal waste amended with sources of alkalinity (steel slag), organic matter (sewage sludge), and soil physical conditioner (rice husk ash). At UCT, soils fabricated from sulphide lean coal tailings from a Middelburg colliery, blended with compost, anaerobic digested sludge and/or microalgae as organic matter and sources of nutrients, and malt residue as a physical ameliorant, were successfully used to cultivate Eragrotis Teff grass (Amaral Filho et al., 2018).

Sulphide-lean tailings can also potentially be used to backfill mine voids. However, to date focus appears to have been mainly on the use of coal ash from Sasol (Digby Wells Environmental, 2013), and tailings from base and precious metal ore processing.

The advantage of the above-mentioned applications is that the coal waste would be used within the mine environment for responsible mine management and closure. The co-disposal would form part of the broader minimisation of ARD associated with mine waste deposits. Backfilling could be used to rehabilitate defunct mine workings, thus also avoiding generation of acidic discharge and the formation of sink holes. The fabricated soil would be available for the rehabilitation of the mined land, which is particularly challenging in open cast mining environments which are common in South African coal mining.

A further potential application, which has not been explored at UCT to date, is the use of sulphide-lean coal waste as construction material. According to a report by Galos and Szlugaj (2014), the coal waste is commonly used in the cement industry in Poland. The high calorific values of coal mining wastes are the main reason for their use in cement production as they result in less fuel consumption during the cement clinker production. A study by Santos et al. (2013) also showed that the coal waste can be used to produce concrete paving blocks by substituting typical sand as a fine aggregate.

ii Direct utilisation of sulphide-rich coal waste fractions

As in the case of the sulphide-lean tailings, sulphide-rich or acid generating fine coal waste tailings can be used directly or after application of a further physical separation step to concentrate the sulphide minerals. The identification and evaluation of potential application for pyrite-rich coal wastes has been the subject of a previous Water Research Commission study (Harrison et al., 2013). According to this report, the two most viable options for the downstream utilisation of sulphide-rich coal waste, include soil amelioration and cemented paste backfill. However, a more detailed scenario analysis indicated that not enough sulphide-rich material coal tailings will be produced in South Africa for the cemented paste backfill alternative to be considered viable. The material is also too reactive for this approach to be environmentally beneficial over the course of many years. Soil amelioration, however, shows some promise, since it should be effective in improving alkaline soil conditions in arid regions in South Africa and there is enough alkaline farmland to absorb the material stream. This solution may be economically constrained though, since the material will have to travel large distances from coal mines to regions with alkaline soil. For example, the distance between Upington, where table grapes are grown, and the eMalahleni (Witbank) coal fields is around 930 km (Google & AfriGIS (Pty) Ltd 2016). Depending on the characteristics of the coal, the suitability of this solution will also be impacted by the safety of the material for agricultural applications.

iii Secondary by-products from sulphide-rich fraction

The conversion of pyrite to sulphuric acid through high temperature roasting is a well-established process. Sulphuric acid is required by a number of sectors, including the mining industry and fertiliser manufacture for the agricultural sector, and is in short supply in South Africa. Sulphuric acid thus has a relatively large and established market with many potential customers that are already in existence. A major drawback of this processing option is that one needs relatively pure pyrite in order to produce sulphuric acid in a cost-effective way. Furthermore, the process is relatively energy intensive, and has a number of environmental implications.

Additional value can be unlocked by using the pyrite cinder, the iron oxide (γ-Fe_2O_3 and Fe_3O_4) resulting from the roasting process, to produce hematite (α- Fe2O3) pigment. Hematite pigment is a well-known product and has an established market and producers. This processing option does not require a very pure pyrite stream in order to produce a good quality pigment, because a simple and effective separation method can be used to purify the feedstock. The roasting pyrite cinder can also be used as a pozzilinic material for cement production.

Pyrite-rich material can also be used to produce ferric sulphate coagulant and ferrous sulphate heptahydrate using a bioleaching (vat or heap) set up (Colling et al., 2011; Vigânico et al., 2011). The acidic leachate leaving the bioleach setup is recirculated until the concentration of ferric ions reaches an acceptable level. In the case of ferric sulphate production, the leachate is then concentrated through evaporation and the resultant concentrated solution used as-is. For the production of ferrous sulphate heptahydrate, the ferric ions are reduced to ferrous ions by exposure to UV light, potentially the sun, and the ferrous sulphate crystallises. The ferrous sulphate may need to be washed and dried subsequent to crystallisation. Both ferric sulphate and ferrous sulphate are used as coagulants in waste water treatment. The ferric sulphate produced using bioleaching has been shown to be as effective as commercial products in waste water treatment (Colling, et al., 2011), demonstrating that this process can produce acceptable quality ferric sulphate coagulant. Ferrous sulphate heptahydrate is also used to control anaemia in mammals and as a fertiliser. Bioleaching and neutralisation also offers an alternative route for the production of haematite as paint pigments.

4.3 Assessment of factors influencing mine waste valorisation in South Africa

Despite the findings of numerous research studies that suggest that mineral waste can be successfully re-used, the re-use of mine waste remains constrained, especially in South Africa. This study takes a barrier and enabler approach to develop a better understanding of the factors both constraining and driving the development and implementation of approaches to eliminate disposal of bulk mine waste through their re-allocation as feedstock for other uses.

4.3.1 Technology

From the previous section, it is evident that recent technological advancements have made it possible to explore the re-use of mine waste. Improved technology has resulted in the recovery of gold (and other minerals) from both lower grade ores and waste tailings (Gericke, 2014). The advances have also resulted in different products being made from mine waste. These products include (but are not limited to) bricks, ceramics, cement additives and backfill. Over the years, many studies have been conducted to test out the various technologies available for waste valorisation on the market. However, this has largely been done at laboratory scale and very few have been demonstrated at a larger commercial scale. Pajunen et al. (2012) argues that the scale up to commercial applications is hindered by the fact that new technologies often have to mature (which often takes years) to become industry standards or techniques. Mature technology is more likely to be transferred successfully than immature technology and the first implementation of a technology carries the most risk and cost of implementation (Teece, 1977; Greiner and Franza, 2003; Johnston, 2012). This is because the particulars of a technology are better understood when it has been successfully implemented in different locations with different challenges (Teece, 1977), and when the success of scale-up has been demonstrated (Grano et al., 2009). Estimation of technology reliability and maintenance requirements are also much more accurate in mature technologies (Souder et al., 1990). When an organisation believes that a technology is both efficient and effective for their application this will impact positively on the transfer process (Kostova and Roth, 2002; Grano et al., 2009).

Interviews with representatives from both the coal and gold industry in South Africa confirmed the literature reports, with “evidence of successful implementation” being considered one of the top drivers, whilst the problem of “piloting and scaling up” were considered the biggest barrier. Respondents stressed the need to have a commercial scale plant, or at least a pilot plant, operational and open for visitors from other mines.

> “You know, there's always this thing that if something has succeeded or proven itself, people tend to start believing in technology once they can actually see it succeeding. So success breeds success.”
> “We spend a lot of time to show people what we've achieved, how it works and where it's implemented. You know, that whole concept of seeing is believing. That helps tremendously.”

It was also noted that mines are not in the technology development and sales business. They therefore do not have adequate R&D departments by and large, and they do not generally have adequate technical skills or manpower to be able to do technology development well. As one respondent noted “*we’re not interested in IP [intellectual property]. We’re not interested in widgets. We’re interested in making money. And we don’t make money by honing widgets or selling widgets even.”* Mines would therefore prefer to buy well-supported off-the-shelf technologies which are robust and effective. New technologies are seldom developed or funded by mining operations.

4.3.2 Legislation

The regulatory environment within which technology transfer for mine waste repurposing takes place can significantly enable or hinder the development and implementation process. On the one hand, regulatory pressure can motivate organisations to make the necessary investments and implement technology faster (Greiner and Franza, 2003; Perkmann et al., 2013). Incentives, for instance, can have a positive impact on implementation (Sizhen et al., 2005). A good regulatory environment can therefore be helpful for promoting the uptake of new waste management approaches and technologies. However, when the regulatory environment is poorly developed and confusing, organisations may not be sure what is really required and therefore put off implementing new technologies (Hilson, 2000; Greiner & Franza, 2003). According to literature reports, uncertainties or ambiguities in regulations can cause organisations to delay implementation of new technology, preferring to 'wait and see' what the regulatory environment will be like; particularly where such uncertainties result in insufficient pressure being placed on companies to implement new approaches (Souder et al., 1990; Johnston, 2012). This often occurs when regulations or policy regarding environmental issues change rapidly and can demotivate organisations to implement new technology for fear that it will not be sufficient when new regulations are passed (Hilson, 2000). The frequency of legislative reforms in South Africa and the shifting roles and responsibilities of the different governmental institutes, whilst generally considered to be necessary, was considered a significant challenge by a number of respondents. Frequent amendments have created confusion and hence a wide range in the quality of compliance by companies (CER, 2016). According to one of the waste experts, the legislation keeps changing, and trying to understand the changes is like '*tap dancing through a minefield'.*

The letter of the law is not the only influencing factor; practical issues around the application of the law also influence the potential viability of implementing value-from-waste initiatives. When the law is not enforced properly, for instance, supportive regulations will not have their full effect (Hilson, 2000; Sizhen et al., 2005). This is also the case with poor co-ordination between government agencies or poor understanding of the environmental issues (Hilson, 2000). A number of issues were raised by respondents in connection to the application and enforcement of regulations in South Africa. Administrative problems with the application process often delayed applications, adding costs and uncertainty to the process of implementation. Also, the penchant for losing documentation at governmental entities adds to this frustration (Anonymous, 2015). According to literature reports, the fast changing nature of the legislative landscape (Chamber of Mines of South Africa, 2017) and the learning curve associated with the implementation of new legislation (Mzamo, 2017) adds to the inefficiency and confusion in the application process. There are also frequent allegations around uneven enforcement of legislation and conflicts of interests and corruption amongst the regulators (CER, 2016; Corruption Watch, 2014; Evans, 2015). A report by the Centre for Environmental Rights (CER, 2016) claims that the Department of Mineral Resources often does not conform to the law where consideration of environmental aspects is concerned, and that the Department of Water and Sanitation has a poor track record of enforcing the Water Act .

Kostova and Roth (2002) also warn that when an organisation is forced to adopt a practice without believing in the objective of the practice, only ceremonial adoption will result. This means that the company will stop as soon as enforcement weakens. In terms of the South African situation, many of the respondents felt that legislation places unreasonable expectations on mines to comply, not only to environmental legislation, but also some health and safety and community-related requirements. None of the respondents argued about whether the aims of the legislation were bad, only that they were too rigid and that forced compliance was used exclusively, rather than being complemented by incentives.

The challenges with the regulations and their administration notwithstanding, for the most part government involvement and legislation was considered a driver to implementation of environmental technologies, if an onerous one. Two thirds of the respondents noted that legislation drove companies to improve the environmental footprint of their operations. On the other hand, by limiting the number of approaches a company can take to re-use waste, strictly regulating waste management, and simply being unsupportive, the legislator and other governmental organisations put companies in a difficult position in terms of adopting new and innovative waste valorisation options. Companies are required to improve their operations but feel that they have limited options for doing so, and many hurdles to overcome.

A summary of the relevant legislation of relevance to mine waste is provided in Appendix D. South Africa has seen many policy and legislative reforms over the past decade, particularly in terms of environmental protection. Recently, the Department of Environmental Affairs has proposed a new regulation to promote the re-purposing of limited waste types (including metallurgical slags, fly-ash, and certain gypsum wastes and biomass wastes). This regulation (Government Gazette No 41380, 12 January 2018) excludes these waste streams, or portions thereof, from the definition of waste (subject to a detailed risk assessment), provided that these wastes are used for specific purposes.

4.3.3 Health, safety and environmental issues

As discussed in Chapters 2 and 3, water pollution due to acid rock drainage, environmental degradation, surface erosion, dust generation and soil pollution are among some of the problems associated with mine waste. This coupled with poor waste management practices can result in severe and long-term environmental and social consequences (Franks et al., 2011). As such, these possible environmental challenges are a driving force and incentive for finding alternative waste management options to current conventional methods. Reusing mine waste also has the added benefit of saving natural virgin resources.

However, there may also be potential environmental liabilities and health risks associated with the re-processing and utilization of mine waste. As such, before it can be re-used effectively, it is imperative that the mine waste is able to produce the required product quality, and that its re-use does not create additional environmental liabilities or health risks. The idea of wastes being environmentally hazardous and concerns about the implications of concentrating the hazardous components when valuable components are removed from waste heaps were mentioned by around half of the respondents interviewed. The lack of adequate data and information on the characteristics of mine wastes, and the uncertainties associated with the potential risks and liabilities of different management options makes it difficult to motivate implementation of new or alternative approaches.

4.3.4 Economics

The findings of the both the gold and coal case studies indicate that the uptake of the various waste valorisation opportunities need strong economic incentives. According to all respondents interviewed, by far the biggest determinant of technology implementation success is the techno-economics of the technology. Although mineral waste is a potential resource, alternative waste management and treatment methods have to be more financially viable compared to the conventional landfill and or stockpiling option in order to be fully recognised. All respondents mentioned the necessity of having a convincing business case. This is consistent with literature findings which show that, in most instances, it is imperative that there be clear financial or market benefits to implementing a technology (Greiner and Franza, 2003; Teece, 1977; Souder et al., 1990; Ankrah et al., 2013; Sizhen et al., 2005, Lamprecht, 2012), often to the exclusion of other factors. One respondent placed the hurdle internal rate of return (IRR) for a project to be considered at between 15% and 20%. This is slightly lower than that reported by Johnston (2012), who found that IRR's in excess of 23% are necessary, even when the technology also holds other less tangible environmental advantages. Lamprecht (2012) places the required return on investment even higher at 30%, in order to offset the market and technical risk associated with innovative technologies. The reason for the high IRRs could be due to the difficulty some organisations have with accessing funding (Sizhen et al., 2005), since the value that a debt provider would be interested in would primarily be financial. It could also be due to the fact that unsuccessful transfer will have tangible financial repercussions (Lee and Win, 2004) and so risk is quantified in terms of financial metrics.

The use of IRRs to "screen" process or technology alternatives, however, ignores medium- to long term benefits and risks to the organisation, as well as external and indirect financial costs and benefits, which are not easily converted into financial metrics. For instance, the abundance and low cost of waste material coupled with the high demand for alternative aggregates, especially within the construction industry, can positively influence the uptake of mine waste reuse. Another incentive is that reusing mine waste frees up land, which can then be used for other uses which may result in different economic activities to mining (Godfrey et al., 2007). Alternative uses of waste materials can also contribute to economic development and job creation. If the technology could secure competitive advantage or reduce production costs to companies, it would be an enabler to technology implementation (Ankrah et al., 2013, Lamprecht, 2012). For instance, the increasingly stringent legislative requirements for waste deposits is making it easier to create a convincing business case for value-from-waste, as conventional disposal costs are becoming very expensive:

> "So that may induce people into it... and it has already, you know, you don't see many people with slimes dams, for example, because it is just too complicated to actually try and get permission for a slimes dam. So now all of a sudden, even though filter presses are expensive, people realise slimes dams are expensive."

For this to be successful, though, the technology needs to be implemented within a window of opportunity. According to Pajunen et al. (2012), the time required for technological innovations is often not in line with the availability of capital investment. As a result, there are substantial delays in influencing changes in technologies, resulting in most organizations being locked in to the current available technologies.

The costs of the technology itself and the costs associated with technology transfer can be a significant barrier, especially in an environment of inadequate organisational financial resources (Hilson, 2000; Teece, 1977; Nikolaou and Evangelinos, 2010; Kostova and Roth, 2002; Rochon et al., 2010; Lee and Win, 2004). Teece (1977), for instance, found that transfer costs in his sample were between 2% and 59% of the total project cost when implementing technology. When the cost of financing itself is added to this, the endeavour can be prohibitively expensive (Johnston, 2012; Sizhen et al., 2005). When there is already another technology in place the sunk cost of that technological solution, as well as the cost of replacing the technology, can be a barrier to implementing innovative technology. The lack of adequate funding for the scale-up of the options as well as lack of other necessary resources (human capital, skilled personnel, time) needed for technology transfer and implementation, is considered a big hindering factor within South Africa (Gericke, 2014). In addition to the massive investment costs and time lags, another barrier results from the high risk and uncertainty associated with committing capital to unproven technology (Pajunen et al., 2013).

4.3.5 Corporate culture and values

Corporate culture and leadership play a key role in the willingness of an organisation to adopt new or alternative technologies. Without support from an organisation's leadership (known as sponsors or champions) technology transfer is unlikely to be successful (Rogers, 1962; Souder et al., 1990; Greiner and Franza, 2003; Jin et al., 2016; Kimberly and Evanisko, 1981). When an adopting organisation has sufficient skills in-house to understand, implement and operate the technologies this is a significant enabler (Teece, 1977; Hilson, 2000; Kimberly and Evanisko, 1981; Kostova and Roth, 2002; Lee and Win, 2004; Grano et al., 2009). When transferring a technology, it is important that people within the adopting organisation understand and approve of the objective of the technology (Hilson, 2000; Kostova and Roth, 2002; Nikolaou and Evangelinos, 2010). If it is a technology to improve the environmental footprint of an operation, for instance, it is important that the organisation views that as a worthy goal (Hilson, 2000). This is more likely if society at large values the objective of the technology as well, since people in the organisation are part of and influenced by the society around them (Kostova and Roth, 2002). The advantages of the technology need to be clear and tangible to those in the organisation (Greiner and Franza, 2003).

In order to understand the current culture within the sector, it is important to note that the mining industry, and the coal sector in particular, views itself as an industry under pressure and largely undervalued by outsiders. Some of the pressures the industry has been facing include low commodity prices, depleting reserves, onerous legal requirements and looming social and environmental liabilities. None of these pressures are surprising to an outsider to the industry, but they are deeply felt by those within it. These pressures will probably have a direct impact on the risk appetite of the mining companies and their desire or ability to try something new. It will also have the effect of making a business case based on financial returns exceedingly important for the implementation of new technology, since mines feel that their livelihoods are at risk. This will also probably serve to diminish the force of any moral argument for waste reprocessing, and around a third of respondents remarked that they felt that complying with legislation was enough to be on the right side of the moral scale.

Another “cultural” barrier to the uptake of mine waste valorisation approaches, was the perception of material classified as waste. Just under half of the respondents voiced the idea that waste is something to be gotten rid of. It is not always that it is the respondent’s own views, however, but that it is the way that the mining industry approaches its waste, even when there are viable value-from-waste alternatives available. The idea of waste as material with positive value was therefore not main-stream, although a third of respondents mentioned that they considered these perceptions in industry to be changing, possibly due to some positive examples from within the mining industry. Even then the reprocessing of mine waste to recover valuable mineral or coal component was the dominant value-from-mine waste paradigm. This means that some entrenched ideas will have to be challenged if a suitable technology for repurposing mine waste is to be identified and presented to mines. Even in the cases where a value-from-waste technology has been implemented on a mine, the value derived from waste is small in comparison to a mine’s normal business and therefore often gets neglected, leading to perceived technology failure.

A third of respondents also suggested that the business strategies of mines are important in the implementation decision. The business strategy of a mine is not manufacturing or electricity production, for instance, which means that they don’t have intimate knowledge of those businesses and markets. This increases the risk and effort associated with such ventures, which means that management may rightly be reluctant to enter such businesses.

> “So, whatever you're proposing needs to align with the core business strategy. For example, I can't propose that we start producing gypsum boards from an offtake of gypsum, because it is not really our core business and it could most likely not be a strategic fit for the company.”

4.4 Stakeholder roles in transfer of technology for mine waste re-purposing

4.4.1 Review of technology transfer processes

Technology transfer is the process whereby a technology is transferred from one organisation to another. This can entail both mature and new technologies and the transferring organisations can be public, private or governmental. The process of technology transfer has been theorised in diverse ways and from different perspectives. This is as expected, since the process of transfer of a ready-built computer will be different from the process of transfer of chemical processing equipment which must be constructed on-site. One comprehensive depiction of the process of technology transfer is shown in Figure 4.2. It shows four different stages of technology transfer as well as what roles are usually important during the execution of the stages. The process stages can take a long or short time and it can be iterative. “Prospecting” is the process of finding a technology, if the adopter is searching for a solution to their problem, or of finding an adopter, if the developer is searching for someone to implement their technology profitably (Souder et al., 1990). Contracting and other similar documentation is done during this stage. Developing implies the laboratory-scale work that is done to adapt the technology to the adopter’s existing operations, while trial is the process of testing it onsite (Souder et al., 1990). Adoption is the process of implementing the technology, including making final modifications (Souder et al., 1990). This process is iterative and some aspects can run in parallel. Information uncovered in the trial stage can, for instance, potentially send a part of the process back to the development stage (Souder et al., 1990).

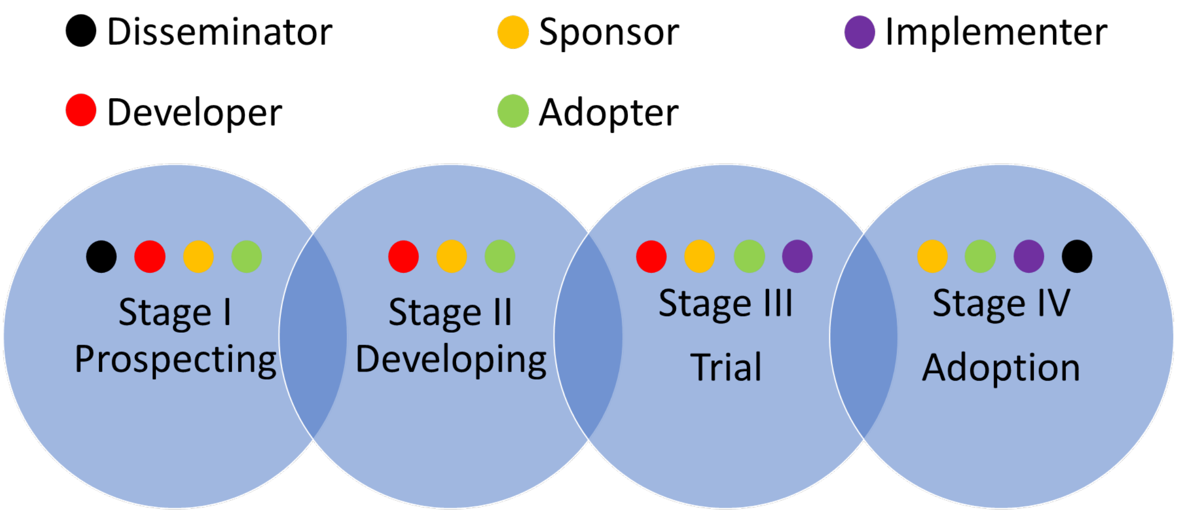


Figure 4-2 The process of technology transfer loosely based on a diagram by Souder et al. (1990)

As indicated by Figure 4.2, there are different roles that are played during the process of technology transfer, but the same organisation can play multiple roles, depending on the stage of technology transfer. Sponsor, developer, adopter, disseminator and implementer are all roles that are commonly identified (Souder et al., 1990; Spann et al., 1995). A disseminator is an organisation that connects the technology developer or originator with the technology adopter (Spann et al., 1995). Developers are those who develop the technology and adapt it to the adopter's operating environment and requirements. This role is played by the technology originator, but the adopter's technical department will also play this role during the development stage. The adopter is the organisation that will be using the technology going forward. The disseminator is commonly a middleman between the two organisations, such as a technology transfer office in the case of university technology transfer. It could also be the technology developer or even the adopter themselves. The sponsor provides political and financial support for the transfer and is often a powerful person or grouping inside the adopting organisation (Spann et al., 1995; Rogers, 1962). The implementers are those who implement the technology for the adopter. This can be a third-party organisation who specialises in construction or manufacturing, or it can be the developers or adopters themselves. The developers and adopters will usually provide significant oversight to the implementer. Spann et al. (1995) considers developers, adopters and sponsors to be the primary parties involved in technology transfer.

There are a variety of ways in which the technology originator and adopter can become aware of each other that does not involve a technology disseminator, including formal or informal relationships between academics and employees at other firms and staff exchanges (Hagedoorn et al., 2000; Perkmann et al., 2013; Santoro and Gopalakrishnan, 2000). Once the players are aware of each other, technology transfer entails either a push or a pull mechanism (Spann et al., 1995; Teece, 1977; Bozeman, 2000). Technology push is when the originating organisation actively seeks to transfer its technology to other organisations (Spann et al., 1995). Technology pull describes a process where adopting organisations or departments seek to implement technology developed elsewhere (Spann et al., 1995). Technology push has historically been the main perspective (Spann et al., 1995). Technology cannot be transferred, however, without some level of pull and push (Greiner and Franza, 2003). There needs to be co-operation between organisations for successful transfer to take place

As discussed in Section 4.3.5, it is important that people within the adopting organisation "buy in" to the underpinning objective and principles. It is therefore imperative for the adopter to be given as many opportunities as possible in many different contexts to interact with the technology and understand how it works before implementing so that their technical risk, or perception thereof, can be managed (Souder et al., 1990).

Examples of interaction with the technology are demonstrations that the adopter can attend, site visits and laboratory visits (Souder et al., 1990; Teece, 1977).

Early involvement of the adopter in the development process is one way of giving them exposure to the technology and ensures that the technology fits with the organisation's strategies and operations (Souder et al., 1990). This also means that practical issues such as development timelines and procurement lead times can be ironed out early. When these timelines are long, this adds additional risk to the project in the form of market risk, since the market conditions that makes a technology desirable may not be prevalent anymore when the technology is finally implemented (Greiner and Franza, 2003).

The interactions between the partners should therefore best be well-organised and focussed (Bozeman, 2000) and it is useful to have an intermediary set up at the outset of a partnership in order to translate between the different organisations and form the administrative backbone (Ankrah et al., 2013; McAdam et al., 2012; Bozeman, 2000; Trencher et al., 2014). Therefore, in many cases, especially the explicitly commercial ones, a technology transfer office, research administration office or other intermediary mediates the relationship between the university and the industry partner (Ankrah et al., 2013). Intermediaries can fulfil functions such as managing the flows of information, providing an administrative "backbone" for the collaboration, interpreting between the different actors, handling the patenting of inventions and supporting the negotiations for subsequent licensing/sales agreements (Ankrah et al., 2013; Bozeman, 2000; Trencher et al., 2014; McAdam et al., 2012).

When an adopting organisation has sufficient skills in-house to understand, implement and operate the technologies, this is a significant enabler (Teece, 1977; Hilson, 2000; Kimberly and Evanisko, 1981; Kostova and Roth, 2002; Lee and Win, 2004; Grano et al., 2009). It will enable the organisation to understand and assimilate the benefits of the technology more readily, since there will be people inside the organisation to translate the benefits and requirements to management. Pre-existent, social knowledge of the technology reduces resistance to the novelty of the technology, while third-party recommendation of the technology lends credibility (Souder et al., 1990; Kostova and Roth, 2002). Credibility of both the technology and the transfer teams are important in order to allow the transfer to progress smoothly. Vehicles for technology transfer include workshops, technical consultations, publications, laboratory visits, research consortia and employee exchanges (Bozeman, 2000; Perkmann et al., 2013). From this list it is clear that one of the important aspects of technology transfer media is the contact it allows employees of the different organisations, which then effects the transfer of knowledge (Lang, 2004) and consequently technology – whether specific or general.

Contact is not enough, though, since good working relationships, communication and trust are imperative for a successful transfer (Greiner and Franza, 2003; Kostova and Roth, 2002; Souder et al., 1990). Communication is more difficult when different levels of technical knowledge and culturally differing ways of communicating are found in the participating organisations (Malik, 2013). Technology transfer is smoothed by an attitude of exploration and willingness to learn between the transfer teams as well as regular opportunities to reflect on the process (Greiner and Franza, 2003). Good leadership in the transfer teams as well as experience with technology transfer within the different organisations facilitate good relationships (Greiner and Franza, 2003). As indicated in Section 4.4.1, the mines, who are frequently the technology adopters, often do not have R&D and technical skills. It is thus important for the developers to communicate the outcomes of their development work effectively and clearly.

4.4.2 Perceptions on stakeholder roles in the South African context

Stakeholders, including representatives from the mining industry, mining consultants and technology transfer experts, were asked to share their perspectives on how waste valorisation technologies could best be transferred from a developer, such as a university, to the mining industry.

Significant emphasis was placed by all respondents on the choice of commercial partner. A third of the respondents mentioned that the mine, or holder of the waste to be processed, should be intimately involved with the process of implementation because they will derive value and are best placed to understand the composition of the waste. Furthermore, getting potential adopters involved early would be a significant advantage in terms of overcoming cultural barriers and ensuring that there is a credible and entrepreneurial champion to take ownership of the technology and drive its implementation. Another suggestion was that commercial waste processors would be better placed to be partners for commercialising waste valorisation technologies. However, more than half of the respondents thought that a better commercial partner should be the original equipment manufacturer (OEM) or technology provider. The balance of evidence suggests that this is indeed the case. The recent commercialisation of Eutectic Freeze Crystallisation process for the recovery of potable water from reverse osmosis brines at Glencore's Tweefontein colliery in Mpumalanga is an example the successful commercial application of a valorisation process by an OEM (Prentech Pty Ltd). This plant is based on technology developed at the University of Cape Town, with financial support from the South African Water Research Commission and Coaltech, an industry-sponsored research consortium. Even in the cases where a waste valorisation technology was implemented on a mine and with the help of the mine, the technology provider is normally the party that runs the plant and maintains it. Two respondents mentioned that they are aware of companies that push much of the technical research that they require on to trusted OEMs, who they then hire to test and implement any technologies that they may need. The key finding here is, therefore, that it would be wise for universities or applied research organisations to partner with well-respected OEMs or technology providers for technology development rather than with the mines themselves. These companies already have the business strategy, experience, technical skills and credibility with industry to be able to commercialise technologies successfully. If the OEM's or technology providers are unwilling to operate and maintain these operations, commercial waste re-processors could step in and fulfil that function. The appetite of OEM's for acting as commercial partners of universities and other research organisations would have to be tested, however, since they fall outside of the sample that were interviewed, and issues such as the ownership of IP is likely to be important considerations in such partnerships.

It was also suggested that, if the technology can be proven to be sufficiently simple to operate and robust, the opportunity to have communities take ownership of the technology would be welcomed as something to include in a mine's social and labour plan. Even in such cases, though, the mine would have to ensure that the community service provider is able to handle the technology from a technical point of view and may need to help the organisation to obtain certain permissions and approvals. An external technical oversight body may, thus still be needed. Mines would still want to provide oversight to the community service provider, because of the long-term liability associated with mining waste.

It was also suggested that early commercialisation research could be done with the help of science councils such as the CSIR or Mintek, which should have more experience in applied research than university researchers, whilst agencies such as the Department of Trade and Industry and the Industrial Development Corporation should be approached for financial support. The US Department of Energy was also mentioned as a potential development partner, who has a strong track record of commercialising technologies.

Another key issue that came to the fore during the course of the study, was the importance of developers making potential adopters or implementers aware that the technology works. This was considered particularly important in the mining context, as the technical skills base in many mining companies has been eroded by years of 'rightsizing', with the result that top management might not have the technical skills to understand the advantages and development requirements of a technology. This means that it might be difficult to get top management aligned and supportive of the technology or to appreciate the technical risks inherent in the technology. A well-crafted communication strategy based on the profile of individual organisations is therefore key. This may entail showcasing at relevant forums and workshops, as well as the implementation of a demonstration or pilot plant. This would then also provide a platform for communication between different role players (developers, sponsors and potential adopters), and opportunity to discuss concerns about technical and market risk, which will be central to their decision-making.

4.5 Summary

A number of opportunities have been identified for the re-use or re-purposing of large-volume mine waste, such as gold tailings and coal processing waste. A review of the available information indicates that mine tailings have found fairly wide application as backfill for mines, and to a lesser extent, in construction or for landscaping. Other potential applications include the fabrication or amelioration of soils, and the manufacture of niche by-products such as pigments, coagulants for wastewater, sulphuric acid, ceramics and stone paper.

This study indicates, however, that despite these opportunities, commercial application of options for the re-purposing of large-volume mine wastes such as gold tailings and coal processing wastes remains relatively constrained, and many of the identified opportunities have not been developed beyond the laboratory scale.

A number of factors have been identified, both technical and non-technical, which constrain the development and transfer of approaches that are designed to extract maximum value from mine waste. A key barrier relates to the costs of developing and transferring technologies for the processing of waste material with relatively low financial value. This is a particularly significant constraint in the case of innovative technologies and processes, as the development and transfer of new technologies carries relatively high risks and cost of implementation. These risks pertain not only to financial matters, but also to health, safety, environmental and regulatory compliance issues. Currently, the lack of adequate information and data on the compositions and properties of mine wastes creates uncertainties around the ability to generate products of the required quality, and the environmental and health risks associated with their processing and use. These uncertainties are aggravated by the changing nature of the current legislative landscape. It was also noted that the mining sector is under considerable financial pressure and facing a number of challenges relating to its legislative and social licence to operate. These pressures and challenges, together with a lack of regulatory incentives, are having a direct impact on the sector’s risk appetite, and their desire or ability to invest in the transfer of innovative approaches to mine wastes.

The study also highlighted the fact that effective communication and collaborative partnerships between all potential stakeholders in the technology innovation chain, particularly the developers, sponsors and adopters, will be required in order to overcome these constraints. Good working relationships, communication and trust between these stakeholders are imperative, as is the need to demonstrate efficacy. Whilst academia, government departments and research organisations, as well as the mining industry are key role players, this study also revealed original equipment manufacturers (OEMs) or technology providers to be an important group of stakeholders, who could be potentially be ideally placed to serve as commercial partners for developers, such as a university.

CHAPTER 5: MINE WASTE CHARACTERISATION FOR ENVIRONMENTAL RISK: A COAL CASE STUDY

In order to be effectively managed, the risks associated with mine wastes first need to be well understood. This is difficult given that mine wastes are generally poorly characterised and their potential impacts, particularly the long-term environmental risks in a disposal scenario, fraught with uncertainty and inaccuracies (Broadhurst et al., 2007; Warhurst and Noronha, 2000). Furthermore, without a quantitative understanding of potential waste impacts, there can be little justification or motivation for the development and implementation of meaningful or alternative mitigation measures. The characteristics of coal processing wastes, in particular, have received relatively little attention, particularly in terms of the potential water-related risks associated with metals and salts.

This chapter of the report outlines a methodological approach, and the associated techniques, for determining the key characteristics of mine wastes in terms of their environmental significance (Section 5.1), using coal processing wastes as a case study (Section 5.2).

5.1 Mine Waste Characterisation

5.1.1 A generic approach

In the broader sense, waste characterisation entails the quantitative description of the compositional and behavioural properties of a particular waste material in terms of its potential environmental and/or health impacts, and consequently its suitability for further processing, treatment, storage or disposal. The specific objectives of a waste characterisation exercise can, however, range in complexity from simple waste classification to the more challenging task of assessing the potential of the waste to pose an impact in any particular scenario (e.g. waste disposal).

As discussed in WRC report No 1550/1/07 (Broadhurst et al., 2007), waste characterisation is an integral part of impact prediction modelling, providing valuable information and data on the contaminants of environmental significance and the reaction mechanisms controlling their behaviours and deportment under any given set of external conditions. This is particularly important in the case of solid mineral wastes, which are generally comprised of a multitude of trace elements in various forms, the availability or mobility of which are controlled by a complex network of competing parameters and mechanisms. The complex compositions and chemical behaviour of these wastes adds considerably to the challenges of reliably and accurately predicting the time-dependant release and dispersion of contaminants into the environment in a disposal scenario. To a large extent, the reliability of these predictions will depend on how much is known regarding the physio- and geo-chemical properties of the wastes involved.

Waste characterisation can be based on a number of criteria including mineralogical and chemical composition, physical properties, and leach behaviour. Of these characteristics, it is the leach behaviour which provides the most pertinent information in terms of potential environmental availability and water-related impacts (such as acid rock drainage) typically associated with mineral wastes. As a result, a number of laboratory-scale tests have been developed for the characterisation of solid wastes (particularly in terms of assessing acid generating potential associated with sulphide-bearing mine wastes), each with their own specific objectives and limitations. These limitations, coupled with the complex nature of mineral wastes, means that more than one empirical characterisation test is likely to be required in order to gain an adequate understanding of the key reaction mechanisms and parameters governing the leach behaviour. In this regard, a number of researchers have proposed systematic characterisation protocols, entailing the integrated application of a number of waste characterisation tests (Broadhurst et al. 2007; Kotelo, 2013; Morin and Hutt, 1998).

In line with this “toolbox” approach, UCT has developed an integrated laboratory-scale protocol for the simple, robust and rapid characterisation of sulphide-bearing mine wastes, in terms of their potential environmental risks (Figure 5.1). In this protocol the physio-chemical properties are first determined using a combination of physical, chemical and mineralogical analytical techniques. The acid generating potential is then determined using laboratory-scale static and biokinetic tests, and mineralogy-based techniques. Finally the potential water-related risks associated with metals (including semi-metals) and salts is assessed using a combination of sequential chemical analysis and a simple ranking and scoring protocol developed by Broadhurst and Petrie (2010). Further detail on these characterisation methods is provided in Section 5.1.2 below.

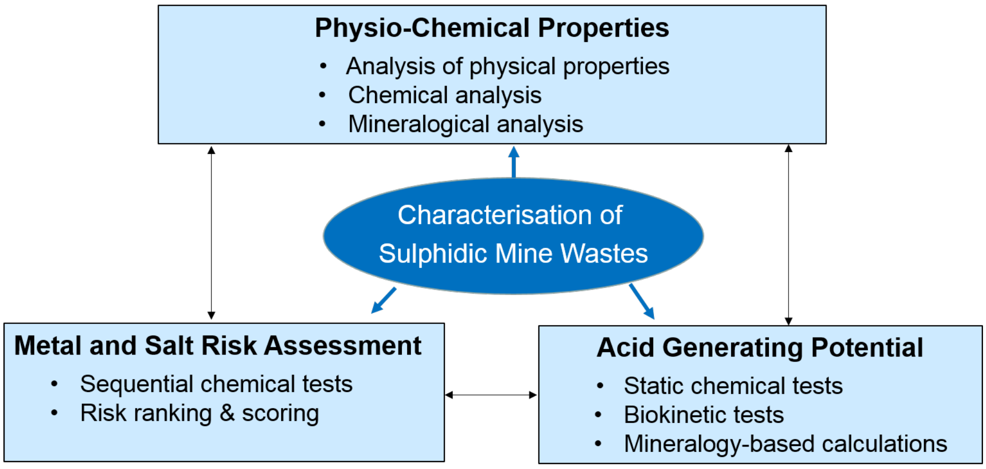


Figure 5-1 Integrated characterisation protocol for sulphidic mine waste

5.1.2 Characterisation methods for coal wastes

This section provides an overview of the current methods for the characterisation of sulphide-bearing wastes, with a specific focus on methods to characterise the properties of coal waste that potentially impact the surrounding environment. In line with the protocol outlined in Figure 5.1, such properties include sulphur and its forms, total and available elements (including metals and semi-metals or metalloids), mineralogical composition and acid rock drainage potential. It should, however, be noted that the majority of these methods are also applicable to metallic sulphide-bearing mine wastes, and some to non-sulphide mine waste materials.

5.1.2.1 Chemical analysis

i Total sulphur

The most widely used methods for total sulphur (S(T)) determination are the Eschka (ASTM D-3177; ISO 351:1995; SABS method 930) and Leco^{Tm} analytical methods. Leco^{TM} sulphur, is an analysis technique which utilises high temperature combustion in order to measure the total sulphur content of a particular sample. Moisture and particulates are first removed from the gas stream by traps filled with anhydrous magnesium perchlorate [$Mg(ClO_4)_2$]. The gas stream is then passed through an infrared absorption cell tuned to a frequency of radiation absorbed by SO_2. The infrared radiation (IR) absorbed during combustion of the sample is proportional to the SO_2 in the combustion gases and therefore the sulphur in the sample. The reference Eschka method is based on igniting a sample of coal (of hard coal, brown coal, lignite, or coke) in intimate contact with Eschka mixture ($2MgO.2Na_2CO_3$) in an oxidizing atmosphere, removal of combustible matter and conversion of the sulphur to soluble sulphate salts $MgSO_4$ and Na_2SO_4, extraction of sulphate with hydrochloric acid solution and gravimetric determination by precipitation with barium chloride.

Other, less commonly applied methods for the analysis of S(T) in coals include:

- the bomb washing methods (ASTM D-2015 and ASTM D-3286)
- techniques involving sample digestion followed by analysis of the dissolved sulphur as sulphate using the wet chemical barium sulphate technique or instrumental techniques such as Inductively Coupled Plasma-Atomic Emission Spectroscopy / Optical Emission Spectroscopy (ICP-AES/ OES), Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) Ultraviolet-Visible Spectroscopy (UV-VIS) Spectrometry
- non-destructive XRF analysis

A comparison of total sulphur with the certified value for the coal standard (Table 5.1) indicates that only the Leco results from ALS are consistent with the 95% confidence limit range reported for the certified coal standard. The mean Leco value obtained by the UCT analytical laboratory was in the order of 10% lower than the "true" mean value, whilst the mean value reported for the Eschka test was over 12% lower.

Table 5-1 Comparison of measured and certified S(T) values for SARM 19

Certified Value (%)		**Mean Measured Value (%)**			**Relative Error of Mean Values (%)**		
Mean	95% confidence limit	Leco-UCT	Leco-ALS	Eschka	Leco-UCT	Leco-ALS	Eschka
1.49	1.42-1.55	1.34±0.01	1.52±0.03	1.30±0.02	-9.86	1.97	-12.55

The relatively high reproducibility for all the total sulphur methods indicates that the relative errors obtained for the UCT Leco results may be due to calibration errors. The reason for the relatively large discrepancies between Leco and Eschka test results are not known but could be indicate that the reliability of this method is dependent on the sample mineralogy.

ii Sulphur speciation protocols

Sulphur-related impacts such as salinisation, air pollution through spontaneous combustion and generation of ARD are not only dependant on the total sulphur content but also sulphur speciation. Generally speaking, the different sulphur species occurring in coal can be categorised as sulphide sulphur (mainly pyrite), but also other sulphide minerals such as sulphate sulphur and organic sulphur. Elemental sulphur can also occur in trace amounts in weathered coal. Sulphide sulphur typically occurs as pyrite (and is often referred to as pyritic sulphur) but also in the form of other sulphide minerals such as pyrrhotite (FeS), sphalerite (ZnS), galena (PbS) and chalcopyrite ($CuFeS_2$). Sulphate sulphur can be further divided into those minerals that are acid forming (such as jarosite, $KFe_3(OH)_6(SO_4)_2$, melanterite, $FeSO_4.7H_2O$, and alunite, $KAl_3(OH)_6(SO_4)_2$), and non-acid forming (gypsum, $CaSO_4.2H_2O$, epsomite, $MgSO_4.7H_2O$, and barite, $BaSO_4$). Organic sulphur occurs embedded in the coal matrix during the formation period.

Currently the accepted standard for sulphur speciation in coal is the ISO 157:1996 standard which utilises the differential solubility of sulphates and sulphides (or pyrite) in dilute hydrochloric acid (HCl) and nitric acid (HNO_3) respectively. The sulphate components are extracted under high temperature conditions (100°C) by means of dilute hydrochloric acid (HCl) digestion. It is assumed that the sulphide minerals remain unreacted in the residue which is then separated by filtration. The filtrate is reserved for determination of dissolved sulphate, normally by means of gravimetric analysis using barium chloride ($BaCl_2$), and the residue containing the sulphides is leached with 9% dilute nitric acid (HNO_3) to dissolve the sulphide minerals. Based on the assumption that the sulphide minerals are all in the form of pyrite, and that no other iron compounds are dissolved in the nitric acid leach stage, the sulphide or pyritic sulphur content is calculated on the basis of dissolved iron concentration in the leachate, normally determined by means of atomic absorption spectrometry (AAS). Organic sulphur is assumed to be insoluble in the reagents used in the procedure and is determined by the difference between the total sulphur content, which is determined from Leco S analysis, and the sulphate and pyritic sulphur contents as determined experimentally. Although relatively simple, the method is based on a number of generalisations and assumptions, which may adversely affect interpretation of results in terms of environmental impact. It also does not distinguish between non-acid forming sulphate sulphur forms and potentially acid forming sulphate species.

The ACARP sulphur speciation protocol (Miller, 2008) was developed to address the shortcomings of the ISO method and provide a comprehensive procedure for isolating the various sulphur forms. The protocol essentially entails three non-sequential steps, as outlined in Figure 5.2.

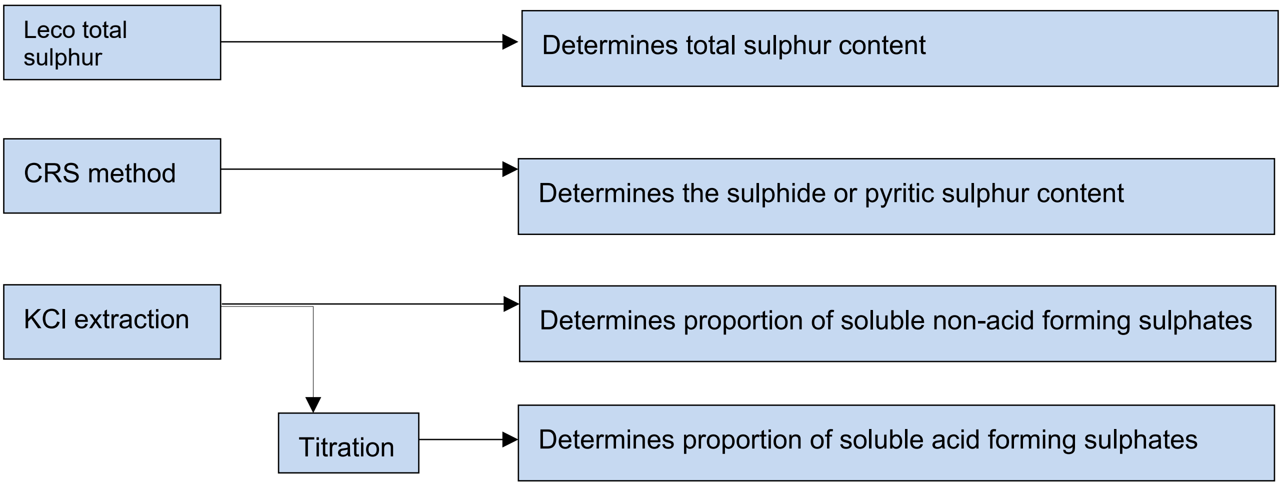


Figure 5-2 Overview of the ACARP sulphur speciation procedure developed by Miller (2008)

The Leco^{TM} sulphur test is first used to determine the total amount of sulphur contained in the sample. Sulphide or pyritic sulphur is determined through the chromium reducible sulphur (CRS) test method. CRS involves the conversion of reduced inorganic sulphur (present as sulphide minerals) to H_2S gas by hot chromium chloride ($CrCl_2$) solution, trapping the evolved H_2S gas in zinc acetate solution as an aqueous zinc sulphide (ZnS) solution (Miller, 2008). The ZnS solution is assayed for sulphide content using a spectrophotometry method developed by Cline (1969), designed specifically for the determination of sulphide content in solution. The pyrite content is then determined by means of stoichiometric calculations. The CRS sulphide test has indicated to have reasonable reproducibility, although some variability in results has been observed. Furthermore, elemental sulphur has been shown to be entrained in the measurement of the pyrite (Stewart et al., 2009). However, the CRS method includes an option for the removal of elemental sulphur by means of an acetone extraction step. The third step involves determination of the soluble (i.e. excluding jarosite) acid forming and non-acid forming sulphates through a selective KCl extraction step. This step is based on the fact that sulphides, organic sulphur and jarosite are effectively insoluble in 1 M potassium chloride (KCl) solutions within extraction periods of up to 1 hour. Furthermore, the acid and non-acid forming soluble sulphates can be differentiated by apportioning part of the extracted solution for titration to determine the acidic content, after which the non-acid sulphate portion is determined by the difference between the total soluble sulphate content and the acid-forming sulphate portion. Organic sulphur present in the sample could then be calculated according to Equation [5.1]

$$OrganicS = LecoS - \left(PyriteS + S^0 + AcidS + Non - AcidS\right) \qquad [5.1]$$

However, if the presence of jarosite is significant then either the organic sulphur would be over-estimated or the difference could be considered a measure of the low-risk sulphur component in the sample, which would therefore include organic sulphur and jarosite. Therefore the low risk sulphur phase would be calculated according to Equation [5.2].

$$LowRiskS = LecoS - \left(PyriteS + S^0 + AcidS + Non - AcidS\right) \qquad [5.2]$$

iii Metals and semi-metals

A number of metal and semi-metals occur in coal, some of which are associated with the organic coal, but many of which are associated with the mineral matter, especially the sulphide minerals, which report to coal wastes. These elements can occur as major (> 1000 ppm), minor (100-1000 ppm), or trace (< 1ppb-100 ppm) elements.

Common methods for analysing inorganic elements (including metals and semi-metals) include X-Ray Fluorescence (XRF) spectrometry and optical adsorption or emission techniques. Historically most elemental analyses were done on coal after low-temperature (normally 525°C) ashing, in order to enrich the elemental concentrations and improve detection precision. Coal ash is also more readily soluble than whole coal. However, ashing can result in a loss of volatile elements such as As, Se, Hg and B. Many of the modern methods are now able to detect elements accurately at low levels (ppb to ppt), whilst microwave-assisted digestion has improved the solubility of whole coal, thus eliminating the need for pre-ashing. Fusing the coal ash or coal powder with flux (usually $Li_2B_4O_7$) homogenizes the sample and improves precision of major elements determination in the case of non-destructive (whole coal) techniques such as XRF and Laser ablation ICP-MS.

- X-ray fluorescence spectrometry (XRF)

This is one of the oldest instrumental techniques still in use in the modern analytical laboratory. The technique is based on the measurement of secondary x-rays emitted from a sample which has been excited with high energy x-rays. The secondary fluorescent x-rays occur at characteristic energies for each element and are determined individually by a wavelength-dispersive detector (WDXRD). XRF is routinely used on a wide range of elements such as aluminium (Al), phosphorus (P), titanium (Ti), calcium (Ca) and chromium (Cr) and has even been extended to determine trace elements (U, As, Se and Cs) in coals. However, the comparative sensitivity of XRF is low, and the accuracy not as high as for other elemental methods (Huggins, 2002). Energy-dispersive XRF (EDXRF) is a recent development which has significantly lowered the detection limits for determining trace-elements. Another advanced XRF techniques is SXRF, which is similar to the conventional XRF except that its X-ray radiation comes from a synchrotron instead of an X-ray tube and therefore the radiation is more intense. The intensity increases its precision and lowers the detection limits. PIXE / PIGE spectrometry uses accelerated particles (protons or other ions) for more energetic radiation of elements, allowing rapid determinations of up to 75 elements simultaneously. Although this technique requires a special source of radiation, it is more sensitive to trace elements than conventional XRF and is well suited to very small samples deposited in small layers (e.g. dust) (Huggins, 2002). Whilst XRF techniques can be successfully employed on whole coal, coarse mineral grains are problematic. Ashing the coal at low temperatures (525 ^{O}C) enriches the elemental concentrations and improves detection precision. Similarly, fusing the coal ash or coal powder with flux (usually $Li_2B_4O_7$) homogenizes the sample and improves precision of major elements determination, particularly in the case of conventional XRF techniques. In general XRF techniques are mainly suitable for the routine analysis of samples with very similar compositions, as the instrument needs to be calibrated and soft-ware programmed for each sample matrix.

A comparison of analytical values with the certified values reported for the SARM 19 coal standard indicated that the XRF method conducted at the University of Stellenbosch was relative accurate for elements in the minor and major concentration ranges (>100 ppm), resulting in mean relative errors of <10% for most of the major and minor elements, except P and Mg. With the exception of these two elements, all the values obtained by these methods fell within the 95% confidence level ranges.

- Conventional optical absorption and emission techniques

Optical absorption and emission techniques are essentially destructive techniques requiring the complete dissolution of the sample, by means of acid digestion, and the subsequent analysis of the dissolved species. The most common methods for the determination of metals in digests in general include Atomic Adsorption Spectroscopy (AAS) and Inductively Coupled Plasma (ICP) techniques.

Atomic Adsorption Spectroscopy can be conducted in flame (Flame Atomic Adsorption Spectroscopy, FAAS) or graphite furnace mode (Graphite Furnace Atomic Adsorption Spectroscopy, GF-AAS). Other atomic adsorption spectroscopy methods include hydride AAS (HAAS) and cold vapour AAS (CVAAS). Of the four methods FAAS, which usually uses an air-acetylene torch, is the simplest and is sensitive for many elements. However, EAAS/GFAAS is the most sensitive (as low as ppt) and therefore most suitable for trace elements. HAAS is usually applied to analyse elements that form stable hydrides when reduced by $NaBH_4$ such as As, Bi, Pb, Sb, Sn and Te. CVAAS is used particularly for determining Hg from a gold or silver amalgamation (ASTM D 6414-99, D-6722 and D-3684). In ASTM 6414-99, mercury is solubilised by heating the sample at a specified temperature in a mixture of a) HNO_3 and HCl or b) HNO_3 and H_2SO_4 with V_2O_5, before determining mercury vapour by flameless CVAAS. In ASTM D 6722, a gold amalgamator that traps Hg selectively is heated rapidly, releasing Hg vapour. Hg concentration is measured as a function of peak height or peak area measured at 253.7 nm by single wavelength AAS. According to ASTM D-3684, a weighed sample is combusted in an O_2 bomb with dilute HNO_3 absorbing the Hg vapours. Then the bomb is rinsed into a reduction vessel with dilute HNO_3 and the Hg is determined by CVAAS. In some laboratories, HAAS and CVAAS has been replaced by atomic fluorescence spectroscopy for the determination of As, Hg, and Se.

Inductively coupled plasma (ICP) can be coupled with Optical Emission Spectroscopy (ICP-OES; also termed ICP-ES or ICP-AES) or with Mass Spectroscopy (ICP-MS). In ICP-OES a high temperature plasma is formed from an electrode-less discharge in argon and maintained by inductive coupling the plasma to a radio frequency electromagnetic field. The plasma excites the elements in the solution aerosols introduced at the base of the plasm. Detection can be sequential or simultaneous for up to 20 elements, and detection is more precise and detection limits lower than other OES methods. ICP-MS has been used extensively in analysing almost all periodic table elements in coal ashes and fly ash that would have been solubilized by acid digestion. Results have shown it is highly selective, has very low detection limits (ppt), very rapid and has few isotopic interferences. The main drawback of ICP-MS are systematic errors on the analyte signal which is affected by plasma nebulizer flow and radio frequency power supply. Another limitation is instrumental drift as the instrument warms up in the first 1-2 hours of operation. The detection limits of ICP-MS for many trace elements in coal is reported to be between 5 ppb and 100 ppb. Precision (in the order of ±20%) and accuracy seemed to be affected by sample homogeneity. Other variations of ICP-MS in literature are flow injection (FI-ICP-MS) for Se, Cd and Hg analysis and hydride generation (HG-ICP-MS) for Se analysis (Huggins, 2002; Wang et al., 2006; Rodushkin et al., 2000).

Table 5.2 summarises the key features, disadvantages and advantages of the more conventional AAS and ICP techniques, complied on the basis of in-house investigation and communications with the Geological Sciences Department at UCT and Varian, a company supplying analytical instruments. As solid mineral wastes are typically characterised by a multitude of components, many of which are present at very low concentrations, the ability of both the ICP methods to simultaneously analyse multiple components down to very low levels in complex chemical matrixes makes them particularly suitable for the characterisation of such wastes. AAS techniques are better suited for the routine analysis of one or two strategic elements, present in relatively significant quantities.

Table 5-2 Key features of commonly used ICP and AAS analytical techniques

Feature	ICP-MS	ICP-OES	FAAS	GF-AAS
Detection limits	Excellent for most elements, except Na, Fe and K (typically ≤ 0.1 ppb)	Very good for most elements (generally 1-10 ppb)	Varies. Can be very good for some elements (typically 0.01-1ppm)	Varies. Can be excellent for some elements. (typically <10 ppb)
Precision	1-3%	0.3-2%	0.1-1%	1-5%
Number of elements	75	73	68	50
Sample throughput	2-6 min/sample for all elements	5-30 elements/ min/sample	15 secs/ element/sample	4 min/element /sample
Spectral interferences	Few	Common	Almost none	Few
Matrix interferences	Moderate	Almost none	many	many
Operating costs	High	High	Low	Medium
Capital costs	Very high	High	Low	Medium/high

Various combinations and proportions of acids are used in the microwave-assisted digestion of coal for ICP or AAS analysis, often with mixed results. Whilst some authors (Huggins, 2002; Iwashita et al., 2006; Wagner and Hlatshwayo, 2005; Wang et al., 2004; Wang et al., 2006; Xu et al., 2005) have reported that HF, in combination with H_2O_2 and HNO_3 is required for complete digestion and accurate analysis using ICP and AAS methods, others (Wang et al., 2004; Wang et al., 2006; Xu et al., 2005) have reported improved results under rigorous (temperatures of 220-250°C and pressures of 2-7.5 MPa) or repetitive digestion conditions in the absence of HF. Some analytical laboratories will not accept solutions containing HF, due to the negative effects on instruments and on operator health and safety. In cases where HF is used for digestion, it is thus usually removed prior to analysis by either boric acid or evaporation. To avoid problems associated with ashing and dissolution of coal or ash samples can be directly introduced in the plasma as suspended solids, slurries or pulverized solids. (Huggins, 2002; Speight, 2005; Wagner and Hlatshwayo, 2005; Ward, 2002). However, as in the case of sample digestion, this method has produced mixed results for elements in coal (Wagner and Hlatshwayo, 2005), and still requires standardisation.

- Laser ablation ICP-MS

Unlike the ICP methods described above, laser ablation coupled ICP-MS does not require prior digestion to solubilise elements prior to analysis. In this method, the coal is finely ground and pressed into pellets which are ablated with pulsed laser forming very fine particles. An argon stream sweeps the particles in the ICP for vaporization and ionisation for mass spectrometry determination. As in the case of XRF, the coal can be fused with a flux to improve precision. The merits of this method are reliability, and moderate-high to very high precision ppm-ppb levels. Sample preparation is inexpensive and fast (can analyse trace elements from the same fusion beads used for XRF major elements analysis) but operational costs are high.

A comparison of analytical values with the certified and uncertified trace elements (< 100 ppm) values reported for the SARM 19 coal standard (see Appendix I) showed that the LA-ICP-MS method at the University of Stellenbosch was relatively reliable, with values falling within the 95% confidence limit ranges for the majority of the certified values, with the exception of As, Cs and Sm. The percentage errors relative to the mean values for the both certified and uncertified values were largely below 10%, with the exception of As, Sm, Zn, Tb, Se and, in particular, Sb. The laboratory confirmed that the LA-ICP-MS method is not suitable for the accurate analysis of As, Sb and Se.

5.1.2.2 Mineralogical analysis

In contrast to the chemical analytical methods described in Section 5.1.2.1, mineralogical analysis is the study of materials to determine mineral composition and mineral structure and can be used to identify mineral species and understand their characteristics and properties. Mineralogy is useful in coal exploration, mining, preparation, use and environmental and process behaviour of coal, its by-products and waste streams. The three most commonly applied mineralogical techniques for coal characterisation include petrography, X-ray diffraction (XRD) and scanning electron microscopy (SEM).

i Petrography

Coal petrography is a microscopy technique which determines the proportions of macerals and to some extent the deportment of mineral matter in coal seams. Petrography is typically used to classify coal in accordance with rank, type and grade. This information, in turn, provides an indication of key combustion properties (ignition temperature; burn-out rates). Petrography can also be used as a screening tool to determine the likelihood for the presence of organic sulphur based on the evaluation of vitrinite content in a sample. Detailed petrographic studies have provided insight on the general condition of coal samples specifically, weathering, extent of disintegration, oxidation of pyrite and alterations to the organic material structure (du Cann, 2011; Wagner, 2008). Studies such as those conducted by Wagner (2007 and 2008) successfully examined the microlithotype features of coal wastes. The greatest advantage of coal petrography is that individual particles can be examined and the data produced is not a bulk average.

- X-ray diffraction (XRD*)*

X-Ray diffraction (XRD) is a method used for the identification of various mineral phases based on their crystallography (Hutton and Mandile, 1996; Ward, 2002; Vassilev and Tascon, 2003). Quantitive XRD (QXRD) is an established technique which provides good reproducibility and has the advantage of producing an average analysis of properties over an entire sample. Organic matter present in coal appears as an amorphous peak on a standard XRD. However, the Rietveld XRD method can be used to assess the weight of the organic lump which can then be used as input data to for the Rietveld method to calculate the mineral contents (Hutton and Mandile, 1996). QXRD analysis can be conducted on both coal samples and low-temperature ash (LTA). Ashing is conducted as a pre-treatment to overcome detection limits associated with whole coal analysis. One of the drawbacks to LTA analysis is the transformation of minerals. This often occurs during ashing.

X-Ray diffraction patterns from coal reflect both the crystalline components and amorphous carbon forms and the determination of mineral matter from these patterns can be associated with higher errors due to the weaker diffraction peak intensities (Huggins, 2002). Furthermore, the XRD detection limits (± 2 wt%) often preclude the use of this technique for the identification of minor phases. However, QXRD can be employed to provide both a qualitative and semi-quantitative understanding of the major mineral phases present in a sample.

- Scanning electron microscopy (QEMSCAN)

Scanning electron microscopy (SEM) is based on the integration of the back scattered electron (BSE) and energy dispersive x-ray (EDX) signals generated by the interaction of the electron beam with the sample. Computer controlled SEM (CCSEM) is usually combined with image analysers to evaluate the mineral nature and distribution. Two automated SEM methods that were developed for identifying composition, association, abundance and nature of minerals in whole coal or ash are the quantitative evaluation of minerals by scanning electron microscopy (QEMSCAN) and the mineral liberation analyser (MLA). These techniques provide visual images and tabulated quantitative data of the ore characteristics; modal mineralogy, elemental distribution, mineral grain size, phase specific surface area, mineral liberation, mineral locking, mineral association and particle shape. QEMSCAN has been used in various coal applications (Kotelo, 2013, Van Alphen, 2007; Moitsheki et al., 2010). In a study by Kotelo (2013), QEMSCAN was used to assess the mineralogical characteristics of ultra-fine coal in the context of potential ARD generation. Apart from quantification of the mineral matter, the QEMSCAN data indicated that between 40% to 80% of the pyrite in the ultra-fine coal waste sample investigated, occurred as liberated particles. The perimeters of the pyrite grains showed greater association with coal than any other constituent, indicating a strong association with the organic phase. Pyrite also indicated to be more strongly associated with the relatively inert mineral of kaolinite, than the acid neutralising minerals of dolomite and calcite. This could have direct implications in terms of ARD generating potential.

As with any mineralogical analysis technique, sample preparation can have a profound effect on the reliability of results. The development of sample preparation for QEMSCAN has resulted in the use of carnauba wax for mounting media rather than epoxy resin, used for petrographic analysis. Liu et al. (2005) explain that this is because the average atomic number of carnauba wax is 5.46 and coal materials have an atomic number ranging from 6.27 to 7.28, thus providing the necessary strong contrast between the mounting media and coal material under the backscattered electron image. However, according to O'Brien et al. (2011), samples prepared with carnauba wax are difficult to polish flat and can contain significant topography which precludes accurate reflectance measurements of maceral groups, and as such coal rank cannot be accurately determined. A sample preparation method which involved mixing the coal sample with carnauba wax followed by setting the sample face down in epoxy resin was propped (O' Brien et al., 2011). The resulting effect is a surface face which is sufficiently resistant for polishing and optical image analysis, allowing for analysis of both the inorganic and organic constituents. Other cases where sample preparation has shown significant importance involve heavy particle segregation. In cases where certain minerals may have a significantly higher density than others, such as in the case of pyrite (S.G 5.02) and coal (S.G 1.55), segregation of the heavier particles from the lighter can occur. The consequence of the disparity between settling rates during preparation will result in a biased distribution. Kotelo (2013) attributed inconsistencies between the mineralogical and chemical analytical results for ultra-fine coal waste to segregation during sample preparation. Furthermore, kaolinite has been shown to have relatively poor reproducibility during QEMSCAN analysis due to its low backscattering electron intensity (BSI). In addition to the low BSI of kaolinite, the mineral typically occurs as finely disseminated particles occluded in the coal structure. According to Van Alphen (2007) these attributes make it very difficult to accurately detect and quantify kaolinite in coal.

5.1.2.3 Acid generating characteristics.

A number of tests exist for characterising the potential for sulphide-bearing solid materials to generate acid, the two most common and important ones being geochemical static, kinetic and biokinetic tests, and mineralogy-based assessments. It should, however, be noted that these methods, particularly those based on laboratory-scale analysis and testwork, are designed to describe the acid generating nature or properties of a material, and do not predict the rate and extent of acid leachate that is likely to be generated in a particular disposal scenario. Such predictions will require consideration of the disposal conditions, and normally entail detailed mechanistic modelling.

i Static geochemical tests

The most simple of the geochemical tests are the laboratory-based static acid rock drainage potential tests, which evaluate the balance between acid-forming processes and acid-neutralising processes which could arise as a result of a sample's mineralogy (Smart et al., 2002). The most common of these tools are acid base accounting (ABA) tests which investigate the maximum potential acidity (MPA) and the acid neutralising capacity (ANC), which together inform the net acid producing potential (NAPP) of a sample (Skousen et al., 1997). The MPA is typically determined from the total sulphur analysis of a sample and is based on the assumption that all the sulphur contained in the sample is in the form of pyrite. In the event of sulphur being present in other forms, such as is the case for coal, calculation of the MPA on the basis of total sulphur will overestimate the MPA, and hence NAPP.

Acid neutralising capacity is commonly determined by means of laboratory tests which involve reacting the material with a known amount of standardised hydrochloric acid (HCl) so as to dissolve all acid neutralising components (carbonates, oxides/hydroxides and reactive silicates), and then back titrating with alkali (NaOH) to a set pH value to determine how much acid was neutralised. The extent to which the acid neutralising compounds are solubilised will be dependent on their mode of occurrence (form and distribution) within the waste, as well as the test conditions, particularly in terms of particle size reduction, extent of acid addition and the back-titration end-point. A summary of commonly used ANC tests the different tests, and the minerals that are typically reported to dissolve under these conditions, is provided in Table 5.3.

Table 5-3 Commonly used ANC test methods (Dyantyi, 2014 after Smart et al., 2002)

ANC Test	Leaching Conditions	Minerals dissolved
Sobek et al. (1978)	Heat for 1-2 hrs at 80-90°C Boil for 1 minute	Carbonates, fast, intermediate & slow weathering silicates (see table 2.1)
Modified Sobek (Lawrence & Wang, 1996)	Shaking at room temperature for 24 hours	Carbonates, fast weathering silicates
Skousen (1997) Siderite correction	Heat for 1-2 hrs at 80-90°C Incrementally add 30% H_2O_2 after back-titrating to pH 4.5 until pH stabilises	As per Sobek excluding Fe & Mn carbonates, slow weathering silicates
AMIRA modified Sobek (Smart et al., 2002)	Heat for 1-2 hrs at 80-90°C Add 2 drops of 30% H_2O_2 after back-titrating to pH 4.5	As per Sobek excluding Fe & Mn carbonates, slow weathering silicates

In general, the relatively aggressive test methods could result in the dissolution of acid neutralising minerals which will be unreactive or extremely slow reacting under conventional disposal conditions, thereby resulting in an overestimation of ANC (see Table 5.4). A study by Becker et al. (2015) on the extent of mineral dissolution from a gold tailings sample under different ANC test conditions gold tailings showed that the more aggressive Skousen and Sobek ANC test conditions resulted in a greater extent of silicate mineral leaching than the less aggressive Lawrence and Wang method, which was consistent with the derived ANC values. In all cases, however, the intermediate weathering aluminosilicate minerals (chlorite and mica) contributed to some extent to acid neutralising capacity. In cases where wastes contain significant quantities of soluble metal hydroxides, re-precipitation of these metals during the back titration stage will result in the underestimation of ANC (Lappako, 2002).

Another static geochemical test that is commonly applied is the Net Acid Generation (NAG) test that determines the balance between the acid producing and acid consuming components of waste rock samples. It also determines the ARD characteristics based on complete oxidation of the sulphide in the sample (Stewart et al., 2009). The NAG test consists of three variations, namely, the single addition NAG test, sequential NAG test and extended boil NAG test. During the single addition NAG test, hydrogen peroxide is added to the sample in a flask, and the acid generation and neutralisation reactions are allowed to proceed simultaneously. The mixture is then heated to oxidise any remaining sulphides and is boiled until the remaining peroxide decomposes. Net acid generating potential of the sample can be determined from a direct measurement of the liquor in the mixture. Single addition NAG tests do not take into account the acid generating potential of samples at higher than 1% sulphide content. This is because the hydrogen peroxide decomposes before complete oxidation of the sulphide minerals. Sequential NAG test is used to overcome the limits experienced by conventional single addition NAG tests. The procedure involves a multi-stage series of single addition NAG tests. Samples with a high organic matter contents (i.e. > 5-7% total organic carbon) such as that found in coal, may also interfere with the NAG tests (Smart et al., 2002). Since coal is composed of high amounts of organic material these may react with the hydrogen peroxide to produce organic acids. In samples with low sulphide contents (i.e. < 1% S), organic matter acidity may give an overestimated account of the sulphidic acid potential (Stewart et al., 2009). Research by Stewart (2005) has shown that the organic acid compounds produced in the NAG solution decomposed through vigorous boiling.

Table 5-4 Relative reactivity's of acid neutralising minerals at pH 5 (Dyantyi, 2014, after Lawrence and Wang, 1996 and Kalinkina et al., 2004)

Mineral Group	Typical Minerals	Relative Reactivity at pH 5
Dissolving	Calcite, aragonite, dolomite, magnesite, brucite	1.00
Fast weathering	Anorthite, nepheline, forsterite, olivine, garnet, jadeite, leucite, spodumene, diopside, wollastonite	
Intermediate weathering	Sorosilicates, (epidote, zoisite), pyroxenes (enstatite, hypersthene, augite, hedenbergite), amphiboles (hornblende, glaucophane, tremolite, actinolite, antophyllite), phyllosilicates (serpentine, chrysotile, talc, chlorite, biotite)	0.02
Slow weathering	Plagioclase feldspars (albite, oligoclase, labradorite), clays (vermiculite, montmorillonite)	0.01
Very slow weathering	K-feldspars, muscovite	0.01
Inert	Quartz, rutile, zircon	0.004

ii Kinetic and biokinetic geochemical tests

Static chemical tests, such as acid base accounting (ABA) and net acid generation (NAG), provide an indication of the absolute potential of a material to generate acid over geographical time, but do not take into account kinetics of the acid forming and neutralising reactions. These tests are thus mainly used as initial screening tests, whereby materials are classified as (non-acid forming (NAF) or potentially acid forming (PAF)) in accordance with universally accepted criteria. Kinetic tests are designed to provide information on the time-related acid generating behaviour of a material. The most common kinetic tests include humidity cell tests and leach column tests, both of which provide long-term dynamic weathering data. A major drawback of these standard kinetic tests is the time required to generate meaningful data, which may often run into years. Furthermore, standard kinetic tests do not take microbial activity into account-this despite the fact that microbial colonisation of sulphide-bearing waste rock or tailings is inevitable (Bryan, 2006). Finally, both humidity cells and leach column tests are carried out using a large particle size distribution of heterologous ore which limits reproducibility. In an attempt to address the short-comings of standard humidity and leach column tests, a microbial shake flask test was developed by Duncan and Bruynesteyn (1979) and subsequently modified and refined at the University of Cape Town (Hesketh et al., 2010). As the name implies this test provides information on the relative kinetics of the acid forming and neutralising reactions under conditions of microbial activity, and is a relatively rapid and cost effective method in comparison to the conventional kinetic tests. Kotelo (2013) conducted biokinetic tests in both batch and semi-continuous mode. In the latter case, approximately 90% of the supernatant was replaced with circum-neutral basalt salt solution at discrete time intervals. The results of this study, shown in Figure 5.3, indicate that although a measured acid neutralising capacity may provide short term alleviation, fluid flow and the movement of effluent in a natural system will likely lead to the loss or depletion of this neutralising capacity in the presence of sulphur-oxidising strains of bacteria. The adaptability of the biokinetic tests to semi-batch conditions provided useful information on the relative rates of acid-forming and acid-consuming reactions not only under microbial oxidation conditions but also in a pseudo open system.

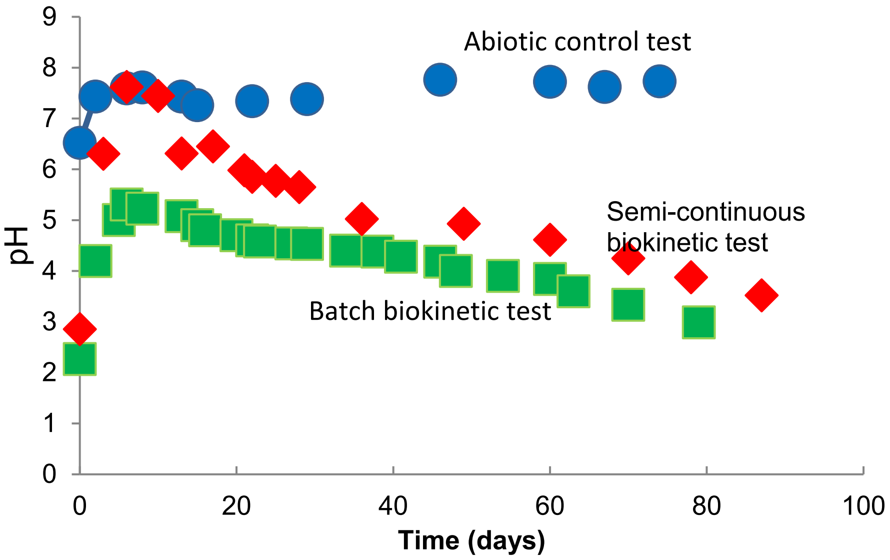


Figure 5-3 Biokinetic test results for an ultra-fine coal slurry waste sample (Kotelo, 2013).

iii Mineralogy-based assessments

The acid generating behaviour of a sample is strongly dependant on mineralogical properties. Acid generating behaviour can thus be estimated on the basis of mineral abundance and textural properties. A number of researchers have developed methods to estimate the acid neutralising and forming capacity of mineral-bearing materials on the basis of their mineralogical compositions (Lawrence and Scheske,1997; Paktunc, 1999; Plante et al., 2012). The Lawrence and Scheske (1997) method accounts for all carbonates (including the non-acid neutralising carbonates) and silicates to calculate the acid neutralising capacity, based on their reactivity's at pH 5 (see Table 5.4). In contrast, the method developed by Paktunc (1999) only takes carbonates into account when estimating the ANC, based on the assumption that silicates make a minor to negligible contribution to the neutralisation potential. As already indicated, a study by Becker et al. (2015) on gold tailings has indicated that some aluminosilicates, such as chlorite, are relatively reactive and hence the Paktunc (1999) method may underestimate ANC. Plante et al. (2012) developed a method that addresses limitations of both the Paktunc (1999) and Lawrence and Scheske (1997) methods, taking into account the acid-neutralising carbonates and reactive silicates. These ANC calculation methods are presented in Table 5.5.

Table 5-5 Mineralogical ANC methods (Dyantyi, 2014)

Method	**Formulation**	**Characteristics**
Lawrence and Scheske (1997)	$ANC = 1000 \times M_{CaCO3} \times \sum_{i=1}^{n} \frac{C_{Mi} \times R_i}{M_{Mi}}$	Takes into account carbonate, including Mn and Fe carbonates, and neutralising silicates
Paktunc (1999)	$ANC = \sum_{i=1}^{k} \frac{10 \times X_i \times w_a \times c_i}{w_i \times n_{Mi}}$	Takes only acid-neutralising carbonates into account
Plante et al. (2012)	$ANC = 1000 \times M_{CaCO3} \times \sum_{i=1}^{n} \frac{C_{Mi} \times R_i \times c_i}{M_{Mi}}$	Includes acid-neutralising carbonates and silicates

Parbhakar-Fox et al. (2011) developed the acid rock drainage index (ARDI) that predicts acid generating potential based on both modal mineralogy and textural properties such as liberation, degree of alteration, association and morphology. The ARDI is a screening stage that forms part of a geochemistry-mineralogy-texture (GMT) approach. Advantages of ARDI are that it saves both time and cost since non-acid forming samples are not taken for further tests (Parbhakar-Fox, 2012). To date the ARDI has only been applied to hard rock ores and waste streams.

5.1.2.4 Metal and salt risk assessment

The potential water-related risks associated with the possible release of metals and salts from wastes into the environment are assessed in a two stage protocol. In the first stage, sequential chemical extraction (SCE) tests are conducted to provide information on the potential availability of elements under various leach conditions. The results from the SCE tests are then used to rank the elements according to their relative significance in terms of potential environmental risk, through the application of a relatively simple ranking and scoring protocol. As in the case of the acid generating potential tests, the results derived from these tests provide an indication of the elements that pose a potential risk if released to the environment, and those that are unlikely to impose an impact. Whilst this information and data can be used to inform more rigorous predictive studies of environmental risk, the SCE results and calculated risk potential factors (RPF) do not provide quantitative data on the rate and extent of contaminants in pore waters or leachates generated from the wastes in an actual disposal scenario.

i Sequential chemical extraction (SCE) tests for availability

Sequential chemical extraction (SCE) tests have been developed to provide information on the partitioning of metals between different mineral phases in soils and other solid materials. These tests are carried out by subjecting either different samples of the waste material to leachants of various strengths in a series of parallel tests, or by subjecting one sample to differing strengths or types of leachants sequentially. In the former case, it is assumed that each stronger leachant will also extract the total sum of the components from weaker leachants. Usually between three and eight leachants or extractants are used, beginning with the least aggressive and ending with the most aggressive. SCE tests have traditionally been developed for providing information pertaining to the partitioning or distribution of trace to minor metals in major soil and sediment phases. Whilst many of the extractants used in these tests are specific to soil systems, a number of authors (see for example Broadhurst et al., 2007; Broadhurst et al., 2009; Dang et al., 2001; Guirco et al., 2000; Hansen, 2004; Leinz et al., 2000; Mitchell et al., 1994; van Herck and Vandacasteele, 2001) have developed and applied modified versions of the traditional SCE tests to inorganic solid wastes. These “modified” SCE tests essentially involved sequential quantification of the relative quantities of components in the water soluble; ion-exchangeable; adsorbed and/or carbonate bound; amorphous oxide bound; crystalline oxide bound; sulphide bound; and residual fractions. Table 5.6 lists possible extractants and the component or phase that they target.

Each fraction can be assumed to representing a different mode of occurrence and potential controlling chemical reaction mechanism. SCE test results can also be interpreted in terms of the relative availability of elements for release into the environment. Water-soluble and exchangeable components can be expected to be readily available for release in the short-term, whilst the environmental availability of components that are associated with the sulphide or residual fractions is likely to be negligible. Together with an appreciation of the hazard potential of individual elements, information on the relative availabilities of the various waste contaminants can be used to identify possible strategic components in terms of potential environmental significance. Both Galan et al. (2002) and Hansen (2004) have developed ranking systems and associated graphical representations for the identification of strategic elements on the basis of total environmental availability, as inferred from SCE test results. Potential modes of occurrence and leach behaviour of constituents on the basis of SCE test results are shown in Table 5.7

Despite the wealth of information that can be derived from SCE tests, there is currently considerable uncertainty regarding the accuracy of the quantitative results. Such uncertainty is due mainly to concerns regarding the specificity (or lack thereof) of the various extractants, as well as potential re-partitioning of components during the extraction tests. Furthermore, many variables will affect the performance of the extractants in liberating specific mineral phases, and test conditions applicable to one material may not be applicable to others. Unless verified by other characterisation tests, the results of the SCE tests should be considered as only semi-quantitative estimates of metal partitioning (Broadhurst et al., 2009).

Table 5-6 Summarised list of possible extractants used in SCE tests and associated extracted phases (adapted from Hansen, 2004)

Fraction Description	Reported Extractants	Specific Extracted Phase or Component
Fraction 1a: Waste soluble	Deionised or distilled water	Water soluble
Fraction 1b: Exchangeable components	Potassium chloride, potassium nitrate, calcium chloride, calcium nitrate and magnesium chloride, lithium chloride and cesium chloride.	Exchangeable, neutral salt exchangeable, water soluble or non-specifically adsorbed
	DTPA	Exchangeable and organically bound metals, “precipitates”
	Ammonium acetate and ammonium chloride	Exchangeable metals
Fraction 2: Carbonate bound and/or specifically adsorbed components	Potassium and sodium fluorides	“Adsorbed” metal, [organic matter]
	Lead nitrate and copper acetate	“Specifically bound” metals
	Sodium acetate in acetic acid (pH5)	Chemically adsorbed metals and elements present as or occluded in carbonate minerals
	Acetic acid	Carbonates, some iron and manganese oxides, “acid-soluble” metals, “specifically bound” metals and decomposed organic matter
	Sodium and potassium pyrophosphate	Organically bound metals [some aluminium, iron and manganese oxides, some metal carbonates and copper sulphides]
Fraction 3: Fe/Mn oxide bound	Hydroxylamine hydrochloride	Manganese oxides (fe oxides)
	Sodium citrate	Iron oxides
	Oxalic acid	Free oxides and primary minerals
	EDTA	Carbonates, “inorganic precipitates”, amorphous and crystalline oxides and hydroxides of iron, organically bound metals
	Acid ammonium oxalate	Iron and aluminium oxides, hydroxides and oxyhydroxides, aluminium and iron from organic complexes, zinc and copper carbonates, [sulphides]
Fraction 4: Organic/Sulphide bound	Sodium dithionate	Iron oxides, organic-iron complexes
	Sodium hydroxide	Organic matter, some metal carbonates
	Sodium hypochlorite	Organic matter, (sulphides)
	Hydrogen peroxide with nitric acid	Organic matter, (sulphides, carbonates and oxides)
Fraction 5: Residual	Strong, mineral acids	Residual minerals

Table 5-7 Potential modes of occurrence and leach behaviour on the basis of SCE test results

Fraction	Potential Mode of Element Occurrence	Potential Mechanism and Parameters Controlling Element Mobility
Water soluble	Present as highly reactive and liberated salts	Mobility will be instantaneous or rapid and will be dependant only on the concentration in this fraction
Exchangeable components	Weakly adsorbed onto clay minerals, iron and magnesium oxides/hydroxides, organic matter and other colloids.	The mobilisation of exchangeable components from solid will most likely occur as a result of rapid ion-exchange reactions, and will be dependent on the soluble salt concentrations and pH
Carbonate bound and/or specifically adsorbed components	Present as or occluded in carbonates and/or chemically adsorbed onto surfaces of simple and complex oxides of iron, manganese and aluminium compounds (simple and complex oxides).	Mobility is likely to be controlled by the rate and extent of carbonate and oxide dissolution/precipitation or by surface adsorption reactions, and will be dependent on pH.
Fe/Mn oxide bound	Present as or occluded in manganese and iron oxides	Mobility is likely to be controlled by rate and extent of Fe and Mn oxide dissolution/precipitation, and will be largely dependent on pH and Eh
Sulphide bound	Present as or occluded within organic matter and/or sulphide minerals	Mobility will be governed by the rate of organic matter/sulphide mineral oxidation, which will be largely controlled by oxygen diffusion
Residual	Present as or occluded in stable primary mineral phases	Element phases are likely to either be inert, or mobilised at extremely slow rates under most disposal conditions

ii Scoring and ranking of risk

Screening environmental performance assessments, entailing the use of simple “ranking and scoring” methodologies based on generic and readily measured environmental risk criteria, are applied in the first instance to identify the significant issues, alternatives and decision points, for which more detailed and accurate assessments are warranted or required (see discussions by EEA, 1997; Lawrence, 1997; Noble, 2000 and 2002; Wentzel, 1999). Such an approach recognises that not all substances in a waste stream raise the same level of concern with respect to their environmental impact, and focuses attention on those components with the potential to present a significant risk to human health and the environment.

In line with this approach, Broadhurst and Petrie (2010) developed a method for screening and ranking solid waste constituents according to their potential environmental impact and risk, on the basis of their potential availability for release to the environment in a disposal scenario, hazardous properties (toxicity, as well as aesthetic and physical effects), and extent of enrichment relative to their natural abundance. These criteria are quantitatively expressed as a risk potential factor (RPF), as presented in Equation [5.3].

$$RPF_i = \frac{(AC_i)^2}{ARC_i \times BC_i} \qquad [5.3]$$

Where:
AC_i= available concentration of element i (mg/kg)
ARC_i= environmentally acceptable concentrations of element i (mg/kg)
BC_i = natural background concentration of element i (mg/kg)

In the absence of site-specific information (as is usually the case in the early feasibility and design stages of a project), standards such as water quality criteria provide a convenient measure of acceptable risk concentrations, as these standards were developed to protect all life. Similarly, generic enrichment factors can be calculated by substituting average crustal abundance values for the natural background concentration levels into Equation [5.3]. Concentrations of elements potentially available for release to the environment can be derived empirically through laboratory-scale tests such as the SCE tests outlined above, or through thermodynamic modelling (Broadhurst and Petrie, 2010).

5.2 A South African Coal Case study

As previously indicated, wastes from the primary processing of coal wastes are largely poorly characterised. This is at least partly due to the fact that the compositions of these wastes are even more complex than those from the processing of hard rock ores, being comprised of both organic and mineral (inorganic) components. Although previous work in Australia (see for example Miller, 2008 and Stewart et al., 2009) and South Africa (see for example Kotelo, 2013) has focused on the development of methods to characterise the acid rock drainage potential of coal wastes, little attention has been paid to the rigorous analysis of metals and salts and associated impacts on the surrounding environment and local communities. In this section of the report, current waste characterisation approaches and methods are applied to slurry and discard coal wastes, with a view to evaluating their applicability, reliability and shortcomings.

5.2.1 Generation of coal processing wastes

Although low in sulphur (<2%), South African coals are considered to be relatively low grade, typically having an ash content of 20-40%. Extraneous, non-combustible matter in coal includes stones, rocks, wood, ash-forming minerals (silicates, sulphides and carbonates), as well as moisture. These materials reduce the energy content or heating (calorific) value; increase the volumes of material to be handled and transported; increase the wear and tear on handling and combustion equipment; and result in hazardous gaseous and particulate emissions during combustion. The preparation (also known as the cleaning or processing) of run-of-mine (ROM) coal, i.e. the raw, unprocessed coal that is mined, essentially entails the removal of these unwanted impurities, thereby generating a uniform product that is more suitable for transport and commercial markets.

Coal preparation can be considered to occur in two distinct stages, viz screening (stage 1) and washing (stage 2). In the screening stage, ROM coal is first crushed to reduce overall topsize, followed by screening to remove large foreign objects and separate the coal into various size fractions-either for direct sale or for further processing by washing. Coal washing, also known as coal beneficiation, is conducted to reduce the content of ash-forming minerals, thus meeting product specifications that cannot be achieved by screening alone. Coal is typically washed using density separation techniques, due to the differences in density of the inorganic, ash-forming minerals and the valuable carbon in the coal. The various coal size fractions are typically treated within their respective size classes by different beneficiation techniques as shown by the generic flowsheet of a South African coal washing plant in Figure 5.4. Coarse coal (>25 mm), is washed in dense medium drums; intermediate coal (1-25 mm) is washed in dense medium cyclones; whilst the fine coal (0.15-1 mm) is washed in spirals. Ultra-fines typically report to the by-pass fraction in beneficiation circuits where filtration methods may be used if the ultra-fine material is of a low ash quality. The high costs associated with filtration typically render the recovery of high ash ultra-fines uneconomical. However, in exceptional cases such as the coking coal market further beneficiation by means of ‘froth flotation’ may be required. This phenomenon results in separation of coal by adhering to the froth created in the reaction vessel which is then skimmed off the top and recovered as higher grade/quality coal. Although froth flotation is a well-known and accepted technique for the treatment of ultra-fine coal, it is not widely practiced in South Africa.

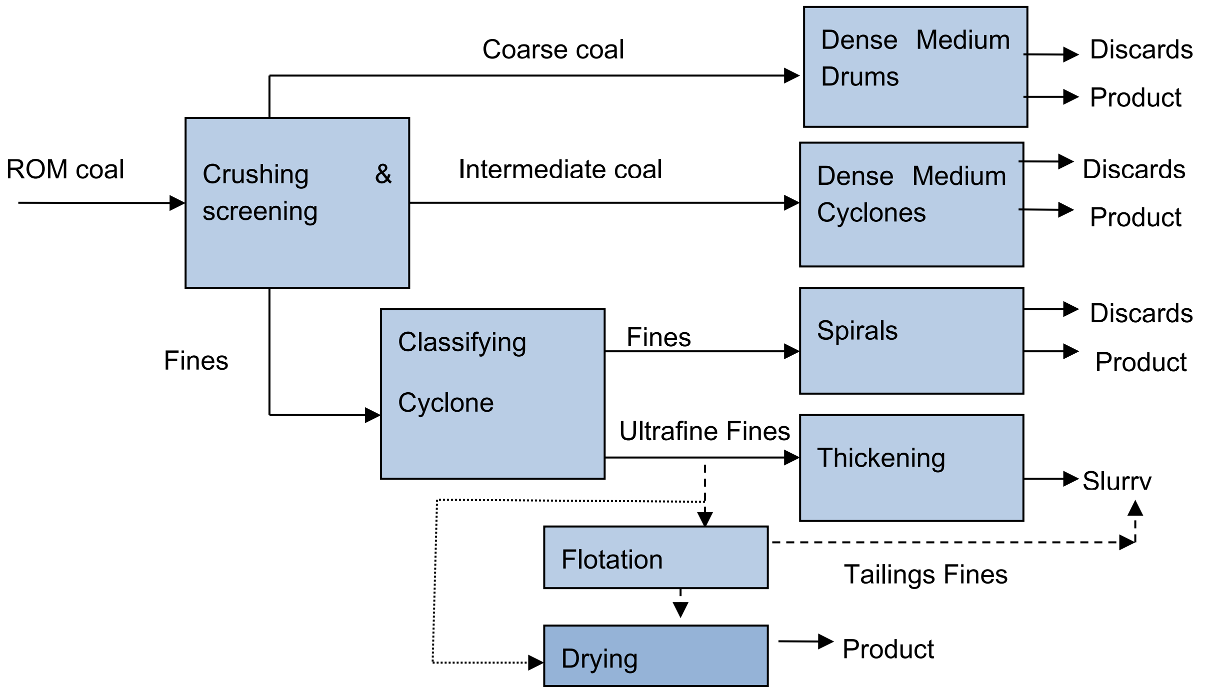


Figure 5-4 Generic flow diagram of a typical South African coal washing plant (adapted from Reddick, 2006 and Harrison et al., 2010)

Coal washing produces two different types of coal processing wastes, namely discards from the coarse, intermediate and fine coal washing circuits, and ultra-fine slurry waste from the thickener underflow, also referred to as "tailings" in cases where flotation separation is used. The term "discard" is sometimes used to describe a combination of these two forms of waste. A South African Department of Minerals and Energy (DME, 2001) inventory of coal waste dumps commissioned in 2001 (Table 5.8) indicated that the quality of ultra-fine slurry waste was similar to that of the ROM coal, with a higher calorific value and lower content of ash and sulphur than discard wastestreams. Due to the relatively high calorific value of ultra-fine slurry waste, studies have sought out ways to reduce the moisture content of ultra-fine waste streams with the aim of directly agglomerating the ultra-fine material with product from collieries (de Korte, 2004; de Korte, 2008). Furthermore, in light of the waste characteristics presented in Table 5.8 and the heightened consciousness of the environmental impact of coal waste, there is greater movement towards re-treating discard streams to produce an acceptable middlings product which is suitable for thermal coal usage and the generation of synthetic fuels (Lloyd, 2002; DME, 2001; Mangena and de Korte, 2005). However, the decline in coal price over the past years has provided little incentive to recover coal from the traditional wastestream, and land disposal remains the dominant practice.

Historically, coal waste disposal has entailed either tipping over the sides of discard dumps or pumping into slurry ponds, depending on the top size of the waste (DME, 2001). However, with the growing understanding of the environmental implications of this "free-tipping" exercise at discard dumps, the material is now being spread and compacted over the dump to eliminate the ingress of air and reduce some of the previously associated environmental risks such as spontaneous combustion. The improved management of discard dumps is such that dumps are currently being constructed with run-off paddocks to control the potentially harmful run-off. Furthermore, seepage from dumps into ground water systems is becoming more strictly controlled through collection paddocks where it is either re-used in the processing plant or gravitated to evaporation dams (DME, 2001). Nevertheless, these measures are not extensively practiced across the entire coal industry spectrum and poor historical practices are said to have a continued long-term effect on the environment (Bosman and Kidd, 2009). The disposal of ultra-fine coal waste in the form of slurries has also considerably changed in recent years (DME, 2001). The co-disposal of these slurries with discard material into dumps is becoming increasingly popular, whilst some collieries are using fine waste to fill surface voids.

Table 5-8 Typical characteristics of coal discard and ultra-fine slurry waste, reported on an as-received basis (DME, 2001)

	Discards	Ultra-fine Slurry Waste
Calorific value (MJ/kg)	11-14	20-27
Ash (%)	30-60	10-50
Sulphur (%)	1-5	< 2
Volatiles (%)	16-24	17-27
Fixed carbon (%)	18-24	41-56

5.2.2 Characterisation of coal processing wastes

As part of this study characterisation testwork was conducted on two fine coal slurry wastes and one discard sample collected as grab samples from the thickener underflow at collieries in the Witbank and Waterberg coalfields of South Africa. Analysis of total sulphur and elements (metals and semi-metals) was also conducted on coal standard SARM 19, in order to assess the reliability of selected methods. A detailed description of the testwork is outlined in Table 5.9.

All received samples (including the coal standard and three coal waste samples) were submitted for elemental analysis using various methods at both the University of Cape Town (UCT) and the University of Stellenbosch (US). Mineralogical analysis was also conducted on the three coal waste samples using the relatively new QEMSCAN instrument acquired by the Centre for Minerals Research at UCT. Mineralogical analysis provided quantitative data on the mineralogy of the bulk sample and size fractions in the range -25 μm to +106-180 μm (for the Witbank slurry waste) and element distribution and was also used to provide a direct estimate of acid generating potential. QXRD analysis was also conducted to validate QEMSCAN results for sulphate and carbonate minerals. Following the assessment of reliability of the various methods for total sulphur analysis (Eschka, Leco analysis at UCT and ALS laboratories), coal waste samples were analysed by means of the Leco analysers at the external ALS laboratories. Sulphur speciation was conducted the coal waste samples using the ISO 157 protocol at ALS laboratories, and in-house using the protocol developed by the Australian Coal Association Research Programme (ACARP protocol). The ACARP test procedure was also used to analyse the residues obtained from the static acid drainage prediction tests. These tests were carried out using the acid base accounting (ABA) and net acid generation (NAG) tests (standard and extended boil). Batch biokinetic tests, both under pH and non-pH controlled conditions, were conducted in triplicate on all three coal waste samples. Residues obtained from the biokinetic tests were analysed for Acid Neutralising Capacity (ANC) using the static (ABA) test. Sequential chemical extraction (SCE) tests were carried out in triplicate on all three coal samples, and the leachates and residues submitted to the analytical facilities at Stellenbosch University for XRF and ICP-MS analysis. These results will be used to compliment mineralogical analysis and also to rank and score the potential environmental risks according to the protocol developed by Broadhurst and Petrie (2010). A comparison of results from different characterisation methods was conducted where relevant in order to assess where these methods could be used to validate and complement each other.

Table 5-9 Overview of coal characterisation testwork

Analysis	Laboratory	Samples/elements Analysed
Physio-chemical analysis		

Particle size distribution		
Dry sieve analysis	Chemical Engineering, CMR, UCT	All three coal waste samples
Ash		
SANS 131:2011/ISO 1171	Chemical Engineering, CMR, UCT	All three coal waste samples
Mineralogy		
QEMSCAN	Chemical Engineering, CMR, UCT	All three coal waste samples: bulk and size fractions
QXRD (Rietveld)		All three samples analysed for selected minerals
Sulphur content and forms		
Leco for S(T)	Chemical Engineering Analytical Laboratory, UCT	Coal standard only (in triplicate)
	ALS laboratories	Coal standard and wastes analysed in triplicate samples over extended time periods
Eschka method for S(T)	In-house	Coal standard only (triplicate)
ISO 157 protocol for sulphur forms	ALS laboratories	Triplicate analyses of coal wastes over a 2-3 week time period, to provide an indication of reproducibility
ACARP protocol for sulphur forms	In-house	All coal wastes samples, as well as static leach test residues analysed in triplicate by the same person and at the same time
Metal and semi-metals		
Pelletization with a flux followed by WDXRF	University of Stellenbosch	Coal standard and all three coal wastes. Elements analysed: Si, Al, Fe, Ti, Ca, Mg, Na, Cr, Mn, P
Pelletization with a flux followed by LA-ICP-MS	University of Stellenbosch	Coal standard and all three coal wastes. Elements analysed: As, Ba, Mn, Sr, Zr, Ce, Co, Cr, Cs, Cu, Ga, Ge, Hf, La, Ni, Pb, Rb, Sm, Th, U, V, Zn, Eu, Mo, Nb, Sb, Se, Sn, Ta, Tb, Y, Yb, Not analysed: Be, B, Hg, Li, W.
Acid generating potential		
Static ARD geochemical tests		
Acid Base Accounting (ABA)	In-house	Static tests were conducted on all the coal waste samples and on biokinetic test residues in triplicate by the same person at the same time, providing an indication of repeatability.
Conventional single stage NAG test	As above	As above
Extended boil NAG test	As above	Only on Witbank slurry and discards wastes
Biokinetic ARD characterisation tests		
Batch shake flask tests with and without pH	In-house	Carried out in triplicate on all coal wastes
Metal and salt risk assessment		
Sequential chemical extraction tests		
7 stage sequential leach protocol	In-house	Leach protocols conducted in triplicate on all three waste samples and the leachates analysed using XRF and ICP-MS at Stellenbosch University. Residues were analysed using XRF and LA-ICP-MS as described above
Risk ranking and scoring		
Protocol by Broadhurst and Petrie (2010)	In-house	Water and soil related risks determined in accordance with method by Broadhurst and Petrie (2010)

5.2.2.1 Physio-chemical characteristics

i Particle size distribution

The particle size distribution of typical coal processing wastes are presented in Figure 5.5.

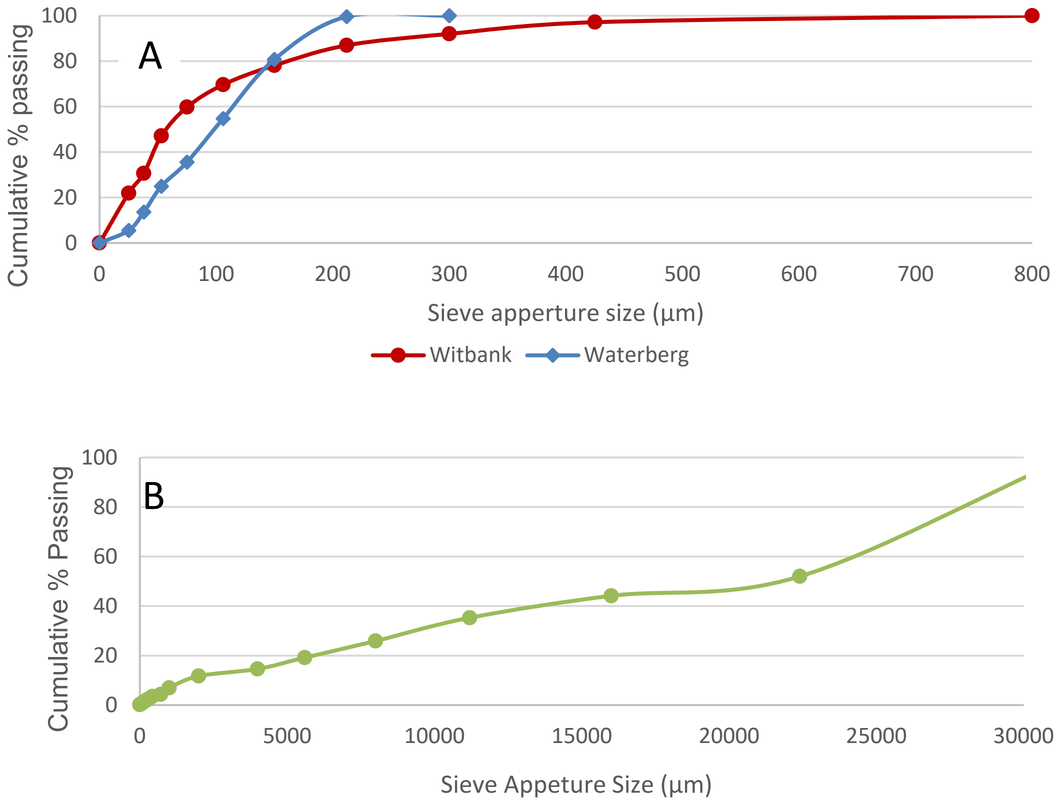


Figure 5-5 Particle size distribution for the typical coal slurry wastes (A) and Witbank discard (B)

The results in Figure 5.5 indicate that, whilst the majority of the particles in the Waterberg (85%) and Witbank (80%) slurry samples can be classified as “ultrafine” (<150 µm), the Witbank sample had a wider particle size distribution than the Waterberg sample, with a higher distribution in both the finer (25 and 50 µm ranges) coarser particle ranges (>150 µm). Hence a significantly higher portion of the Witbank slurry waste occurred in the finer particle size ranges (30.59% and 21.93% passing 38 µm and 25 µm respectively) than in the case of the Waterberg slurry waste (13.59% and 5.52% passing 38 µm and 25 µm respectively). The majority (93%) of the Witbank coal discards occurs in the “middling” (1-25 mm) and “coarse” (> 25 mm) particle size ranges, accounting for 58% and 35% of the sample respectively. Approximately 5.6% and 1.4% of the discards occurs in the fine (0.15-1 mm) and ultra-fine (<150 µm) ranges respectively.

The Waterberg and Witbank slurry wastes had ash contents of 49.2% and 40.9% respectively, and the Witbank discard sample an ash content of 63%. Although the ash content of the discard sample is on the high side, these results are relatively consistent with previous results reported (see Table 5.8., Section 5.2.1), and confirm that Waterberg coal slurry wastes have a higher ash content than those from the Witbank coalfields.

(i) Sulphur content and forms

The results for typical coal processing wastes are presented in Table 5.10. A comparison of S(T) results indicates that the S(T) content decreases in the order: Waterberg coal slurry > Witbank discard waste > Witbank coal slurry. Whilst the S(T) content of all coal wastes are within the typical range for ultra-fine waste (<2%) and discards (1-5%) reported by the DME (2001), the values in the Witbank coal slurry waste are lower than those reported for previous slurry wastes from different collieries in the Witbank coalfields (between 2.5 and 4.8%). This is consistent with the reported variance in the sulphur content of different coal seams within this region.

Table 5-10 Total sulphur and sulphur forms in the coal slurry wastes

	Waterberg Slurry		**Witbank Slurry**		**Witbank Discards**	
	ACARP (%)	ISO (%)	ACARP (%)	ISO (%)	ACARP (%)	ISO (%)
Sulphide sulphur[1]	1.13±0.01	1.04±0.02	0.55±0.00	0.42±0.01	1.02±0.03	1.10±0.01
Sulphate sulphur						
Total	0.32±0.00	0.37±0.06	0.20±0.00	0.19±0.01	0.23±0.01	0.31±0.02
Acid sulphate[2]	0.00	-	0.01±0.00	-	0.23±0.01	-
Non-acid sulphate[2]	0.32±0.00	-	0.19±0.01	-	0.00	-
Organic/low risk sulphur[3]	0.39±0.00	0.43±0.04	0.32±0.00	0.45±0.04	0.69±0.00	0.54±0.06
Total S[4]	1.84±0.01		1.06±0.06		1.94±008	

1. Determined as pyritic sulphur in the ISO protocol
2. Not determined in the ISO protocol
3. Calculated by difference. In accordance with the ACARP method, low risk sulphur includes elemental sulphur and sulphur associated with jarosite
4. Determined by LECO (ALS laboratories)

In terms of sulphur forms, the results for both the ACARP and ISO protocols indicate that the sulphide and sulphate sulphur, as in the case of S(T), decreases in the order: Waterberg coal waste slurry > Witbank discard > Witbank coal slurry waste. The ACARP results also indicate that, whilst the soluble sulphate sulphur in the ultrafine slurry wastes is mainly in the form of non-acid generating minerals (e.g. gypsum, $CaSO_4.2H_2O$, and epsomite, $MgSO_4.7H_2O$), the majority of the sulphate sulphur in the Witbank discards is in the form of acid-forming sulphates (e.g. melanterite, $FeSO_4.7H_2O$).

A comparison of sulphur distribution for the two samples (Figure 5.6) indicates, furthermore, that sulphide (or pyritic) sulphur accounts for more than 50% of the sulphur in the coal standard and coal wastes samples, with the proportion of sulphide sulphur being higher for the Waterberg ultra-fine slurry waste (59-64%) than for the Witbank coal waste samples (52% and 58% for the slurry and discard wastes respectively).

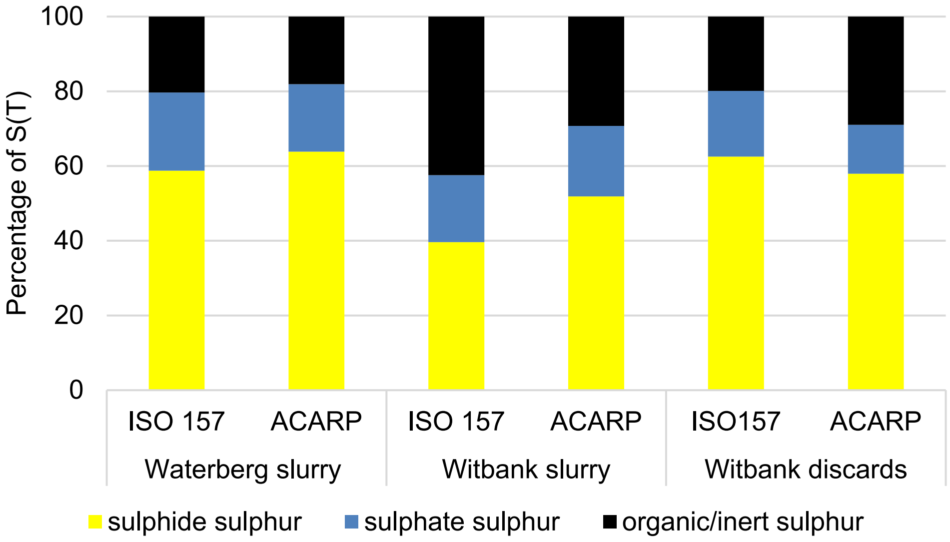


Figure 5-6 Distribution of different sulphur forms in the coal standard and coal waste samples

This is consistent with previously reported results (Kotelo, 2013) for coal slurry wastes. Sulphate sulphur accounts for 18-20% of the total sulphur for both the coal standard and coal slurry wastes, but only approximately 13% of total sulphur for the Witbank coal discards. The contribution of the remaining sulphur, comprised mainly of organic sulphur, varies between 18% and 30%, with the proportion of organic sulphur being lower in the Waterberg slurry coal waste (18-20%).

A comparison of results obtained for different protocols indicated that the ISO 157 protocol gave consistently lower pyritic sulphur values than the chromium reducible sulphur (CRS) method, used to determine sulphide sulphur in the ACARP protocol. This is particularly the case for the Witbank slurry waste. As discussed in Section 5.2.2.1, the ISO 157 method makes a number of simplifying assumptions. The higher sulphate concentrations and the lower sulphidic or pyritic sulphur values obtained for the ISO 157:1996 protocol in comparison to the ACARP C15034 protocol indicates that the relatively aggressive HCl leach, may have resulted in some dissolution of sulphide or pyritic sulphur, thus overestimating the sulphate sulphur and underestimating the sulphide or pyritic sulphur.

Results in Table 5.10 indicate that the ISO 157 results were less repeatable (higher standard deviations) than those generated using the ACARP protocol (standard deviations of <0.01). It should, however, be noted that these two protocols were conducted by different laboratories, and it is not known if the repeat analysis were conducted by the same analyst in the case of the ISO 157 protocol.

ii Mineralogical composition

The coal waste samples can be considered to be made up of three major components: coal (the organic matter), inorganic mineral matter, and carbominerte, a microlithotype comprising ash-forming minerals (20-60%) in close association with coal (40-80%). The values obtained from the QEMSCAN analysis are compared with the calculated mineral matter content on the basis of the total ash and sulphur content (Parr formula) in Table 5.11.

These results indicate that the analysed mineral matter contents are relatively consistent with those calculated from the ash and sulphur contents (Parr formula), although QEMSCAN results gave slightly lower values for the slurry wastes and higher values for the Witbank discards (6-8% variance). The results in Table 2.13 also reflect the relatively high content of ash-forming minerals in the discards relative to the slurry waste samples. This is to be expected, as the discards are generated from the density and gravity separation circuits which are designed to selectively remove ash-forming minerals to the discard waste stream. QEMSCAN results also indicate that the Waterberg slurry waste has a higher content of carbominerite (coal with high content of mineral matter) than the Witbank slurry which, in turn, has a higher carbominerite content than the Witbank discards.

Table 5-11 Concentrations of major components in the coal waste samples

Component	% of sample		
	Waterberg slurry	**Witbank slurry**	**Witbank discards**
Coal	19.13	44.49	19.64
Carbominerite	30.09	13.39	6.18
Mineral Matter (QEMSCAN)	50.78	42.12	74.14
Mineral Matter (Parr formula)[1]	54.04	45.62	69.32

1. Mineral matter (%) = 1.08* Ash content (%) + 0.55 * Total sulphur content (%)

The detailed compositions in the mineral matter of the three waste samples are presented in Table 5.12 and presented graphically in Figure 5.7.

Table 5-12 QEMSCAN analysis of the mineral composition of the coal waste samples

Mineral	% of Sample			% of Mineral Matter		
	Waterberg slurry	**Witbank slurry**	**Witbank discards**	**Waterberg slurry**	**Witbank slurry**	**Witbank discards**
Pyrite (FeS_2)	2.54	1.83	2.72	4.70	4.01	3.93
Chalcopyrite ($CuFeS_2$)	0.15	0.00	0.53	0.28	0.00	0.76
Gypsum ($CaSO_4.2H_2O$)	0.21	0.08	0.00	0.39	0.17	0.00
Jarosite $[KFe_3(SO_4)_2(OH)_6]$	0.01	0.00	0.00	0.01	0.00	0.00
Kaolinite $[(Al_4Si_4O_{10}(OH)_2.H_2O]$	21.38	34.94	51.76	39.56	76.60	74.67
Muscovite $[KAl_2(AlSi_3O_{10})(OH)_2]$	0.51	0.28	0.41	0.95	0.61	0.60
K-feldspar ($KAlSi_3O_8$)	1.34	0.58	1.69	2.49	1.27	2.43
Quartz (SiO_2)	20.81	3.13	15.38	38.50	6.87	22.18
Amphibole $[Ca_2Mg_5Si_8O_{22}(OH)_2]$	0.73	0.03	0.01	1.35	0.06	0.01
Calcite ($CaCO_3$)	1.39	0.01	0.00	2.57	0.01	0.00
Siderite ($FeCO_3$)	0.06	0.02	0.00	0.10	0.04	0.00
Fe-oxyhydroxide	1.40	0.37	0.20	2.59	0.81	0.28
Rutile (TiO_2)	0.18	0.61	1.35	0.32	1.34	1.95
Apatite $[Ca_5F(PO_4)_3]$	0.02	0.21	0.03	0.04	0.47	0.05
Other	0.05	0.04	0.06	0.10	0.08	0.08

Note: Negligible amounts of epsomite ($MgSO_4.7H_2O$), dolomite $[CaMg(CO_3)_2]$ or acid-forming sulphates such as alunite $[KAl_3(SO_4)_2(OH)_6]$ and melanterite ($FeSO_4.7H_2O$) were detected.

As in the case of coal, kaolinite and quartz are the dominant contributors to mineral matter in all the waste samples, accounting for between 80% and 95% of the mineral matter. However, the mineralogical composition of the two slurry samples are significantly different, with the Witbank sample containing more kaolinite but less quartz than the Waterberg sample. The Waterberg slurry sample also contains a higher concentration of carbonate minerals than the Witbank coal slurry and discard samples, made up predominantly of calcite. Whilst pyrite accounts for the majority of the sulphide sulphur, chalcopyrite is also present in fairly significant quantities in both the Witbank discard and Waterberg slurry waste samples. Other silicates present in the waste samples include the silicate minerals k-feldspar, mica and tremolite (an amphibole), as well as complex oxide minerals, which include the hydroxyoxides of iron, rutile and apatite. The relatively low concentrations of sulphate minerals, gypsum and jarosite, indicate that the samples have undergone relatively little weathering.

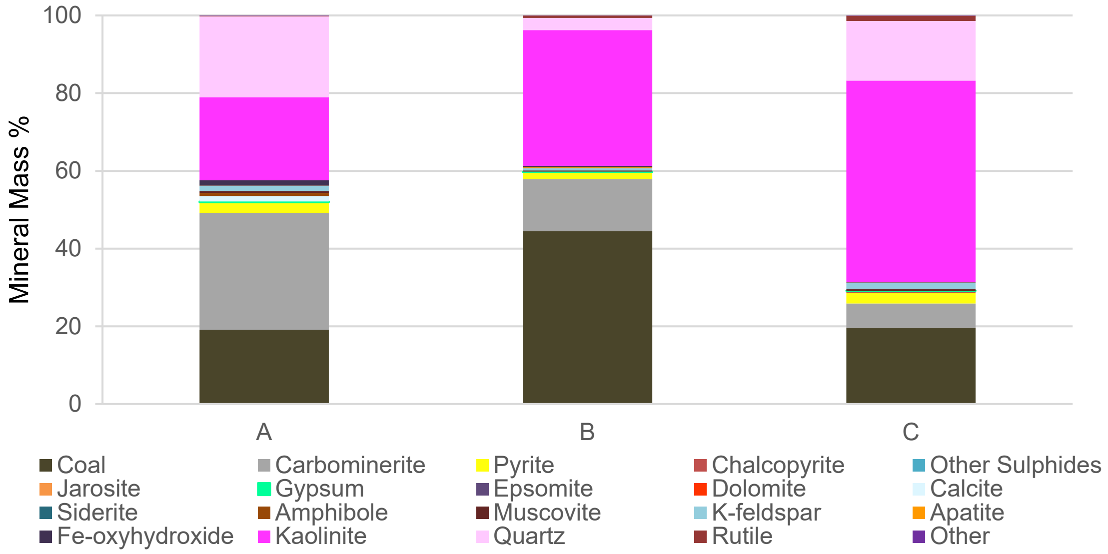


Figure 5-7 QEMSCAN analysis of the mineral composition of the coal waste samples (A = Waterberg coal slurry waste; B = Witbank coal slurry waste; C = Witbank discards)

QEMSCAN analysis conducted on the finer size fractions (-180+106 µm; -106+75 µm; -75+53 µm; -53+38 µm; -38+25 µm and -25 µm) in the Witbank coal slurry waste to determine grain size distributions of quartz, pyrite and kaolinite in the Witbank slurry waste, all of which have been associated with occupational lung disease (See discussions in Chapter 3), is presented in Figure 5.8.

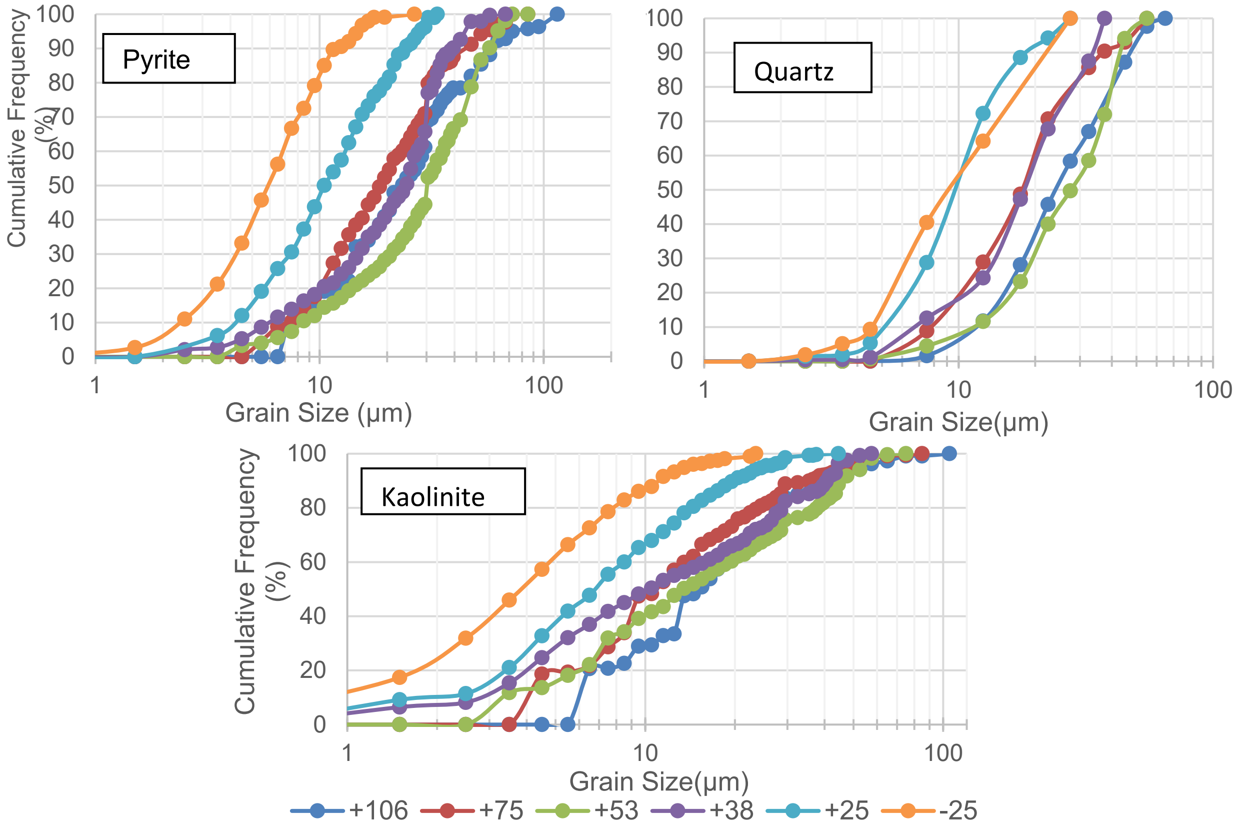


Figure 5-8 Grain sizes distributions of pyrite, quartz and kaolinite in selected particle size ranges of the Witbank slurry waste

The results in Figure 5.8 indicate that a significant portion of the pyrite, quartz and, in particular, kaolinite particles in the -25 µm (80%, 55% and 87% respectively) and -38+25 µm (50%, 55% and 68% respectively) particle size ranges have grain sizes of smaller than 10 µm. The fraction of mineral grains smaller than 10 µm in the coarser particle ranges (+38-180 µm) vary between 10% and 20% for pyrite, and between 30% and 50% for kaolinite.

A comparison of the concentrations of sulphur forms derived from mineralogical (QEMSCAN) analysis and chemical (ACARP) analysis is presented in Figure 5.9. These indicate that QEMSCAN analysis resulted in higher sulphide sulphur and lower sulphate concentrations for all samples. The higher carbon sulphur values derived from QEMSCAN analysis of the slurry wastes samples, particularly Waterberg coal slurry, may be attributed to the relatively high deportment of sulphur to carbominerite. A comparison of the relative distribution of sulphur species (Figure 5.10) indicates that significant quantities of sulphur are associated with this mineral in the slurry wastes.

Sulphide sulphur distributions are relatively consistent (<10% discrepancy) for the two slurry wastes, the QEMSCAN results indicate a much higher fraction of sulphur as sulphide sulphur than the ACARP method in the case of the Witbank discard waste. This may be at least partially due to the fact that QEMSCAN overestimated mineral matter and underestimated coal content in this sample. The relatively low distribution of sulphate sulphur species derived from QEMSCAN analysis is consistent with the low to negligible amounts of sulphate minerals detected by means QEMSCAN (see Table 5.12 and Figure 5.9).

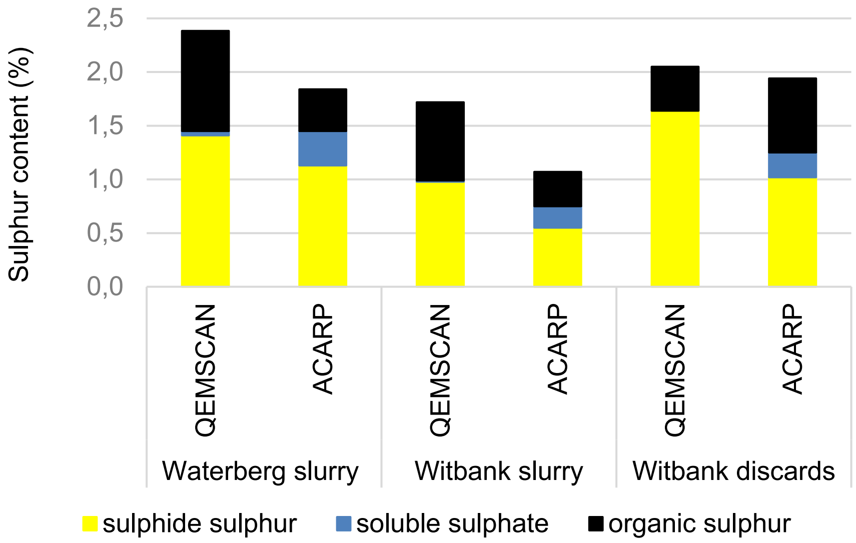


Figure 5-9 Comparison of QEMSCAN and ACARP sulphur speciation (where sulphur associated with carbominerite is assumed to be present as organically bound carbon)

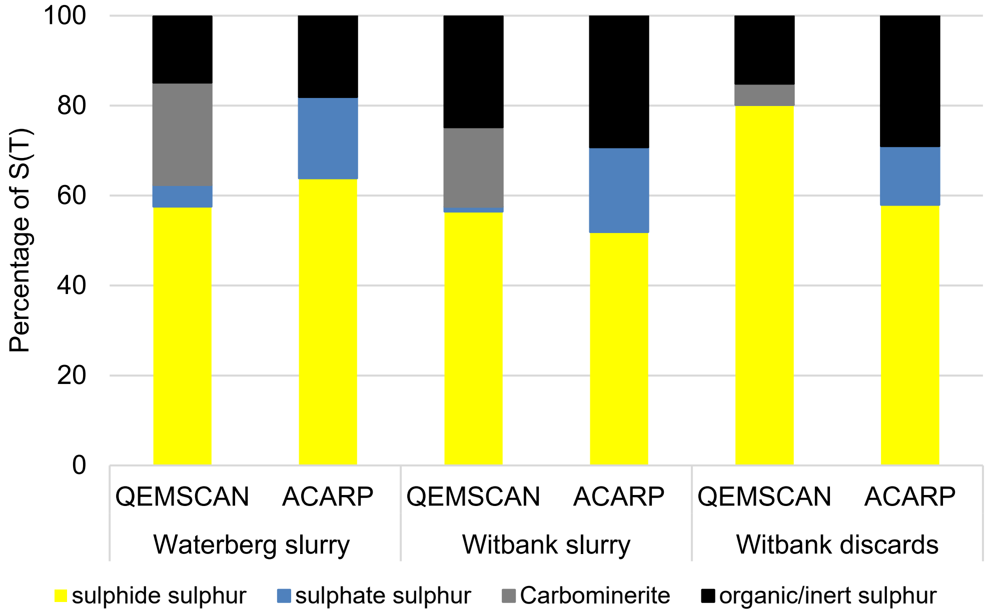


Figure 5-10 Comparison of relative sulphur species distributions derived from QEMSCAN and ACARP analysis

In comparison, XRD analysis showed higher concentrations of sulphates (including jarosite, epsomite and gypsum), as well as dolomite in the coal slurry wastes than QEMSCAN analysis (Table 2.13). In contrast to chemical analysis, however, neither QEMSCAN nor XRD techniques identified acid-forming sulphate minerals (e.g. melanterite) in the Witbank discards. QEMSCAN results also indicated a slightly lower distribution (3-5%, amounting to a 15-18% discrepancy) of sulphur to the coal phase than that determined by chemical analysis (organic/inert sulphur). As previously discussed, discrepancies between QEMSCAN and chemical analysis may be partly attributed to the deportment of sulphur to the carbominerite phase, particularly in the case of the Waterberg sample. It is of importance to note that the sulphur deporting to carbominerite could be both organic and inorganic since carbominerite is a mixture of coal and mineral matter. The analysis of mineral matter in the carbominerite fraction by means of QEMSCAN was not resolved during the course of this study.

Table 5-13 Comparison of QEMSCAN and XRD mineralogical analysis of sulphate and carbonate minerals

Mineral	**Waterberg Slurry**		**Witbank Slurry**		**Witbank Discards**	
	QEMSCAN (%)	XRD (%)	QEMSCAN (%)	XRD (%)	QEMSCAN (%)	XRD (%)
Jarosite [$KFe_3(SO_4)_2(OH)_6$]	0.01	0.61	0.00	2.61	0.00	0.00
Gypsum ($CaSO_4.2H_2O$)	0.21	0.72	0.08	0.84	0.00	0.00
Epsomite ($MgSO_4.7H_2O$)	0.00	0.00	0.00	0.85	0.00	0.00
Calcite ($CaSO_4.2H_2O$)	1.39	1.39	0.01	0.01	0.00	0.00
Dolomite [$CaMg(CO_3)_2$]	0.00	3.80	0.00	0.03	0.00	0.00

iii Metal and semi-metal content and distribution

- Major and minor elements

The XRF and LA-ICP-MS results for the major and minor elements in the three coal waste samples are summarised in Table 5.14.

Table 5-14 Analytical results for major and minor elements in typical coal waste samples

	Waterberg Slurry		Witbank Slurry		Witbank Discards	
	Content[1]	Enrichment[2]	Content[1]	Enrichment[2]	Content[1]	Enrichment[2]
Major (%)						
SiO_2	28.49	0.50	22.58	0.39	47.21	0.82
Al_2O_3	3.83	0.25	13.16	0.85	15.39	0.99
Fe_2O_3	5.22	0.58	2.33	0.26	2.50	0.28
TiO_2	0.41	0.37	0.77	0.70	0.98	0.89
CaO	3.83	0.55	0.83	0.12	0.06	0.01
MgO	1.08	0.62	0.20	0.12	0.06	0.03
Na_2O	0.04	0.01	0.03	0.01	0.28	0.09
K_2O	0.55	0.30	0.34	0.19	0.31	0.17
Minor (ppm)						
Ba	1040.00	3.05	942.50	2.77	267.61	0.79
Mn	593.15	0.54	102.95	0.09	42.44	0.04
P	132.67	0.13	1084.27	1.08	351.72	0.35
Sr	158.35	0.44	480.80	1.34	115.90	0.32
Zr	160.85	1.24	248.00	1.91	338.14	2.60

1. Analysis by XRF except for Ba, Sr and Zr which were analysed by LA-ICP-MS. All analyses were carried out at the University of Stellenbosch
2. Relative to average crustal abundance (www.webelements.com)

The relatively high element concentrations for the Witbank discard samples, particularly in terms of Si, Na and K contents, are consistent with the higher content of ash-forming minerals, such as quartz and the silicates (see Table 5.14). The results also indicate that the Witbank coal slurry waste has a slightly lower Si, but significantly higher Al content than the Waterberg sample. This is consistent with the higher kaolinite/quartz ratio for the Witbank sample, as per the results of the mineralogical composition (see Table 5.12 and Figure 5.7). A comparison of the concentrations of major and minor metals in the coal wastes in comparison to their average crustal abundance indicates that there is a slight enrichment of Ba in the slurry wastes (by a factor of approximately 3) and, to a lesser extent, Zr (enrichment factor between 1-3) in all waste samples. The majority of the remaining major and minor elements in the coal are present in lower concentrations than the average crustal abundance values, particularly in the case of Na (all wastes), Mn (both Witbank slurry and coal wastes) and, in the case of the Witbank discards, Ca and Mg. All these elements had enrichment factors of <0.1. In comparison to the Witbank coal wastes, the Waterberg coals slurry is relatively depleted in Al and Ti, and enriched in Ca and Mg. This is consistent with the lower kaolinite and rutile concentrations and higher calcite and amphibole concentration values for the Waterberg slurry waste, as derived from QEMSCAN analysis.

Element deportment in accordance with QEMSCAN analysis is presented graphically in Figure 5.11. As expected Si and Al are mainly present as kaolinite and, in the case of Al, quartz, while Ti is almost exclusively present as rutile. The majority of the iron is present as pyrite and, to a lesser extent, Fe. Ca is mainly present as apatite in the Witbank coal wastes and as calcite and amphibole in the Waterberg waste. K is predominantly present as kaolinite in all wastes, and also associated with quartz in the case of the Waterberg sample. A small quantity of K is present as an unidentified mineral. Mg is largely present as amphibole, muscovite and an unidentified mineral. XRD analysis indicates that the minerals not identified by QEMSCAN could possibly be jarosite (K), epsomite (Mg) or dolomite (Mg, Ca).

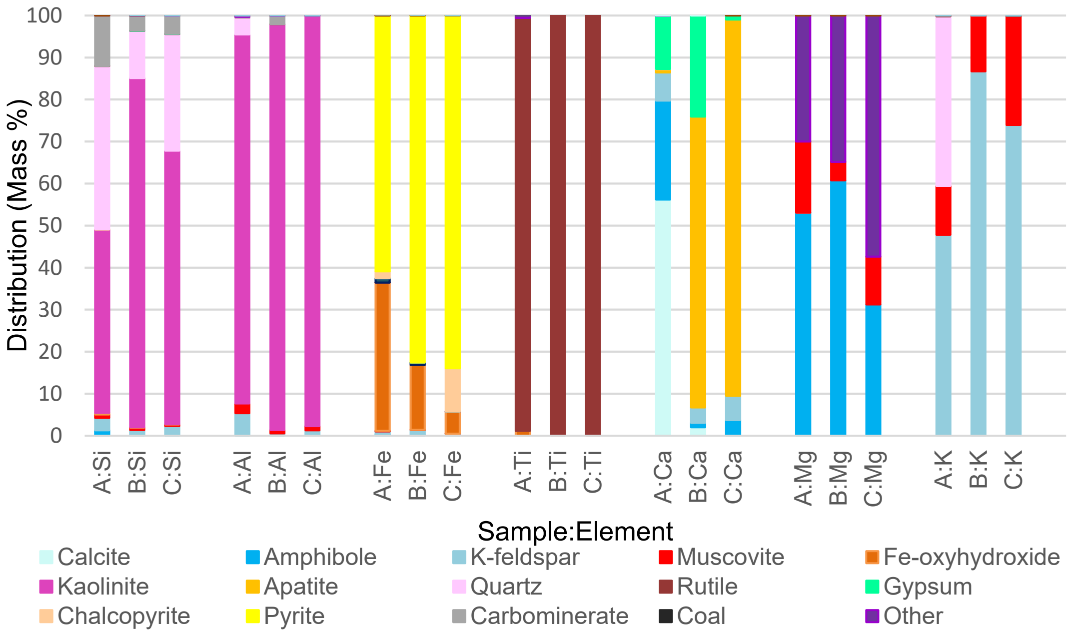


Figure 5-11 Deportment of elements in the coal slurry wastes according to QEMSCAN analysis (A = Waterberg coal slurry waste; B = Witbank coal slurry waste; C = Witbank discards)

The parity graphs in Figure 5.12 compare the mineralogical (QEMSCAN) and chemical (XRF or LA-ICP-MS) concertation values for selected elements. Whilst Al and Si were not included in Figure 5.12 parity graphs, a comparison of values (Table 5.12 and 5.14) indicates good correlation between QEMSCAN and XRF data for both these elements. In terms of other major and minor elements, the results in Figure 5.121 indicate that the QEMSCAN results for Ca, Fe, Mg were significantly lower than those obtained by means of XRF analysis in the case of the Waterberg coal slurry waste. Although there was better parity for the Witbank coal slurry waste, QEMSCAN analysis also resulted in lower Ca and, to a lesser extent, Fe concentrations than chemical XRF analysis. QEMSCAN analysis, however, resulted in higher sulphur contents for both the slurry wastes, particularly Waterberg slurry. As indicated in Figure 5.9, this can be attributed to the higher QEMSCAN values for sulphide sulphur (mainly in the form of pyrite) and carbon sulphur. Parity between the mineralogical and chemical analysis was good for all elements in the case of the Witbank discards. The discrepancies could be attributed to underestimation of for the coal slurry wastes. A comparison between QEMSCAN and XRD analysis for selected sulphate and carbonate values (Table 5.13) indicates that the discrepancies in the case of the slurry coal wastes and Waterberg coal slurry in particular, may be attributed to the fact that QEMSCAN underestimated the content of sulphate minerals gypsum, epsomite and jarosite, as well as the Ca and Mg bearing dolomite mineral. XRD analysis gave significantly higher values for these minerals, particularly in the case of dolomite in the Waterberg coal slurry (3.8%), which could account for almost 1% additional Ca and 0.5% additional Mg.

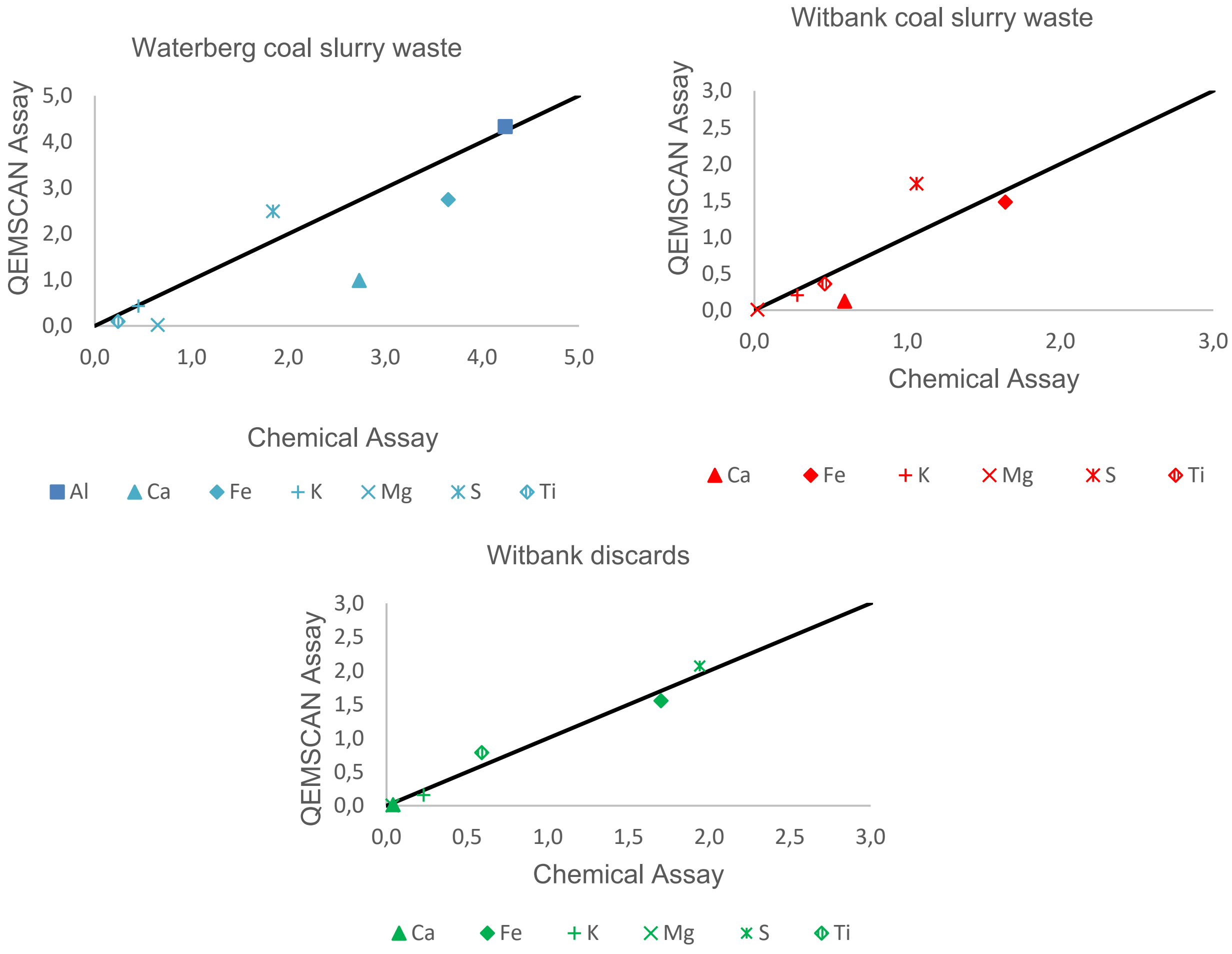


Figure 5-12 Parity graphs for mineralogical (QEMSCAN) and chemical (XRF and LA-ICP-MS) analysis.

- Trace elements

The results for the LA-ICP-MS analysis of trace elements (namely transition and post-transition metals, semi-metals, alkali metals, rare earth elements and actinides) are summarised in Table 5.15.

These results indicate that the concentration ranges of trace elements are similar across all the coal wastes, and largely similar to those reported for the coal standard. Exceptions are Co, Ni and more particularly V, Zn and Rb, which are relatively enriched in the coal slurry wastes. The Witbank coal wastes have significantly higher concentrations of Th than the Waterberg slurry waste. It should be noted that Hg and B were not able to be analysed using this method.

Table 5-15 LA-ICP-MS results for trace elements

Element	Analytical results (ppm)			Element	Analytical results (ppm)		
	Waterberg Slurry	**Witbank Slurry**	**Witbank Discards**		**Waterberg Slurry**	**Witbank Slurry**	**Witbank discards**
Transition and post-transition metals							
Bi	0.42	0.24	0.79	Ni	34.15	31.05	24.81
Cd	0.28	0.06	0.30	Pb	26.06	23.00	26.60
Co	15.92	12.13	4.64	Nb	14.14	20.96	20.76
Cr	82.10	87.50	180.82	Sn	4.55	3.34	5.73
Cu	32.75	34.85	34.81	Ta	0.83	1.50	1.62
Ga	13.04	19.29	19.89	Tl	0.20	0.08	0.22
Hf	4.32	6.58	9.79	V	80.55	69.20	52.72
In	0.09	0.08	1.84	Zn	80.25	32.15	38.44
Mo	3.39	2.88	7.00				
Semi-metals							
As	7.86	4.49	6.94	Sb	1.67	1.15	0.88
Ge	2.18	3.24	<2.20	Se	1.33	1.25	1.55
Alkali-metals							
Cs	3.75	3.75	2.83	Rb	32.40	20.03	15.13
Rare earth metals							
Ce	53.92	90.35	66.70	Pr	6.27	9.20	6.70
Dy	6.05	5.96	5.12	Sc	16.20	14.48	11.33
Er	3.22	3.46	2.92	Sm	6.47	7.05	4.65
Eu	1.11	1.27	0.82	Tb	0.97	0.94	0.73
Gd	6.11	5.92	4.60	Tm	0.45	0.50	0.43
Ho	1.17	1.25	0.91	Y	31.74	33.20	28.40
La	25.57	44.12	32.00	Yb	2.87	0.17	2.96
Lu	0.44	0.49	0.50				
Nd	25.70	35.25	23.28				
Actinides							
Th	10.77	20.12	19.02	U	3.84	5.43	4.44

A comparison of trace element concentrations with average crustal abundance values (Table 5.16) indicates that, in contrast to the major and minor elements, a number of trace elements are enriched in the coal wastes relative to their average concentrations in the earth's crust. This pertains particularly to Bi and Se, the concentrations of which are more than 10 times higher than the average crustal abundance values. Other elements which are enriched by a factor of between 1 and 10 include Mo, In (discards only), Pb, Sn, As, Sb, Ge, Cs, Ce, U and Th.

Table 5-16 Enrichment of trace elements in coal wastes, relative to the average crustal abundance values

Element	**Enrichment Factors**			**Element**	**Enrichment Factors**		
	Waterberg Slurry	**Witbank Slurry**	**Witbank Discards**		**Waterberg Slurry**	**Witbank Slurry**	**Witbank Discards**
Transition and post-transition metals							
Bi	16.8	9.60	31.6	Ni	0.38	0.35	0.28
Cd	1.9	0.40	2.0	Pb	2.61	2.30	2.66
Co	0.53	0.40	0.15	Nb	0.83	1.23	1.22
Cr	0.59	0.63	1.29	Sn	2.06	1.52	2.61
Cu	0.48	0.51	0.51	Ta	0.49	0.88	0.95
Ga	0.69	1.01	1.05	Tl	0.38	0.05	0.13
Hf	1.31	1.99	1.97	V	0.42	0.36	0.28
In	0.56	0.50	11.50	Zn	1.02	0.47	0.57
Mo	3.08	2.62	6.36				
Semi-metals							
As	3.74	2.10	1.87	Sb	8.35	5.75	4.40
Ge	1.56	2.31	<1.57	Se	26.60	25.00	31.00
Alkali-metals							
Cs	1.97	1.97	1.49	Rb	0.54	0.33	0.25
Rare earth metals							
Ce	0.90	1.51	1.11	Pr	0.72	1.06	0.77
Dy	0.98	0.96	0.83	Sc	0.62	0.56	0.44
Er	1.07	1.15	0.97	Sm	1.08	1.18	0.78
Eu	0.62	0.71	0.46	Tb	1.00	1.00	0.78
Gd	1.18	5.92	0.18	Tm	1.00	1.11	0.96
Ho	0.98	0.95	0.15	Y	1.09	1.14	0.98
La	0.75	1.30	0.94	Yb	1.03	0.06	1.06
Lu	n/a	n/a	n/a				
Nd	0.78	1.07	0.71				
Actinides							
Th	1.80	3.35	3.17	U	2.13	3.02	2.47

5.2.2.2 Acid generating potential

The acid generating properties of the coal waste samples were investigated on a laboratory scale using both the standard static test methods, as well as the batch biokinetic test method developed at the University of Cape Town. Mineralogical and chemical analytical results were used in the validation and interpretation of the laboratory-scale analysis, whilst mineralogical data was also used to characterise the acid generating potential of the coal waste samples directly.

i Static test results

All three coal waste samples were analysed using the conventional acid base accounting (ABA) and net acid generation (NAG) test methods. In the case of the Witbank waste samples, both standard single stage and extended boil tests were conducted. The results are summarised in Table 5.17.

Differentiating between S(T) and acid-forming sulphur (including sulphide sulphur and acid-forming soluble sulphate) results in a significant difference to the calculation of maximum potential (MPA). The lower MPA values for the Witbank slurry samples is consistent with the lower total S (1.06%) and acid forming sulphur (0.56%) values than for the Waterberg slurry waste (1.84% S(T) and 1.13% acid forming S) and the Witbank discards (1.94% S(T) and 1.41% acid forming S). The acid neutralising capacity (ANC) is also significantly higher for the Waterberg coal slurry waste, than for the Witbank coal wastes.

Table 5-17 Static acid rock drainage test results

Sample	**MPA (kg H_2SO_4/t)**		**ANC (kg/t H_2SO_4)**	**NAPP (kg H_2SO_4/t)**		**NAG pH**	
	S(T)[1]	Acid S		S(T)	Acid S	Single Stage	Extended Boil
Waterberg slurry	56.30	34.52	102.29	-46.79	-67.71	5.19	-
Witbank slurry	32.44	17.14	29.22	3.22	-12.39	3.97	5.24
Witbank discards	59.36	38.27	29.10	30.26	9.15	2.56	2.54

1. Based on the mean value from the Leco analysis at ALS laboratories
2. Based on the mean value for the pyritic S value and acid forming sulphate from the ACARP protocol

The high ANC values relative to the MPA values results in a negative net acid producing potential (NAPP) for the Waterberg coal slurry waste, which is consistent with the circum-neutral final NAG pH. In contrast, the ANC is lower than the MPA in the case of the Witbank discards, even when excluding the non-acid generating sulphur forms, resulting in positive NAPP values, consistent with the acidic NAG pH values. The similarity in the NAG values for the standard and extended boil NAG test indicate that the formation of organic acids under NAG tests conditions was negligible for this sample. Although the Witbank slurry and discards wastes have similar ANC values, the lower MPA values for the slurry waste resulted in lower NAPP values, varying from slightly positive to slightly negative (depending on how the MPA is calculated), and a weakly acidic final NAG pH. Extended boiling of the NAG solution in the case of the Witbank slurry waste resulted in a decline in the final pH to 5.24, indicating that formation of soluble organic acids is contributing to the acidity of the NAG solutions in the case of this sample.

A combined classification plot on the basis of the above-mentioned results is presented in Figure 5.13. In accordance with the classification criteria, the Waterberg sample is non-acid forming regardless of whether the total or acid-forming sulphur contents are used to calculate NAPP. Similarly, the Witbank discards sample remained potentially acid forming, even when only acid-forming sulphur was considered. In contrast, the classification of the Witbank slurry sample varies considerably, depending on whether the presence of non-acid forming sulphur compounds and formation of organic acids is taken into account.

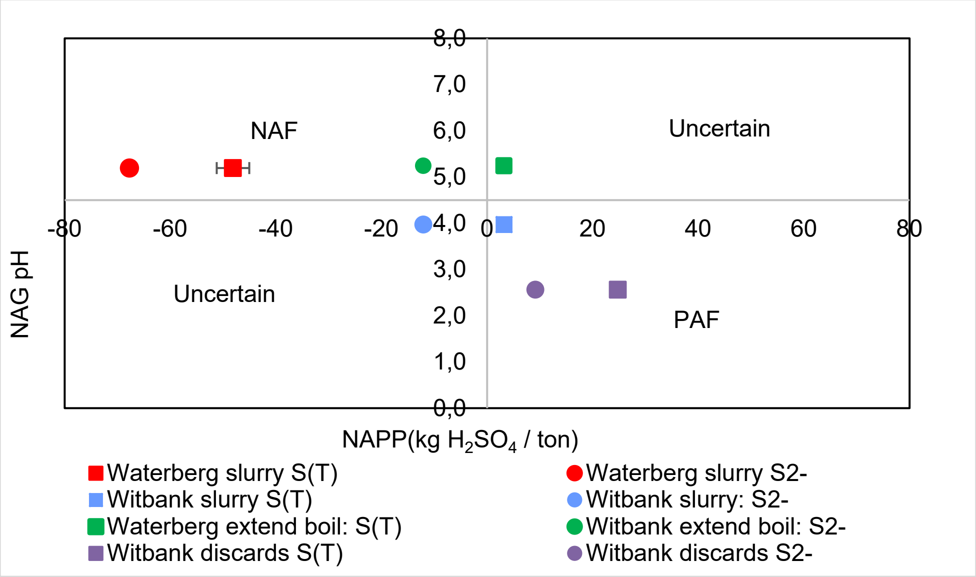


Figure 5-13 Classification of acid generating potential on the basis of static test results (NAF denotes non-acid forming and PAF potentially acid forming)

Sulphur speciation tests were conducted on the leach residues from the static chemical tests in order to assess the behaviour of the various sulphur forms under the static test leach conditions (Figure 5.14)

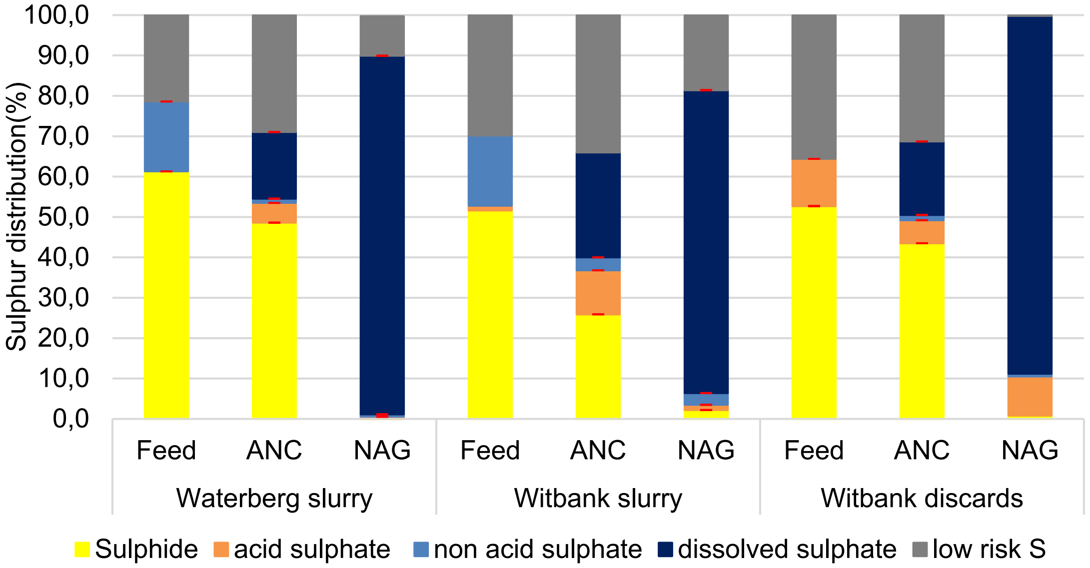


Figure 5-14 Comparison of sulphur distributions in the feed and residues from the static acid prediction tests

The results in Figure 2.15 indicate dissolution of sulphide sulphur under the relatively aggressive conditions of the ANC tests, particularly in the case of the Witbank slurry waste, could possibly underestimate the acid neutralising capacity of the samples (by between 5.5 Kg/t H_2SO_4 for the Waterberg slurry and Witbank discards (i.e. underestimation of 5% and 19% respectively) and 8.3 Kg/ton H_2SO_4 for the Witbank slurry (i.e. underestimation of 25%). NAG tests, resulted in 99.9%, 95.8% and 98.5% conversion of sulphide sulphur for the Waterberg slurry waste, Witbank slurry waste and Witbank discards respectively. The presence of unoxidised sulphide minerals and acid forming sulphates in the residues from the Witbank coal wastes could mean that the NAG residues are still net acid forming, and the net acid generating potential thus slightly underestimated.

ii Theoretical ARD from Mineralogy

QEMSCAN results were used to calculate the acid generating potential (AP) and neutralization potential (NP) in accordance with the method developed by Paktunc (1999). The results (Table 5.18) indicate that pyrite is the major acid producing mineral, accounting for between 88% and 99.9% of the calculated acid producing potential.

Table 5-18 Acid generating potential (AP) of coal waste samples A (Waterberg coal slurry), B (Witbank coal slurry) and C (Witbank coal discards) calculated from QEMSCAN results

Mineral	**Acid Generating Potential (AP) (kg H2SO4/ton)**		
	Waterberg Slurry	Witbank Slurry	Witbank Discards
Pyrite	41.47	29.91	44.48
Chalcopyrite	1.60	0.00	5.62
Sphalerite	0.11	0.04	0.07
Jarosite	0.03	0.00	0.00
Total	43.21	29.95	50.17

A comparison of the acid producing potential (AP) on the basis of mineralogical (QEMSCAN) analysis and the maximum potential acidity (MPA) on the basis of chemical sulphur speciation (ACARP) analysis is provided in Figure 5.15.

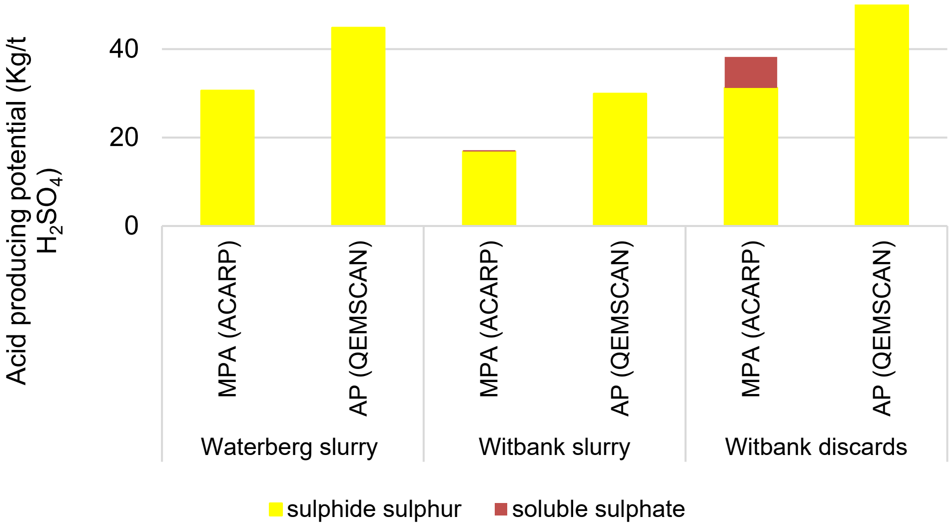


Figure 5-15 Comparison of acid producing potential results derived from mineralogy (QEMSCAN) and chemical sulphur speciation (ACARP) results

The results in Figure 5.15 indicate that the calculated acid producing potential derived from QEMSCAN analysis is significantly higher than that derived from chemical sulphur speciation analysis. This is consistent with the higher sulphide sulphur values (mainly as pyrite) derived from the QEMSCAN analysis (see Figure 5.9). In contrast the QEMSCAN analysis did not identify any acid-forming soluble sulphate minerals.

The results in Figure 5.16 indicate that the NP calculated from QEMSCAN mineralogical analysis is generally higher than the ANC derived from empirical chemical static ABA test for the slurry coal wastes.

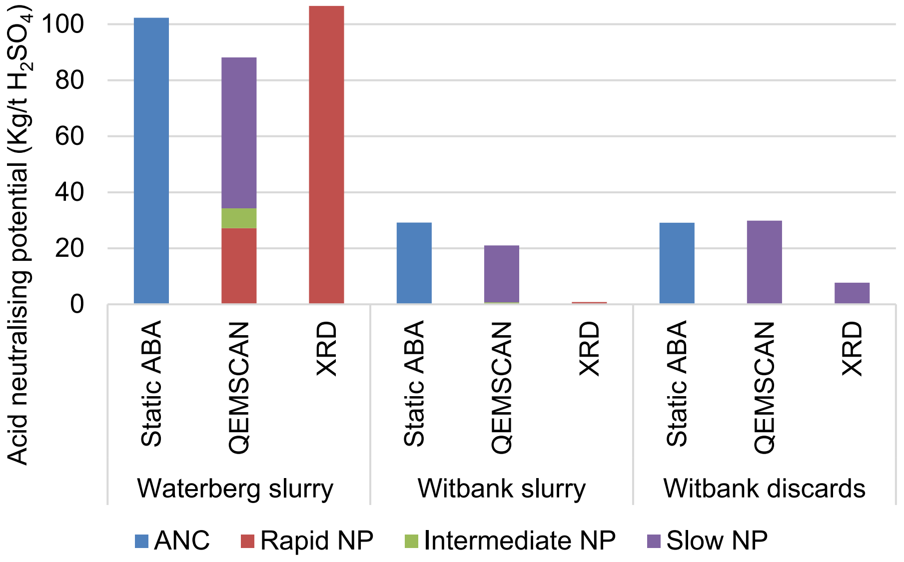


Figure 5-16 Comparison of neutralization potential as derived from mineralogical analysis (QEMSCAN and QXRD) and static chemical tests (ABA)

QEMSCAN data indicates, furthermore, that the net NP is associated predominantly with relatively slow weathering silicate minerals (54% in the case of the Waterberg slurry waste and almost 100% in the case of the Witbank coal wastes) (Table 5.19). In contrast, the higher QXRD values for carbonate mineral values resulted in a similar NP to that obtained for the ANC analysis in the case of the Waterberg slurry waste. A comparison of the QESMCAN and chemical analytical results (Figure 5.12) has indicated that QEMSCAN possibly underestimated the concentration of relatively rapid weathering carbonate minerals, particularly dolomite. Nevertheless, the results indicate that significant quantities of slow weathering silicate minerals may have dissolved under the relatively aggressive ANC test conditions, thus resulting in an overestimation of the acid neutralising capacity under disposal conditions.

Table 5-19 Neutralisation potential for coal waste samples calculated on the basis of mineralogical analysis

Relative Reaction Rates	**Mineral**	**Neutralization potential (kg/t H_2SO_4)**					
		Waterberg Slurry		Witbank Slurry		Witbank Discards	
		QXRD	QEMSCAN	QXRD	QEMSCAN	QXRD	QEMSCAN
Rapid	Calcite	25.68	27.20	0.20	0.12	0.00	0.00
	Dolomite	80.82	-	0.60	-	0.00	-
Intermediate	Amphiboles	-	7.06	-	0.59	-	0.06
Slow	Apatite	-	0.20	-	2.05	-	0.30
	K-feldspar	-	48.68	-	15.48	-	25.33
	Fe-oxyhdroxide	-	0.02	-		-	0.79
	Muscovite	-	5.17	-	2.78	7.72	4.17
Total		106.50	88.31	0.72	21.02	7.72	29.86

Despite the discrepancies in the quantitative data, the mineralogical analysis resulted in a similar classification for all wastes on the basis of the net NAPP values, i.e. Waterberg slurry waste is NAF and the Witbank coal wastes are PAF (see Table 5.20). The ARD classification on the basis of mineralogy was also consistent with that obtained from static chemical tests in the case of the Waterberg slurry and Witbank discard wastes (Figure 5.13). However, classification of the Witbank slurry waste was inconclusive in the case of the Witbank slurry waste. NAPP results derived from the mineralogical results were generally higher than those obtained from chemical static tests, with the exception of the values derived from the QXRD analysis for the Waterberg slurry waste.

Table 5-20 Classification of ARD potential calculated from mineralogy of coal samples

Sample	**QEMSCAN Mineralogy**			**QXRD Mineralogy**	
	NAPP (kg H_2SO_4/ton)		ARD Class	NAPP (kg H_2SO_4/ton)	ARD Class
	Total NP	Rapid NP			
A	-45.10	-8.95	NAF	-96.64	NAF
B	8.93	29.95	PAF	15.72	PAF
C	20.34	50.11	PAF	23.66	PAF

iii Biokinetic test results

The time-related pH profiles for the biokinetic tests are presented in Figure 5.17. These results indicate that, despite the relatively high sulphide sulphur content and maximum potential acidity, the Waterberg slurry sample is net acid neutralising under the non-pH controlled biokinetic conditions, with the pH remaining above neutral for the duration of the test period. This is consisitent with the results of the static chemcial tests and mineralogy-based assessment, (Table 5.20 and Figure 5.13), and can be attributed to the high acid neutralising capacity of the sample. The relatively low redox potentials (< 350 mV vs SHE) observed through the duration of the test were consisitent with the absence of microbial catalytic activity. It should, however, be noted that under conditions where the pH was controlled at a pH of 2.0, the acid neutralising capacity of the sample became depleted within 4 days, followed by an increase in the redox potential to 700 mV, indicative of microbial catalytic activity. These results indicate that the sample could become net acid generating if exposed to acidic conditions.

Consistent with the static tests and mineralogical analysis, the time-related pH profile for the biokinetic test is indicative of the relatively low acid neutralising capacity of the Witbank slurry wastes, with the pH increasing to only 2.9 after day 2 of the biokinetic test. This neutralising capacity is, furthermore, rapidly depleted, with the sample becoming net acid generating over the 4-22 day period. A rapid increase in the redox potential to >700mV over this period is, furthemore, consistent with microbially assisted pyrite oxidation. However, this was followed by a prolonged period (22-100 days) in which the pH gradually increased and the sample exhibited acid neutralising behaviour. These test results confirm that the acid generating potential of the Witbank slurry waste is likely to vary with time and be highly dependant on test conditions.

The initial pH profiles of the Witbank discard waste are similar to those obtained for the slurry waste, except that the pH values are generally lower for the discard waste, and there is very little evidence of long-term acid neutralising behaviour, with the pH remaining very acidic (<2) for the duration of the test period. This can be attributed to the higher content of acid-forming sulphur, and is consistent with the potentially acid-forming classification of the sample on the basis of static test and results and mineralogy-based assessments.

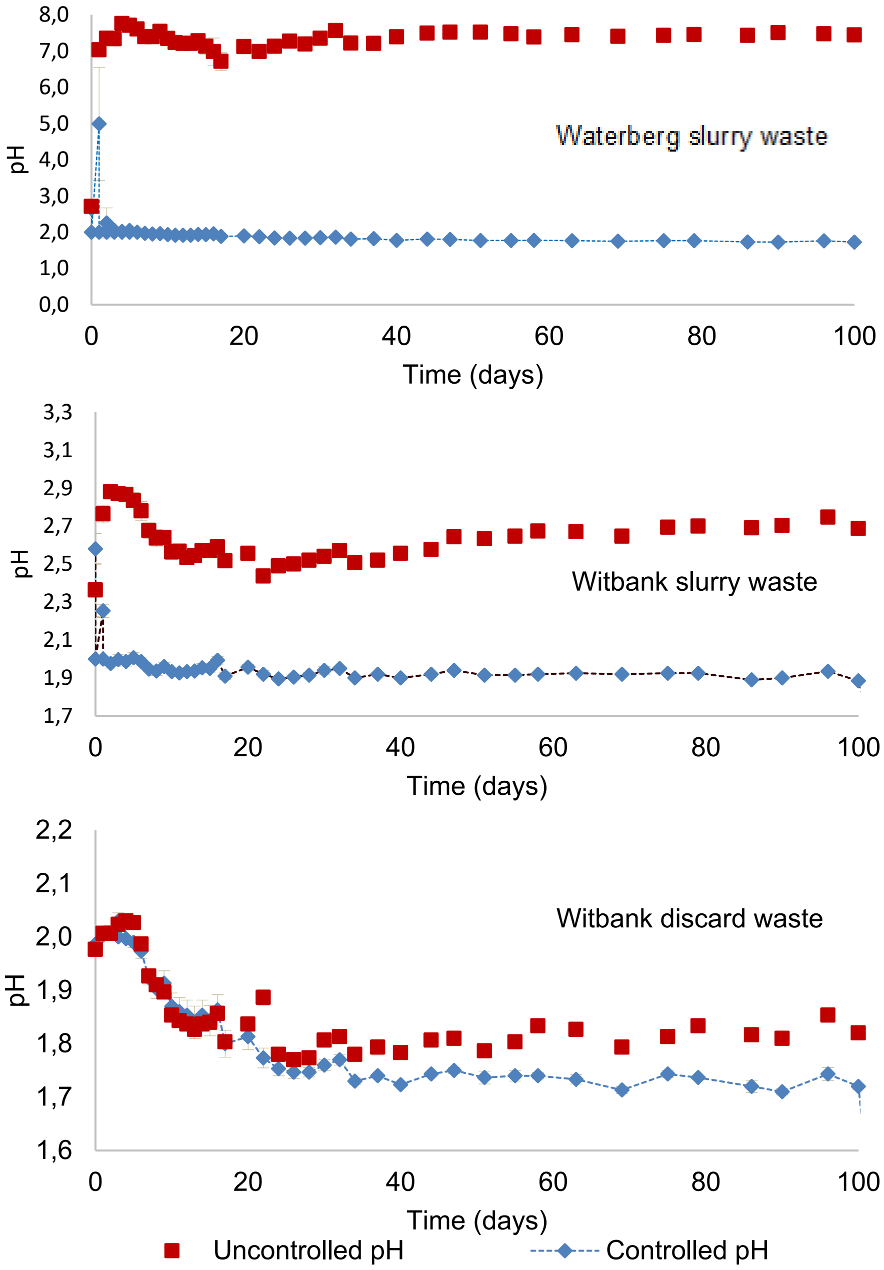


Figure 5-17 pH profiles for the pH controlled and uncontrolled batch biokinetic tests

In light of the discrepancies associated with the neutralisation potential of the coal slurry wastes, and the need to develop a better understanding of the availability of acid neutralising capacity, ANC tests were conducted on the biokinetic test residues in accordance with the standard ABA method. The results in Table 5.21 indicate that the ANC is only partially depleted under biokinetic test conditions (30% and 65% in the case of the Waterberg slurry waste under uncontrolled and controlled pH conditions respectively; between 12% and 13% for the Witbank slurry waste; and between 24% and 27% for the Witbank discards). The differences between the uncontrolled and controlled pH tests for the Waterberg slurry waste can be attributed to the neutral pH conditions of the uncontrolled test, under which limited weathering of potentially neutralising minerals may be expected. Similarly, the higher depletion of ANC for the Witbank discards relatively to the slurry waste can be attributed to the lower pH, and hence more aggressive weathering conditions, in the case of the highly acid generating Witbank discards. A comparison with the mineralogy-derived NP values (Table 5.19) indicates that partial weathering of intermediate and slow weathering neutralising minerals under biokinetic test conditions is likely to have taken place. However, these results also confirm that the standard ANC tests tend to result in a significant overestimation of the neutralising capacity of coal wastes, even under conditions of microbially catalysed sulphide oxidation.

Table 5-21 Results of ANC tests on the residues from the Biokinetic tests

Sample	Feed ANC (kg/t H_2SO_4)	Residual ANC (kg/t H_2SO_4)		ANC depletion (kg/t H_2SO_4)	
		Uncontrolled pH	Controlled pH	Uncontrolled pH	Controlled pH
Waterberg slurry	102.30	70.90	36.35	31.40	65.95
Witbank slurry	29.21	25.46	25.25	3.75	3.96
Witbank discard	29.10	21.02	22.00	8.08	7.10

5.2.2.3 *Metal toxicity and salinity water-related risk potential*

In accordance with the method outlined in Section 5.2.1, sequential chemical extraction (SCE) tests were conducted on the three coal wastes to provide information on the potential availability of elements under various leach conditions, and the results from the SCE tests then used to rank the elements according to their relative significance in terms of potential water-related environmental risk, through the application of a relatively simple ranking and scoring protocol.

i Element partitioning and availability

- Major and minor elements

The partitioning of major and minor elements to the various SCE fractions is represented graphically in Figure 5.18. The partitioning of the majority of the Si, Al, Ti and K to the residual fraction is consistent with the QEMSCAN results, which indicate that these minerals are mainly present as inert silicates and oxides, such as rutile (see Figure 5.10). Similarly, the portioning of Fe in the SCE tests is consistent with its deportment as oxide and sulphide minerals. However, in contrast to QEMSCAN results, the partitioning of significant quantities of Ca and Mg to the water soluble and exchangeable fractions (equivalent to 80%) in the case of the slurry wastes is indicative of their occurrence as readily reactive and available salts, such as sulphates and possibly partially weathered carbonates. The partial deportment of sulphur to water soluble and exchangeable fractions (equivalent to 15% to 25%) is consistent with the results from chemical sulphur species analysis and confirms the presence of sulphur as soluble sulphates. SCE results also indicate that P, Ba and Sr are mainly associated with the sulphide/organic and residual phases. Whilst a significant fraction (approximately 63%) of the manganese in the discards is associated with the relatively inert residual fraction in the slurry wastes manganese appears to be present as, or associated with, soluble salts (exchangeable fraction), carbonates, oxides and, to a lesser extent, sulphide minerals.

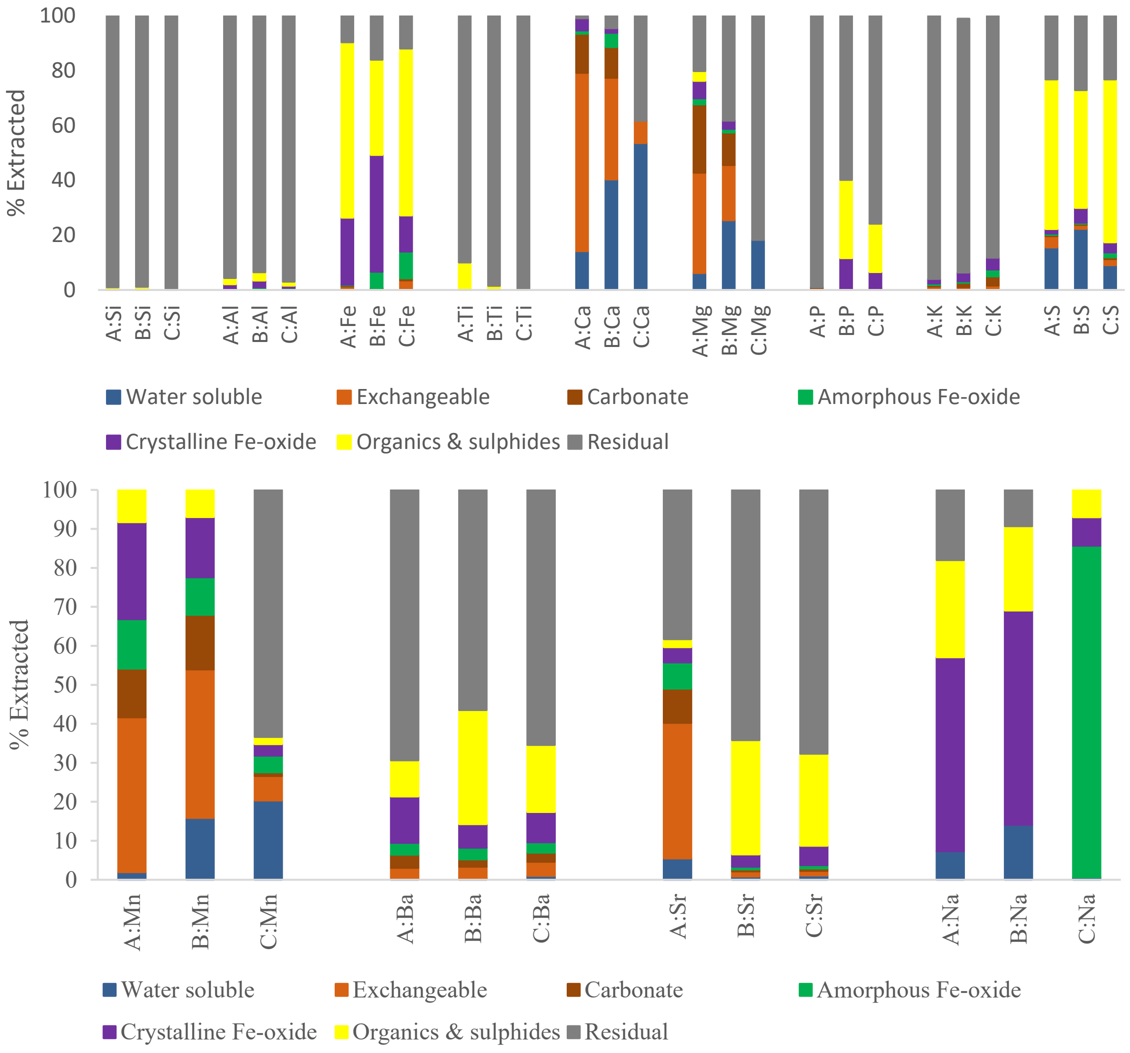


Figure 5-18 Partitioning of major and minor elements to the SCE fractions (A=Waterberg slurry; B=Witbank slurry and C=Witbank discards)

On the basis of these results, the concentrations of potentially available major and minor elements under various leach or weathering conditions have been calculated and are presented in Table 5.22. The results in Table 5.22 are indicative of relatively high available concentrations (> 10 000 mg/kg) of S and, particularly in the case of Waterberg slurry waste, Ca and Mg, even under mild neutral leach conditions. Available Fe concentrations are also relatively high under oxidising leach conditions for all waste samples. The relatively high available concentrations of Ca, Mg and Mn in the Waterberg slurry waste relative to the Witbank coal wastes is consistent with their higher total concentrations levels (see Table 5.14), coupled with their occurrence in relatively reactive forms (see Figure 5.17).

Table 5-22 Potentially available concentration of major and minor elements in coal waste samples A under neutral, acid and oxidising leaching conditions

	Waterberg Coal Slurry			**Witbank Coal Slurry**			**Witbank Coal Discards**		
	Neutral Leach[1]	Acid Leach[2]	Oxidising Leach[3]	Neutral Leach[1]	Acid Leach[2]	Oxidising Leach[3]	Neutral Leach[1]	Acid Leach[2]	Oxidising Leach[3]
Major elements in mg/kg									
Si	53.54	626.46	1350.96	27.10	462.36	1160.61	24.75	557.24	1136.49
Al	165.98	899.47	1878.47	216.97	2122.61	4013.61	556.77	1203.32	2311.07
Fe	437.25	8966.81	30744.31	75.84	7575.60	12918.10	598.32	4625.37	14985.37
Ti	0.75	2.21	269.40	0.43	1.87	70.76	0.39	1.16	25.67
Ca	18539.75	23186.65	23186.65	4236.20	5225.87	5225.87	252.33	252.33	252.33
Mg	2317.80	4132.76	4326.81	623.74	845.45	845.45	84.03	84.03	84.03
P	0.00	1.41	1.41	0.00	112.80	390.58	0.00	21.17	78.17
K	85.13	283.66	283.66	80.50	282.12	282.12	45.04	303.83	303.83
S	10818.88	12271.72	42346.65	7549.83	9499.09	23144.05	6557.01	10110.20	44642.06
Minor elements in mg/kg									
Mn	253.37	557.56	607.81	57.30	98.81	106.18	16.74	21.88	23.04
Ba	34.48	240.24	344.69	29.72	126.53	385.69	14.80	55.60	110.68
Sr	66.36	98.40	101.75	9.40	28.47	157.02	2.74	10.53	39.10
Na	23.51	183.29	263.30	55.60	271.90	357.18	8.23	1191.35	1280.89

1. Accumulative concentration of elements in the water soluble and exchangeable fractions (1 and 2)
2. Accumulative concentration of elements in the water soluble, exchangeable, carbonate and oxide fractions (1-5)
3. Accumulative concentration of elements in all fractions except the residual fraction (i.e. 1-6)

- Trace elements

The partitioning of major and minor elements to the various SCE fractions is represented in Figure 5.19.

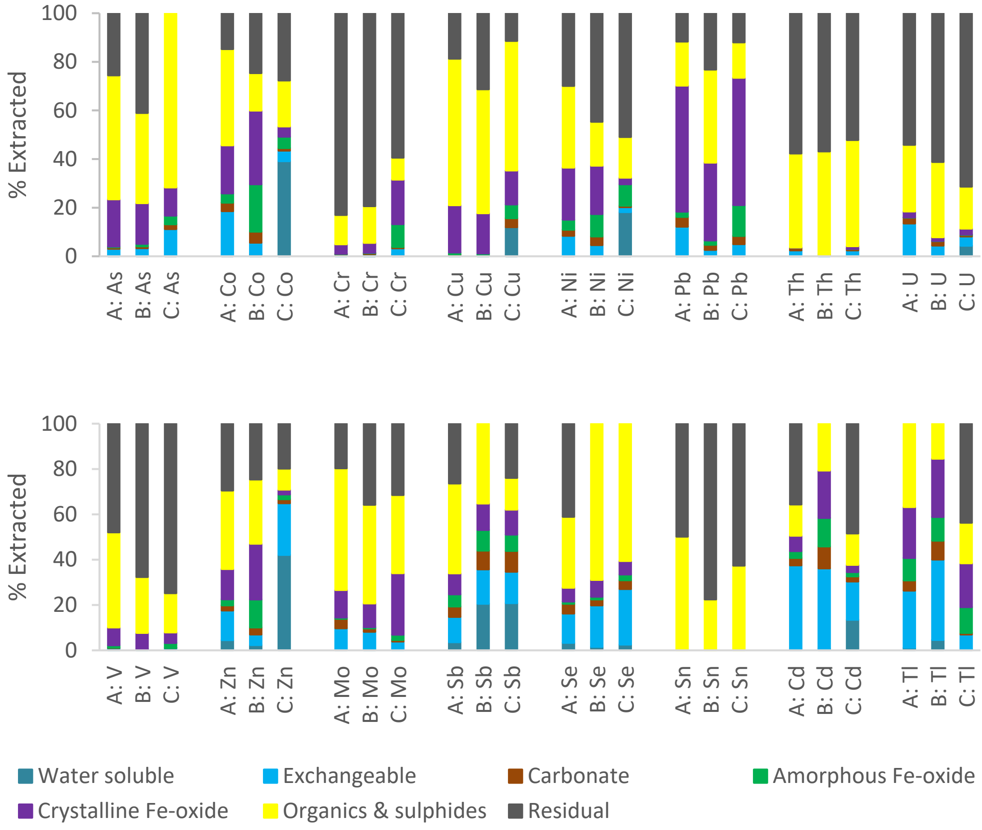


Figure 5-19 Partitioning of trace elements to the SCE fractions (A=Waterberg slurry; B=Witbank slurry and C=Witbank discards)

These results indicate, that in contrast to the major and metal elements, trace elements generally deport across all seven SCE fractions, although in most cases the majority (60% to 90%) occurs in the sulphide/organic (fraction 6) and residual (fraction 7) phases. Exceptions are Sb, Cd, Tl and, in the case of the discards, Zn, a significant fraction of which occur as, or are associated with, relatively reactive water soluble and exchangeable minerals. The results in Figure 5.19 also indicate that significant quantities of Pb are present as oxide minerals and/or associated with Fe oxide minerals

The concentrations of potentially available trace elements under various leach or weathering conditions are presented in Table 5.23. These results indicate that the available concentrations are relatively low for the majority of the trace elements, even under oxidising leach conditions. Elements with significant available concentrations (> 10 ppm) include B and Zn for all leach conditions; Ni and Pb under both non-oxidising and oxidising acidic leach conditions; and Ce, Co and V only under oxidising leach conditions.

Table 5.23 Potentially available concentrations of trace elements in coal waste samples under neutral, acid and oxidising leach conditions

	Waterberg coal slurry			Witbank coal slurry			Witbank coal discards		
	Neutral Leach[1]	Acid Leach[2]	Oxidising Leach[3]	Neutral Leach[1]	Acid Leach[2]	Oxidising Leach[3]	Neutral Leach[1]	Acid Leach[2]	Oxidising Leach[3]
As	0.32	2.41	7.64	0.24	1.53	4.13	0.45	1.14	4.02
B	12.20	16.65	27.10	6.27	9.58	17.87	7.66	9.93	14.39
Be	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.19	0.19
Bi	n/a	n/a	0.32	n/a	n/a	0.09	n/a	n/a	0.70
Cd	0.16	0.21	0.27	0.07	0.15	0.19	0.10	0.13	0.18
Ce	n/a	n/a	8.19	n/a	n/a	36.53	n/a	n/a	28.20
Co	3.06	7.51	14.01	0.57	6.11	7.68	2.72	3.34	4.52
Cr	0.59	3.98	13.71	0.65	3.98	14.88	3.54	34.03	43.73
Cs	n/a	n/a	0.60	n/a	n/a	1.54	n/a	n/a	0.90
Cu	0.17	7.73	29.92	0.03	7.04	27.21	3.04	8.93	22.39
Ga	n/a	n/a	2.36	n/a	n/a	4.28	n/a	n/a	2.65
Hg	0.02	0.04	0.21	0.00	0.04	0.35	0.00	0.04	0.24
In	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.40
Li	0.09	0.67	2.36	0.10	4.05	4.05	1.26	4.81	8.32
Mo	0.44	1.20	3.62	0.29	0.74	2.28	0.35	3.08	6.19
Ni	2.94	12.73	24.45	1.40	11.26	16.70	6.14	9.82	14.90
Pb	3.48	20.00	25.17	0.88	12.79	25.51	1.40	20.61	24.70
Sb	0.40	0.91	1.98	0.59	1.07	1.64	0.58	1.04	1.28
Se	0.33	0.57	1.21	0.24	0.38	1.21	0.22	0.32	0.81
Sn	0.00	0.00	2.30	0.00	0.00	0.98	0.00	0.00	0.68
Th	0.27	0.39	4.59	0.06	0.09	7.75	0.44	0.74	8.52
Tl	0.07	0.18	0.28	0.06	0.14	0.16	0.02	0.13	0.19
U	0.54	0.74	1.83	0.23	0.41	2.03	0.37	0.52	1.30
V	0.88	8.74	45.13	0.10	5.37	22.53	0.58	4.70	14.95
Zn	17.92	36.57	71.85	3.00	20.21	32.39	48.97	53.50	60.45

1. Accumulative concentration of elements in the water soluble and exchangeable fractions (1 and 2)
2. Accumulative concentration of elements in the water soluble, exchangeable, carbonate and oxide fractions (1-5)
3. Accumulative concentration of elements in all fractions except the residual fraction (i.e. 1-6)

ii Ranking and scoring potential risks

Elements in the coal samples were ranked and scored in accordance with the environmental water-related risk potentials, calculated on the basis of available concentrations levels, typical drinking water limits and average crustal abundance levels as per Equation [5.3] in Section 5.1. The results are summarised in Table 5.24.

The results indicate that no elements pose a high risk in the Witbank slurry waste under any leach conditions. Fe poses a potentially high risk in Waterberg slurry and Witbank discards and a moderate risk in the Witbank slurry waste under oxidising conditions and a moderate risk in all wastes under non-oxidising acid leach conditions. Other elements posing a moderate environmental risk include Mn (Waterberg slurry waste; all leach conditions); Pb (both non-oxidising and oxidising leach conditions for all coal waste samples), S (oxidising leach conditions for all coal waste samples), Sb (oxidising leach conditions for all coal waste samples); Al (Both coal slurry wastes; oxidising leach conditions) and Hg (Witbank coal slurry waste; oxidising leach conditions). Risks from Fe and Al relate largely to physical and aesthetic effects, whilst Mn, Pb, Sb and Hg are all potentially toxic to mammals and eco-systems. Salinity of water sources is mainly as a result of elevated concentrations of soluble sulphates.

Table 5.24 Identification of significant elements on the basis of potential environmental risk under neutral, acid and oxidising leach conditions

Sample	Environmental Risk Potential (ERP/1000)		
	Low (ERP/1000 = 0.1-1)	Moderate (ERP/1000=1-10)	High (ERP/1000 = 10-100)
Neutral leach conditions[1]			
Waterberg slurry	S, Ca, Sb, Pb	Mn	-
Witbank slurry	S, Sb	-	-
Witbank discard	S, Sb	-	-
Acid leach conditions[2]			
Waterberg slurry	S, Sb, Ca, As, Ba, Se, Al	Mn, Fe, Pb	-
Witbank slurry	Mn, S, Sb, As, Al	Fe, Pb	-
Witbank discard	S, Sb, Al, Mo, Cr	Fe, Pb	-
Oxidising leach conditions[3]			
Waterberg slurry	Se, Hg, Al, Ba, Ca, Ni, Mo, B, U, V, Cd	Mn, Pb, S, Sb, Al	Fe
Witbank slurry	As, Se, Ba, Mn, Ni, U	Fe, Pb, S, Sb, Al, Hg	-
Witbank discard	Hg, AS, Mo, Al, Se, Cr, Ni	S, Pb, Sb	Fe

1. Accumulative concentration of elements in the water soluble and exchangeable fractions (1 and 2)
2. Accumulative concentration of elements in the water soluble, exchangeable, carbonate and oxide fractions (1-5)
3. Accumulative concentration of elements in all fractions except the residual fraction (i.e. 1-6)

5.3 Summary

The results of this study show that application of a combination of laboratory-scale tests and analytical methods needs to be applied to mine wastes, such as coal processing wastes, in order to develop a comprehensive understanding of the key properties of environmental significance.

This study has also shown that chemical static acid base accounting (ABA) and net acid generation (NAG) tests are simple and fast tools for characterising the acid rock drainage (ARD) potential of coal processing wastes, but the classification of some samples may be uncertain. The relatively aggressive conditions of the static chemical tests can cause reaction of acid-forming sulphur species and non-carbonate acid neutralising minerals, thus underestimating and overestimating the acid neutralising capacity (ANC) and net acid producing potential (NAPP) respectively. Similarly, formation of organic acids can cause an overestimation of net acid generating (NAG) capacity, and an extended boil step may thus be required in order to decompose organics prior to back-titrating. As sulphur in coal is present in different forms, only some of which are acid-forming, sulphur speciation is of critical importance when calculating the maximum acid potential (MPA). The study also showed the total sulphur in coal wastes can be reliably evaluated using the standard LECO combustion method, whilst both the ISO157:1996 and the ACARP C15034 protocols can be used to determine the various forms in which sulphur is present. The ISO method was found to be less reliable though, as it entails a number of simplifying assumptions, and does not distinguish between acid-forming and non-acid forming sulphates. Nevertheless, differences in the calculated MPA derived from these two methods were not significant. Both biokinetic tests and mineralogical analysis can be used to compliment and validate chemical static tests, the biokinetic test providing a rapid method for assessing the time-related behaviour of coal wastes under conditions of microbial activity. Both of these techniques require further development to maximise their potential, however. A flow-through biokinetic test would provide a more rigorous understanding of the acid generating behaviour under the type of conditions occurring in a disposal scenario, whilst a more rigorous and quantitative analysis of mineralogical composition could provide further information on the components controlling the acid-forming and neutralising reactions. Sequential chemical extraction tests can, furthermore, be combined with a relatively simple ranking and scoring method to identify elements of potential environmental significance under various weathering conditions.

The results of this study show that South African coal processing wastes contain significant quantities of sulphur in the form of sulphide sulphur (0.55% to 1.13%) and are enriched in a number of trace elements, including Mo, In, Pb, Sn, Sb, Ge, Cs, Ce, U, Th and, in particular Bi and Se. Static chemical and biokinetic tests for characterising acid rock drainage potential indicated that the Waterberg slurry waste sample is potentially non-acid forming, the Witbank discard sample potentially acid forming, and the Witbank slurry waste sample uncertain in terms of ARD classification. Elements identified as being of potential environmental significance under acid generating conditions for the wastes include iron, sulphur, lead, antimony, and in certain cases arsenic, manganese and mercury. The results of this study also emphasised the variability in the environmental characteristics of the coal wastes, making it important to characterise samples on a case-by-case basis. The coal waste elemental compositions may be in similar ranges, but there can be significant differences in the relative concentrations of minerals, and in their acid generating properties and specific environmental risks.

CHAPTER 6: CONCLUSIONS AND RECOMMNEDATIONS

Whilst contributing significantly to the economies of mineral-rich countries such as South Africa and Zambia, the resource extraction sector is also responsible for a disproportionately large impact on the environment. Part of the environmental impact is related to the large volumes of mine waste that the industry produces, which are typically condemned to landfill. The responsibility of these deposits have traditionally been externalised, leading to prolonged pollution and significant inter- and intra-generational liabilities. An alternative management approach, and one that is more consistent with the goals of sustainable development, focuses on the generation of wastes that can be re-purposed for other uses, thus minimising or completely eliminating the volume of waste disposed to landfill. This study set out to support the development and implementation of such an approach for the management of large volume mine waste in the Southern African context, by developing an enhanced understanding of (i) the environmental and social risks associated with mine waste deposits; (ii) the opportunities for mine waste re-purposing or valorisation; (iii) the factors constraining and/or driving the implementation of opportunities identified in (ii); and (iv) potential roles of the relevant stakeholders in enabling implementation of identified opportunities.

To this end, the study made use of both primary and secondary quantitative and qualitative data, generated through a combination of experimental testwork, reviews of published literature and semi-structured interviews with relevant stakeholders. The study scope was divided into three inter-related but discrete programmes as described in Chapter 1 (Background), each comprising specific case studies. A detailed synthesis of the outcomes of these programmes is provided in Chapters 2 to 5 of this report. This chapter summarises the key findings of the study with respect to the specific aims as outlined in points (i) to (iv) above (Section 6.1), and makes recommendations for further studies (Section 6.2).

6.1 Conclusions

6.1.1 Impacts and liabilities associated with mine waste deposits

A review of the published literature, as well as interviews with stakeholders in the Mpumalanga Coalfields, the Witwatersrand Basin Goldfields and the Zambian Copperbelt, bears testimony to the adverse impacts of mining on the surrounding environment and on the quality of lives and livelihoods of local communities. Mine waste deposits were identified as a major source of these impacts, mainly as a result of contaminated effluent and wind-blown dust emissions. Of particular concern to local communities in all three case studies was the exposure of humans and livestock to metals contained in contaminated water, soils, crops and dust. Although data directly linking health and other impacts to specific mine waste deposits is limited, these concerns are largely supported by reports in the literature, which show that the weathering of mine wastes can result in metal-rich drainage and airborne particulates, and that the inhalation of air borne contaminants and the ingestion of water and food containing metals can give rise to significant human and animal health issues. Water-borne metal contamination is of particular concern for sulphide-bearing wastes, as the weathering of these minerals gives rise to acid, which enhances the mobilisation of metals and salts. The characterisation testwork conducted in this study confirmed that coal processing wastes generated in the Mpumalanga coalfield region are potentially acid generating and contain elevated concentrations of a number of trace elements, including Mo, In, Pb, Sn, As, Sb, Ge, Cs, Ce, U, Th and, in particular, Bi and Se. Elements in coal processing wastes posing a potential risk to water quality under acidic conditions include Fe, S, Mn, Pb, Sb and, in some cases, Al and Hg. Other concerns associated with mine wastes include siltation of rivers, due to direct discharge of tailings in the Zambian Copperbelt, and the potential health effects associated with the informal mining and direct combustion of coal from defunct coal dumps in Mpumalanga. The case studies, particularly the gold tailings study in the Witwatersrand basin, highlighted the long-term impacts of mine waste dumps and the difficulties in maintaining reasonable buffer zones between human settlements and defunct mine waste dumps in perpetuity.

Apart from the above-mentioned concerns and experiences, the case studies also indicated that communities, community-support organisations and environmental consultants do not consider that either the governments or the mining industry are doing enough to mitigate the environmental and associated social impacts, associated with mining operations, particularly in terms of rehabilitation of contaminated land and defunct mine dumps. Increasing public knowledge and awareness of these impacts, at least in South Africa, can be largely attributed to the activities of the relatively large number of civil society organisations that now exist with the purpose of protecting the local environment and communities against "injustices" by mining companies. In general, communities and community-support organisations feel that are not been taken seriously, and that government and industry are failing to alleviate the environmental degradation and human suffering in the mining regions. These findings are consistent with global trends, which show environmental pollution to be the most common cause of mine-community conflict globally. These conflicts can furthermore have significant financial implications, particularly where they lead to delayed start-ups and unscheduled shut-downs.

6.1.2 Mine waste valorisation as an alternative approach

Historically, approaches for managing environmental risks associated with mine waste dumps largely involved collection and active treatment of contaminated leachate, with a view to preventing subsequent dispersion of contaminants into the surrounding environment. Although still quite widely applied in practise, this type of end-of-pipe approach has become increasingly unacceptable. Focus over the past decade or two has thus shifted towards prevention of environmental risks by control at source (i.e. at the waste dump itself), through implementation of site selection, design, management and rehabilitation measures. These measures are, however, not always consistently applied, and even in the best cases, have yet to be proven effective in creating what one might term a "walk-away" situation – one that delivers a maintenance free, self-sustaining site which complies with acceptable environmental standards over the long-term without further intervention. In many cases, remediation may be insufficient to deal with long-term degradation, while a loss of societal memory can mean that the sites may be excavated in the future, re-exposing the waste body to the elements. Hence, whilst the traditional waste remediation practices are effective in the short term, they tend to extend the risks that waste pose into the future. The land disposal of mine wastes also represents a loss of valuable natural resources, including water, land and mined minerals. Even where mine dumps are reprocessed to recover targeted resources such as gold, PGMs and even coal, the bulk of the mined resources remains condemned to disposal as unwanted material. This loss of resources, coupled with the often excessive clean-up and site maintenance costs, not to mention the potential "costs of conflict", means that the indirect costs of land disposal may far exceed the direct costs associated with the construction of waste impoundments, particularly over the long-term. This is because the time-scales involved normally span decades and even centuries, making mine waste disposal both a post-mine closure and an inter-generational issue.

An alternative approach is to consider mine waste as a secondary resource which can be re-allocated as feedstock for other uses and purposes, as opposed to unwanted or displaced material requiring disposal. By simultaneously minimising waste burden and maximising efficient utilisation of mined resources, this so-called "valorisation" approach goes beyond the recovery of targeted metals for economic gains, consistent with the principles of resource efficiency, industrial economy and the circular economy. A detailed review of available information, derived from both published literature and expert interviews, on valorisation opportunities for gold and coal processing wastes indicated that mine tailings have found fairly wide application as backfill for mines, and to a lesser extent, in construction or for landscaping. Other potential applications proposed for the re-purposing of gold tailings include the manufacture of ceramics and stone paper, whilst coal processing wastes can potentially be used in the fabrication or amelioration of soils, and the manufacture of niche by-products such as pigments, coagulants for wastewater and sulphuric acid.

Apart from reducing the waste burden on the environment and recovering resources from a material that has already been mined and processed, the re-allocation of mine waste for other purposes can also reduce the occupation of land, making it available for other uses, whilst contributing to the local economy by creating additional business and employment opportunities. Despite these advantages, the review conducted here has indicated that there has been little systematic development and commercial implementation of mine waste valorisation options, particularly in the South African context.

6.1.3 Barriers and enablers for the transfer of mine waste valorisation options

This study adopted a barriers and enablers approach to the development of a better understanding of the factors both constraining and driving the implementation of opportunities for mine waste valorisation, with specific focus on gold mine tailings and coal processing wastes in the South African context. The main influencing factors identified include: the availability of proven technology; the legislative and regulatory climate; health, safety and environmental issues; corporate culture and values; and economic feasibility

According to the respondents interviewed, the biggest determinant of the success of mine waste valorisation options pertains to the techno-economic viability of the technology. In order to be considered viable, mine waste valorisation options need to be more cost-effective than conventional disposal. This can be a particularly significant constraint in cases involving new or innovative technologies and processes, as the costs and financial risks associated with development and transfer of unproven technology can be significant.

Furthermore, whilst the re-purposing of mine waste may remove the environmental and social risks associated with land disposal, the potential health, safety and environmental risks and liabilities associated with the re-processing and utilisation of the waste can also be a barrier to mine waste valorisation. Currently, the lack of adequate information and data on the compositions and properties of mine wastes creates uncertainties around the ability to produce products of the required quality, and the environmental and health risks associated with their processing and use. New waste regulations to promote the re-use of listed mine wastes requires a risk assessment to demonstrate that the use of mine waste will not impact on the environment. In this regard, the experimental study conducted here showed that a combination of laboratory-scale tests and analytical methods is required to effectively and reliably characterise the environmentally significant properties of mine wastes, such as coal processing wastes. The testwork also highlighted some of the uncertainties and deficiencies with respect to current characterisation tools, particularly with regards to laboratory tests and mineralogical analysis to characterise the potential acid generating behaviour. The laboratory-scale tests also showed how the characteristics of coal processing wastes from different sources may vary, highlighting the need to assess wastes on a case-by-case basis.

In theory, legislation was considered to be a driver to the implementation of more responsible mine waste management. In practice, however, South African legislation provides little incentive and support for companies to adopt new and innovative mine waste valorisation options, with regulations on waste remaining very restrictive, particularly in terms of re-use options, and compliance onerous. This is despite the fact that community and community-support organisations are of the opinion that government departments in South Africa and Zambia are not doing enough to enforce regulations, and that mining companies are exploiting this situation. The lack of legislative incentives in combination with other external pressures facing the mining industry, is having an adverse impact on the sector’s risk appetite and the desire or ability to invest in the transfer of innovative approaches to mine wastes.

6.1.4 Developing and implementing mine waste valorisation approaches and technologies

Overcoming the above-mentioned barriers and challenges is not a trivial matter and is going to require effective communication and collaborative partnerships between all potential stakeholders in the technology innovation chain, particularly the developers, sponsors and adopters. Good working relationships, communication and trust between these stakeholders are imperative, as is the need to demonstrate efficacy. Whilst academia, government departments and science councils, as well as the mining industry are all potentially key role players, this study also revealed original equipment manufacturers (OEMs) or technology providers to be an important group of stakeholders, who could be potentially be ideally placed to serve as commercial partners for developers, such as a university.

It was also suggested that local mine waste valorisation could be conducted by, or in collaboration with, local communities, thus providing opportunity to simultaneously promote local socio-economic development. Such an approach would be consistent with the call by community and community-support organisations for more active engagement and inclusive partnerships between mining companies and external stakeholders, whilst simultaneously contributing to overcoming the considerable trust deficit that currently exists, mainly on the part of the communities.

Another key issue that emerged was the need to make potential adopters aware that technology works, through forums and workshops, as well as the implementation of pilot or demonstration plants.

6.2 Recommendations

The discussions in Section 6.1 indicate that there is certainly a moral and ethical case for more innovative approaches to mine waste management which focus on the re-purposing of mine wastes to create a minimal or zero waste scenario. However, the successful transfer of these approaches and associated technologies also requires the development of a more rigorous case from a business perspective. Of key importance is the need to demonstrate the efficacy of potentially viable options and develop operating parameters on a case-by-case basis. This will require laboratory and subsequent pilot-scale studies on those options identified as being potentially viable on a case-by-case basis.

There is also a need to develop a more detailed understanding of the techno-economic performance of different waste management approaches, particularly in terms of the indirect, and less tangible, costs relating to long-term environmental degradation and related socio-economic costs (such as health care, loss of income, costs of mine-community conflicts and reputational damage) that are typically externalised by conventional economic models and criteria. Such a study should also aim to develop a better understanding of the value of mine wastes that extends beyond sale revenue, by taking into account the utilisation of resources (energy, water, land, materials) associated with their production and disposal.

The use of mine wastes as secondary resources also requires that these material be adequately characterised, both in terms of their ability to generate products of adequate quality and the environmental and health risks associated with their processing and utilisation. Currently mine wastes are poorly characterised, the characterisation protocols fraught with uncertain and inaccuracies, and the health and environmental implications not well understood. This creates difficulties in assessing and justifying potentially viable management options and alternatives.

Last but not least, it is clear that the successful transfer of processes and technologies for more sustainable mine waste management requires the establishment of effective partnerships between the various stakeholders, right from the early prospecting and development stages. It is furthermore suggested that this would best be achieved through the establishment of a multi-stakeholder body, with representatives from all stakeholder groups including mining houses, government, research organisations, OEMs, business and community representatives. This body would provide a platform for communication between different role players (developers, sponsors and potential adopters), and opportunity to discuss developmental needs and concerns about technical and market risk. Such a body would be similar to the multi-stakeholder Mine Water Coordinating Body, established to address mine water challenges on a national level.

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APPENDIX A DETAILED METHODOLOGIES FOR THE CASE STUDIES ON THE RELATIONSHIP BETWEEN MINING, ENVIRONMENTAL DEGRADATION AND COMMUNITY QUALITY OF LIFE

A.1 Coal Case Study: Mpumalanga, South Africa

A.1.1 Interview process

Stakeholder engagement took the form of semi-structured interviews, allowing further interaction and discussion of responses. Prior to the interviews, participants were contacted by e-mail requesting their participation in the study and providing them with a brief project background. A questionnaire (see interview schedule below) was developed to facilitate the interview process. Part A of the questionnaire consisted of pre-set variables from which participants had to rate their responses using a Likert scale, whilst part B consisted of simple but comprehensive open ended questions which allowed participants to express their views and understanding of the impacts and risks associated with coal mining. Prior to conducting the interviews, the research abstract, a copy of the consent form, and the interview schedule were made available to the participants to ensure that they understood the objectives of the study and to give them the opportunity to ask any questions about the project and their participation. Participants were informed of the procedures regarding confidentiality and of the audio-recording of interviews. This ensured that they made an informed decision to participate voluntarily. The anonymity of was guaranteed, and the researcher did not collect data that was outside the purpose of the research.

Of the 10 interviews conducted, nine were conducted face-to-face and one took the form of an electronic interview, involving a combination of e-mail and telephonic correspondence. The interviews lasted between 45 minutes and one hour and were conducted at the participants’ preferred location. One interview took the form of a group discussion with three community representatives after conducting a field tour around the Witbank (eMalahleni) area in Mpumalanga. Participants did not have to fill-in or do any writing except for signing an informed consent form prior to undertaking the interviews. All the face-to-face interviews were audio-recorded and later transcribed for purposes of accurate interpretation and quoting where applicable.

The research complied with the ethical practises as prescribed by the University of Cape Town. Prior to data collection, and to ensure compliance, the proposed research was reviewed and approved by the Engineering and Built Environment Ethics in Research Committee (EiRC).

A.1.3 Interview schedule

a. *Survey Questionnaire – Section A*

As part of the study, a list of variables (risks/impacts) has been compiled to assess perceptions and understanding. Based on experience, observation and practice would you say that coal mining influences on the variables listed and to what degree? This will require you to rate your responses. Rate the risk/impacts from 1-5 with 5 been a very high risk and 1 being a very low risk/impact. Place a cross under the relevant response.

Risk/Impact	1	2	3	4	5
Land occupation/loss					
Subsidence (ground stability)					
Land pollution and erosion					
Air pollution					
Dust					
Water consumption					
Surface water quality					
Underground water quality					
Human health					
Livestock production and health					
Soil fertility					
Crop production and health					
Aquatic life and health					

c. *Interview Questionnaire – Section B*

Based on your responses in Section A, please answer the following questions:

1. What is your current understanding of the following risks and impacts in relation to coal mining?

a) Land occupation/loss

b) Subsidence (ground stability)

c) Land pollution and erosion

d) Air pollution

e) Water consumption

f) Water quality

g) Human health

h) Livestock production and health

i) Soil fertility

j) Crop production and health

k) Aquatic life and health

2. Are there any other impacts and risks relating to coal mining that you are aware of? If yes, please provide additional details.

3. Would you say these risks/impacts affect you and/or the community at large? If yes, please give details on the effects and specific incidents of which you are aware.

4. Have these concerns or incidents been reported; how and to whom? Give details on your response.

5. Have these concerns been attended to or are there any plans in place? Give details on your response.

6. What roles do you think that government, mining corporations and civil society should be playing in addressing the impacts and liabilities associated with (a) active coal mines (b) abandoned coal mines?

7. What are your future expectations regarding coal mining and the associated risks and impacts in the community (s)?

e. *Participant details*

Selected participants included community members (participants 1-2, with participant 2 comprising a group of 3 community activists), representatives of civil society organisations (CSOs, participants 3, 4, 5, 9 and 10) and professional environmental consultants (participants 6, 7 and 8) actively involved in services and programmes relating to environmental and social justice in the context of coal mining within the Mpumalanga Province. Further details pertaining to the participants are presented in below:

Participant ID	Organisation	Location	Role/ Level of Expertise
Participant 1	Community	Mpumalanga	Activist in affected communities
Participant 2: (in individual capacities as part of a group)	Community Community Community	Mpumalanga Gauteng Mpumalanga	Activist in affected communities Community Liaison Activist in affected communities
Participant 3	CSO	Gauteng	Education & organisation of affected communities in Mpumalanga
Participant 4	CSO	Gauteng	Lead researcher on community impacts associated with mining, including coal mining in Mpumalanga
Participant 5	CSO	Gauteng	CEO with extensive experience in human rights advocacy and environmental risks in mining affected communities
Participant 6	Environment Consultancy	Gauteng	Considerable experience and expertise in environmental issues associated with impacts associated with the mining sector
Participant 7	Environmental & Social Services Consultancy (Mineral resources)	Gauteng	CEO/Expert in environmental and social impact assessments in Mpumalanga
Participant 8	Environment Consultancy	Gauteng	Expert in water and energy-related issues associated with mining, including coal mining in Mpumalanga
Participant 9	CSO	Western Cape	Head of mining sector/expertise in environmental litigation, with experience in Mpumalanga
Participant 10	CSO	KwaZulu-Natal	Considerable experience on environmental and social issues associated with impacts associated with the coal mining sector

Participants 1 and 2 (group) were representatives of coal mining communities, whilst participants 4 to 10 were representatives of civil society organisations (non-governmental and non-profit organisations) and consultancies.

A.2 Gold Tailings Case Study: Davidsonville, South Africa

a. *Interview process*

Semi-structured interviews were conducted with relevant stakeholders active within the Davidsonville area. During the course of the interview, participants were asked to rate specific impacts and risks arising from the Princess gold tailings dam. Following this rating and ranking (from 1: no impact to 5: very high impact), participants were encouraged to expand on their experiences and perceptions on these risks and impacts, using open-ended questions. A questionnaire was used to guide the interview process.

Risk/Impact	1	2	3	4	5
Air quality					
Water quality					
Soil fertility					
Crop production					
Health of natural ecosystems					
Human health					
Land loss/occupation					
Tailings dump overflow/leakage					
Tailings dump material erosion					
Metal contamination					
Human quality of life					

b. *Interview Questions*

1. What is your current understanding of the following risks/impacts in relation to impacts associated with the gold tailings dump?
   - Air pollution (includes dust)
   - Water pollution (underground and surface water)
   - Soil pollution
   - Soil erosion
   - Land loss/occupation
   - Crop production and health
   - Human health
   - Tailings dump overflow/leakage
2. Are there any other risks/impacts relating to metal contamination by gold tailings dump that you are aware of? If yes, please provide additional details.
3. Would you say these risks/impacts affect you and/or the community at large? If yes, please give details on the effects and specific incidents of which you are aware of.

Before conducting the interviews, a copy of the abstract, consent form and the questionnaire were made available to the participants. Prior to data collection, and to ensure compliance with ethics policies of the university, the proposed research was reviewed and approved by the Engineering and Built Environment Ethics in Research Committee (EiRC). All interviews were transcribed and analysed for themes.

d. *Participant details*

Interviews were conducted with seven participants, including 3 Davidsonville community members, 2 representatives from non-profit organisations supporting the Davidsonville community (CSOs) and 2 environmental consultants active in the area. Details on participants are provided in the table overleaf.

Participant ID	Organisation	Location	Role/ Level of Expertise
Participant 1	Community	Gauteng	Activist in affected communities
Participant 2	Community	Gauteng	Activist in affected communities
Participant 3	Community	Gauteng	Community member
Participant 4	Community support organisation	Gauteng	Lead researcher on community impacts associated with mining
Participant 5	Community support organisation	Gauteng	CEO and environmental and human right activist in mining affected communities
Participant 6	Environment Consultancy	Gauteng	Considerable experience and expertise on environmental issues associated with impacts associated with the mining sector
Participant 7	Environmental & Social Services Consultancy	Gauteng	CEO/Expert in environmental and social impact assessments

A.3 Zambian Copperbelt Study

A.3.1 Interview process

The interview process was facilitated by the developed questionnaire (below). Section A of the questionnaire consisted of pre-set variables from which participants had to rate their responses whilst part B consisted of simple but comprehensive open-ended questions which allowed participants to express their views and understanding of the impacts and risks associated with copper mining in the selected region. Before conducting the interviews, a copy of the abstract, consent form and the questionnaire were made available to the participants to make sure they had and understanding of the objectives of the study and to give them the opportunity to ask questions relating to the project and their participation. Participants were notified of the procedures with regard to confidentiality and of the subsequent audio-recording of interviews. This enabled the participants to voluntarily take part with an informed decision. The researcher did not collect data that was outside the purpose of the research.

The selected participants included eight representatives from the community (participants 5-14), one representative from a community support organisations (CSO) (participant 1), environmental consultants working in the area (participant 3 and 4), and one representative from the Konkola Copper Mines (participant 2). The interviews with the community representatives were conducted in two groups; one group comprised 4 members from the community around the Mopani Copper Mines, and the other group comprised 4 members from the community around the Konkola Copper Mines. The remaining six interviews were conducted individually. Participants did not have to fill in or do any writing except for signing the informed consent form prior to undertaking the interviews. All the face-to-face interviews were audio-recorded and later transcribed using NVivo software for purposes of better interpretation and citing. Prior to data collection, and to ensure compliance with ethics policies of the university, the proposed research was reviewed and approved by the Engineering and Built Environment Ethics in Research Committee (EiRC).

A.3.2 Interview Schedule

a. *Survey Questionnaire – Section A*

Risk ratings: 1= nor risk, 2 = low risk; 3 = high risk, 4= very high risk and 5=critical risk

IMPACTS	**1**	**2**	**3**	**4**	**5**
a) Water pollution					
b) Air pollution					
c) Soil Contamination					
d) Vibrations					
e) Geotechnical Issues					
f) Siltation					
g) Land degradation					

b. *Interview Questionnaire – Section B*

B.1. Impacts

1. What impacts have been reported as a result of mine waste from copper mining at Mopani Copper Mines or Konkola Copper Mines? (Tick the applicable boxes below)

   ☐ Water

   ☐ Air

   ☐ Soil Contamination

   ☐ Vibrations

   ☐ Geotechnical Issues

2. What risks have these impacts had on the community? (Tick the applicable boxes below)

   ☐ Human health issues

   ☐ Loss of livelihood

   ☐ Loss of hunting skills

   ☐ Land erosion

   ☐ Surface water quality

   ☐ Ground water quality

   ☐ Livestock and production

   ☐ Soil fertility

3. What actions have been taken by the government, the community, mining houses and the community based organisations to address these incidences?
4. How does the community and community based organisations perceive or understand the mine-environment-community cause-chain effect?
5. Have any concerns been raised by other stakeholders apart from mining houses with regard to the impacts of copper mining?
6. Which statement best describes how you feel about impacts of copper mining?

   ☐ I am not aware of any risks

   ☐ I only know about some of the risks

   ☐ I know about most of the risks

   ☐ I already know everything I need to know about the risks

B.2 Conflicts and expectations

1. In your view what are the major causes of company-community conflict as a result of impacts of copper mining?

1. What impacts of copper mining, causing conflict have been reported in the last 5 years?

2. What has been the response of the mining houses?

3. What has been the response of the government?

4. What has been the response of the community and civil society?

5. Do you think there is necessary government legislation to curb the impact of copper mining?

6. Have there been any responses or interventions/initiatives by the mining houses to reduce impacts of mining? If yes what have been the interventions?

7. What roles do you think that government, mining houses and civil society should be playing in addressing the impacts and liabilities associated with copper mines?

8. What are your future expectations with regard to copper mining and the associated impacts on the community?

APPENDIX B TOXICITY OF SELECTED METALS

B.1 Lead

Lead is abundant and occurs as metallic lead, inorganic ions or salts (Harrison, 2001). It is a toxicologically relevant element that has been brought in huge amounts and distributed to the environment by humans. This is despite lead having low geochemical mobility (Morais et al., 2012). Lead has no vital function in a human body but it can have a toxic effect irrespective of the exposure pathway. One of the major sources of lead exposure is food (that is, lead contaminated vegetation or animal foods) and other sources are through the air, soil and drinking water. Contaminated soils pose a risk through direct ingestion, uptake in vegetable gardens or trailing into households. Soils that are contaminated contains lead concentrations that are less than 50 ppm with the Environmental Protection Agency's standard for lead in bare soil in play areas is 400 ppm by weight (ATSDR, 2012). In water the maximum contaminant goal is zero and the maximum is 10 µg/L (WHO, 2004, ATSDR, 2012). When inhaled, about 20 to 50% inorganic lead is absorbed and when ingested about 5 to 15% of inorganic lead is absorbed (Morais et al., 2012). On the other hand, organic lead is absorbed readily when ingested and about 80% is absorbed when inhaled. Lead is primarily distributed among blood, soft tissue, and mineralizing tissue once it has entered the bloodstream (Ming-Ho, 2005). Children are particularly sensitive because of their developing nervous system that is associated with more rapid growth rate and metabolism (ATSDR, 2007; Castro-González and Méndez-Armenta, 2008). When exposed to lead, children can suffer from reduced physical and mental growth and may have a lower intelligence quotient (IQ). During pregnancy, lead can be passed on to the child from the mother and when breastfeeding (WHO, 2011). Lead is neurotoxic, which means it destroys brain and nerve cells and can cause irreversible neurological damage (ATSDR, 2012). Exposure to lead is also been associated with attention deficit hyperactivity disorder and antisocial behaviour. Lead has been determined to be a probable human carcinogen by the Environmental Protection Agency.

B.2 Cadmium

Cadmium occurs naturally in the environment. It is found in the air, soils, sediments and in unpolluted seawater (Morais et al., 2012). Recently the use of cadmium has increased due to increasing technological use hence consideration has been given to cadmium as a possible contaminant. Although most countries have strict controls for the emissions of metals, cadmium is discharged to the air by mines, metal smelters and industries using cadmium compounds for alloys, batteries, pigments and in plastics (Harrison, 2001). One of the largest sources of cadmium exposure in humans is tobacco smoking (Ming-Ho, 2005). Other than smoking, food products account for most of the human exposure to cadmium (Morais et al., 2012). This is due to the fact that the cadmium ions are readily absorbed by plants and equally distributed over the plant. As a result, people are exposed to cadmium when consuming plant-based and animal-based foods. As recommended by the World Health Organisation, the threshold for cadmium in soils is 0.007 ppm (JEFCA, 2004). The EPA maximum contaminant level for cadmium in drinking water is 5 µg/L whereas the WHO adopted the provisional guideline of 3 µg/L (WHO, 2004). Cadmium has the ability to accumulate in human bodies affecting the organs negatively. Organs that can be affected and/or damaged are: liver, kidneys, lungs, bones, placenta, brain and central nervous system (Castro-Gonzalez and Mendez-Armenta, 2008). Other damages include reproductive, and development toxicity, hepatic, haematological and immunological effects (Apostoli and Catalani, 2011; ATSDR, 2008). Cadmium can be passed from mothers to children through breast feeding and during pregnancy can cause negative effects on behaviour and learning, as well as abnormal foetal metabolism, low foetal weight and skeletal deformations.

B.3 Mercury

Found in air, water and soil, mercury is a naturally occurring element. However, coal combustion and gold mining are a source of mercury contamination (Oosthuizen et al., 2010). 45% of the total mercury emissions in Africa are accounted to by gold production from large and small-scale mining (Dabrowski et al., 2008). Mercury is used to bind gold from the ore and then it is burned to recover the gold. This is usually done in artisanal mining. Mercury is toxic even at low concentrations in particular the methylmercury (organic form of mercury) and it can accumulate in fish. Mercury in the human bodies is associated with personality changes, deafness, changes in vision, loss of muscle coordination or tremors, loss of sensation, and difficulties with memory. Mercury can be passed from pregnant mothers to unborn children and also to babies through breast feeding. Children are most sensitive to harmful effects of mercury because of their developing nervous systems, fetuses and children are especially sensitive to the harmful effects of mercury. The current standards for mercury in drinking water were set by EPA and WHO at the very low levels of 2 µg/L and 1 µg/L, respectively (WHO, 2004).

B.4 Arsenic

Arsenic is a metalloid that is rarely found as a free element in the natural environment. It is commonly found as a component of sulfidic ores in which it occurs as metal arsenides (Morais et al., 2012, National Research Council, 1977). Arsenic is associated with geological sources but it is quite widely distributed in natural waters. However, in some localities anthropogenic inputs, such as the use of arsenical insecticides and the combustion of fossil fuels, can be very significant extra sources of arsenic. In natural waters, arsenic occurs in oxidation states III and V, a form of arsenous acid (H_3AsO_3) and its salts, and arsenic acid (H_3AsO_5) and its salts, respectively (Sawyer et al., 2003). Although arsenic occur naturally, human activities, more especially mining and the burning of coal has increased the mobilization of mercury into the environment, as a result elevated amounts in the atmosphere, soils, fresh waters, and oceans. The toxic effects of arsenic depended on oxidation state and chemical species with inorganic arsenic known to cause carcinogenic and are related mainly to lung, kidney, bladder, and skin disorders (Morais et al., 2012; ATSDR, 2003). The toxicity of arsenic in its inorganic form has been known for decades for the following forms: acute toxicity, subchronic toxicity, genetic toxicity, developmental and reproductive toxicity, immunotoxicity, biochemical and cellular toxicity, and chronic toxicity (Sakurai et al., 2004; Mudhoo et al., 2011; Schwarzenegger et al., 2004). One of the primary sources of inorganic arsenic exposure is drinking water (Mudhoo et al., 2011; National Research Council, 2001). Chronic arsenicosis and arsenic toxicity is of a worrying magnitude and is a major environmental health disaster. Carcinogenic and noncarcinogenic health effects are known to be caused by chronic arsenic ingestion of drinking water. Chronic arsenic ingestion from drinking water has been found to cause carcinogenic and noncarcinogenic health effects in humans (ATSDR, 2003; Mudhoo et al., 2011; Morais et al., 2012). The maximum contaminant limit of arsenic in drinking water is 10 µg/L as per WHO guidelines and USEPA in 2001 (USEPA, 2005).

APPENDIX C DETAILED METHODOLOGIES FOR THE CASE STUDIES ON MINE WASTE VALORISATION IN SOUTH AFRICA

C.1 Gold tailings case study

C.1.1 Case study scope

The project aimed to develop an enhanced understanding of the opportunities, enablers and barriers to the utilization and down-stream processing of gold tailings in the context of South Africa. More specifically the study set out to meet the following objectives:

(i) Establish what opportunities exist for the re-use of mining waste with a specific focus on gold tailings

- What are the available alternatives for reusing mining waste in South Africa?
- What potential benefits (e.g. financial, socio-economic) can be gained from the re-use of mining waste?

(ii) Identify the key drivers and constraints to the re-use of mining waste within South Africa

- Are there technological constraints (i.e. lack of technology, inappropriate technology, etc.) to the re-use of mining waste?
- Are there any policies or legislation governing the re-use of mining waste?
- Establish what perceptions exist regarding the re-use of mine waste
- What is the position of the mining companies regarding the re-use of mine waste?

(iii) Establish the role that the relevant stakeholders (i.e. government, mining industry, other industries, e.g. construction, ceramics) need to play in enabling the re-use of mining waste.

(iv) Identify any entrepreneurial opportunities that exist for the re-use of mining waste.

These objectives and research questions were addressed through a desktop study of the published literature and semi-structured interviews with relevant stakeholders.

C.1.2 Literature review

A comprehensive review of published literature (including journal articles, company and research reports, newspaper and magazine articles) was conducted on the re-use of mine tailings, with specific focus on gold tailings, the factors influencing mine waste valorisation within the local gold industry, and the role that various stakeholders play in facilitating the re-use of mine waste.

C.1.3 Stakeholder interviews

Semi-structured interviews were conducted to determine stakeholder awareness, perspectives and concerns regarding the utilisation and processing of mine waste, drivers and or barriers affecting the re-use of mine waste in South Africa, as well as potential participatory roles in the development and implementation of such approaches.

A total of 9 interviews were conducted with selected professionals, including 4 representatives from the mining industry, 3 environmental consultants, 1 legal practitioner and 1 government representative. Details of the participants are presented in the table below.

Participant ID	Summary of expertise
Participant 1	Participant 1 works for a government institution and has significant experience in the waste sector.
Participant 2	Participant 2 has over 10 years' experience in the gold mining industry. Most of the participant's work has focused on dealing with environmental issues coming from gold processing wastes. Participant 2 has previously worked closely with government on quantifying
Participant 3	Participant 3 works for a multinational mining company in a senior managerial position influencing the sustainability strategy approach undertaken by the company.
Participant 4	Participant 4 is a director of a consulting company that focuses on environmental and mine waste management. Most of the participant's work include mine residue disposal, designing and managing tailings storage facilities, rehabilitation and closure design.
Participant 5	Participant 5 is a CEO of an environmental consultancy that provides environmental services to mining industry. The participant is considered an expert in environmental impact assessments, risk assessments, rehabilitation, mine closure issues affecting the mining industry.
Participant 6	Participant 6 has an environmental engineering background and holds a top managerial position in one of the largest multinational mining companies. Areas of expertise include environmental management and impact assessments, rehabilitation and has also been involved in projects that have re-used mine waste.
Participant 7	Participant 7 is a director for an environmental consulting company and specialises on environmental pollution, mine wastewater treatment and designing tailings facilities, environmental and social impact assessments.
Participant 8	Participant 8 works for a gold mining company working mostly on water management and is also a community liaison officer. Before joining the company, the participant worked for a NGO that aimed at creating awareness of mining risks and hazards to communities located closed to mines.
Participant 9	Participant 9 is an in-house legal practitioner working for one of the biggest environmental consultancies. Permission to record the interview was denied and so only scribbled notes from the interview are available.

A questionnaire was constructed for the semi-structured interviews. This was done in order to guide the interview process. However, the extent to which specific questions were addressed differed with each interview, depending on the interviewee's knowledge of the subject area. The semi-structured nature of the interviews also allowed for interaction and further questioning where necessary.

Prior to data collection, and to ensure compliance with ethics policies of the university, the proposed research proposal was reviewed and approved by the Engineering and Built Environment Ethics in Research Committee (EiRC) at the University of Cape Town. The study made use of informed consent, thereby ensuring ethical practices during the project. At the start of each interview, the researcher explained the objectives of the study, outlined the procedures that would be taken to ensure confidentiality, and requested the participants to sign an informed consent form. All research participants were assured of their anonymity and, as such, no direct reference to the participants are made in the research write up. All interviews were recorded and pseudonyms used for all research participants to ensure the protection of their privacy, as some of them shared sensitive information. The data analysis commenced during the interviews, with the researcher noting down specific themes and making notes of key points being discussed. During the transcription of the interviews, the researcher noted down recurring threads and formed preliminary categories as a means of interpretation the data. The transcripts were reviewed again to ensure that the data had been captured appropriately.

Interview Questions

1. What waste management practices are common in South Africa wrt to mine waste?
2. Which options are you using and why? How are decisions made about the relevant waste management options?
3. What opportunities are there for reusing mine waste? What are the available alternatives for reusing mining waste in South Africa?
4. What potential benefits (e.g. financial, socio-economic) can be gained from the re-use of mining waste?
5. What is your position (as an organisation) on reusing gold tailings for other purposes such as road construction, ceramic making, etc.?
6. Have you ever undertaken or are aware of any projects that have re-used gold tailings in South Africa?
    - If so what were the different options?
    - Was the project a success?
    - What was the most challenging aspect about the project?
7. What do you see as incentives and or barriers to reusing gold tailings in South Africa?
8. What would be the most important factors or drivers for reusing mine waste
    - Enabling legislation? Are there any policies or legislation governing the re-use of mining waste?
    - Technology advancement? Are there technological constraints (i.e. lack of technology, inappropriate technology, etc.) to the re-use of mining waste?
    - Are financial benefits and avoiding extra costs important to encourage your organisation to act on environmental issues?
    - Social perspectives? What perceptions exist regarding the re-use of mine waste?
9. From a legal perspective, do you think the legislative promotes/hinders the re-use of gold tailings/mine waste?

10. What are the legal drivers and barriers for re-use? What can be done to promote the re-use of mine waste? What do you think are the appropriate structures (organisational, legislative) that need to in place to allow for re-use of gold tailings.
11. In your opinion, which stakeholders (i.e. government, mining industry, other industries, e.g. construction, ceramics) are important in ensuring the uptake of reusing gold tailings in other industries in South Africa? What role should each stakeholder play?

C.2 Coal processing waste case study

C.2.1 Identification of re-purposing opportunities for coal processing wastes

In the first instance, a literature review was conducted to identify potential options for the re-purposing of coal processing waste. This built on previous reviews conducted under the auspices of the Water Research Commission (Harrison et al., 2013).

Analysis of barriers and enablers for technology transfer

This phase of the case study aimed to develop an understanding of enablers and barriers for the further development and implementation of technologies for the processing of sulphide-rich coal wastes in the South African context, with a view to developing active partnerships and collaboration between the university and the coal mining industry, as well as other relevant stakeholders. Specific research questions include:

- Who are the important stakeholders when considering technology implementation?
- What are the important barriers and enablers of technology transfer in the South African coal mining context?
- How should a university go about transferring technologies delivering beneficial value-from-waste to industry?

Whilst the data from the interviews was analysed in an inductive manner, the outcomes were synthesised with secondary data and information derived from the published literature information. The literature was also consulted so as to develop a better understanding of the generic technology transfer

C.2.2 Stakeholder interviews

The purpose of considering the field of technology transfer for this body of work was to understand driving influences in the coal mining industry from the point of view of people inside it and those serving it. This included understanding attitudes towards value from waste technology, as well as considering ways to increase the likelihood of successful transfer of value from waste technologies to the South African coal mining sector. Participants were selected based on the need to have representation by a variety of individuals active in the industry and so, rather than being chosen based on statistical grounds, were based on the practical grounds of access and stakeholder representation. Stakeholder groups were identified in the literature review, and individuals from each stakeholder group were identified with the help of academics and industry professionals.

Stakeholder group	number
Executives from major mining companies	6
Executives from junior mining companies	2
Individuals who have successfully transferred technology	2
Consultants to the mining industry	4
People active in coal-related research	2

The interviews were semi-structured to get a rich response, while still focussing on specific aspects.

Interview Questions

1. Introduction – who I am, this is for a PhD, privacy/disclaimer, what is the importance of processing sulphide-rich waste,
2. How do you make the decision to pilot a new technology?
3. How do you make the decision to implement a new technology?
4. What if someone from outside the company wants to implement?
5. What does the process of bringing a technology to implementation look like in most mines?
6. How do you fund your projects?
7. Which industry players would be the most likely to implement? Mines? Boutique waste processors?
8. Do you think the process of implementation will be easy or difficult?
9. What are the most important barriers to implementation?
10. Which are the most important drivers of implementation?
11. How would the barriers and drivers be different for different implementers?
12. What do you think needs to happen for implementation to become more likely or easy?
13. Are there any stakeholders whose buy-in is especially important?
14. Have you implemented and what were the issues?
15. Do you think that reprocessing coal tailings for other purposes is a good idea?
16. Questions should be more from lit – consider using table on barriers and enablers as a prompt.
17. Would you be willing to receive a follow-up phone call to respond to the results of this study?

The questions were worded in a concise and to-the-point manner to avoid confusion, only one concept was probed per question and effort was taken to not make the questions leading. Since a semi-structured interview method was followed, the order of the questions was changed to follow the flow of the conversation. Interviews were mainly conducted over the phone or using Skype calls. In four cases, however, the interviews were conducted in person due to the respondents' preferences. In two cases the respondent invited other experts to the interview, creating mini focus groups. The interviews were recorded for completeness and transcribed using NVivo software to enable identification and analysis of all the main themes of the conversation. This was done to remove any researcher memory and preference bias, which may impact data gathered using notes. The data gathered was analysed using thematic analysis. The interview data was analysed in an inductive manner, meaning that prior theory was not taken into consideration in the analysis.

APPENDIX D A REVIEW AND ANALYSIS OF POLICY AND LEGISLATION OF RELEVANCE TO MINE WASTES

Legislation plays a crucial role in facilitating mine waste re-use, providing either motivation for, or constraining implementation of innovative processes for the re-purposing of the large volume wastes produced during extraction and primary processing of mineral resources. In this regard, a detailed review of South African policy and legislation of relevance to the bulk re-use or re-purposing of mine wastes, either with or without prior processing, has been carried out in consultation with specialists in environmental law, with a view to identifying the current regulatory drivers and/or constraints.

D.1 The current legislative framework

Mines and their operations are regulated by the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA), which is enforced by the Department of Mineral Resources. As part of the 'One Environmental System', legislation drawn up by the Department of Environmental Affairs is implemented by the Department of Mineral Resources for mining related authorisations (NEMA S24C; Waste Act S43(1A); Air Quality Act S40(3A)). The Department of Environmental Affairs is, however, still the appeal authority for environmental matters (NEMA S24C(2C(a))). Therefore, environmental issues, while under the authority of the Department of Mineral Resources, are regulated by the National Environmental Management Act 107 of 1998 (NEMA), the National Environmental Management: Waste Act 59 of 2008 (Waste Act) and the National Environmental Management: Air Quality Act no 39 of 2004 (Air Quality Act). Water-related issues are under the authority of Minister of Water Affairs and Forestry and are regulated by the National Water Act No 36 of 1998 (Water Act).

Proposed amendments to the Waste Act will see residue stockpiles and residue deposits regulated under NEMA and not the Waste Act as is currently the case (Diemont et al., 2017). This should streamline environmental authorisations and make it easier to obtain permission to backfill mines with waste rock or tailings.

Mine waste is referred to as 'residue stockpiles' and 'residue deposits' in the MPRDA, NEMA and the Waste Act, although the position of the MPRDA is not clear and is discussed in the following section. It is considered a special class of waste in the Waste Act and has separate regulations regulating the condition of its disposal. However, according to the Regulations Regarding the Planning and Management of Residue Stockpiles and Residue Deposits 2015, the hazard classification of residue stockpiles and deposits are done in the same way that other wastes are classified. When the residue stockpiles and residue deposits contain hazardous components, the same regulations control the requirements for safe disposal as other hazardous waste.

> *"residue stockpile" means any debris, discard, tailings, slimes, screening, slurry, waste rock, foundry sand, beneficiation plant waste, ash or any other product derived from or incidental to a mining operation and which is stockpiled, stored or accumulated for potential re-use, or which is disposed of, by the holder of a mining right, mining permit, production right or an old order right;*
>
> *"residue deposit" means any residue stockpile remaining at the termination, cancellation or expiry of a prospecting right, mining right, mining permit, exploration right, production right or an old order right;"*

The aim of the MPRDA is to *“make provision for equitable access to and sustainable development of the nation's mineral and petroleum resources”*. Another express object of the MPRDA is to promote economic growth and mineral resource development in the Republic. These aims are consistent with the development of resource-efficient management approaches to large-volume mine waste, in line with the principles of cleaner production, the circular economy and industrial ecology. However, as highlighted by Humby (2016), the option of using mining waste for non-mineral related purposes is not specifically addressed in current mining legislation, and there is no clear authority if a non-mineral use is decided upon. The implementation of options for the re-use or re-purposing of mine wastes is thus likely to be subject to the regulations stipulated by the current MPRDA, NEMA, Waste Act and Water Act, or future amendments thereof. Sub-sections (i) to (v) provide a more detailed discussion of the legislation applicable to the management and handling of mine waste, as summarised in Table D1.

Table: D-1 Relevant legislation and their short names for this analysis

Legislation	Short name
Mineral and Petroleum Resources Development Act 28 of 2002	MPRDA
National Environmental Management Act 107 of 1998	NEMA
National Environmental Management Act, 1998 Financial Provisioning Regulations, 2015	Financial Provisioning Regulations
National Environmental Management: Waste Act 59 of 2008	Waste Act
National Environmental Management: Waste Act, 2008 Regulations Regarding the Planning and Management of Residue Stockpiles and Residue Deposits from a Prospecting, Mining, Exploration or Production Operation	Regulations Regarding the Planning and Management of Residue Stockpiles and Residue Deposits 2015
National Water Act no 36 of 1998	Water Act
National Environmental Management: Air Quality Act no 39 of 2004	Air Quality Act

D.1.1 Mining and prospecting rights under the MPRDA

The MPRDA regulates mining and petroleum production in terms of the acquisition and exercise of the right to prospect and mine and matters relating thereto. In terms of the MPRDA the Minister of Mineral Resources may grant Prospecting Rights, Retention Permits, Mining Permits and Mining Rights. It prohibits, in Section 5A, prospecting for, removal, mining or production of any mineral, defined below, or commencement with any work incidental thereto on an area, without a) an environmental authorisation; b) a prospecting right, permission to remove, mining right, mining permit as the case may be; and c) giving the landowner or lawful occupier at least 21 days written notice. Prospecting and mining rights entitles the holder thereof to prospect for or mine the mineral on the land for which the relevant rights have been granted S5(3)(b). Section 5A, prohibits prospecting for, removal, mining or production of any mineral without a corresponding prospecting right, mining right or mining permit.

The MPRDA defines "mineral" as follows:

> *"**mineral**" means any substance, whether in solid, liquid or gaseous form, occurring naturally in or on the earth or in or under water and which was formed by or subjected to a geological process, and includes sand, stone, rock, gravel, clay, soil and any mineral occurring in residue stockpiles or in residue deposits, but excludes-*

> *(a) water, other than water taken from land or sea for the extraction of any mineral from such water; (b) petroleum; or (c) peat*

In terms of this definition all minerals occurring in residue stockpiles and in residue deposits are minerals for purposes of the MPRDA. The question that is raised is whether the utilisation of the minerals occurring in residue deposits and in residue stockpiles as feedstock for other purposes, either with without prior extraction, will require a mining right in terms of the MPRDA. The answer to this question, in the context of treating mining waste, hangs on (i) the definition of residue stockpiles and residue deposits (definitions above) and (ii) on the definition of "mine" as a verb.

The term "mine", when used as a verb is defined as follows:

> *"(b) used as a verb, in the mining of any mineral, in or under the earth, water or any residue deposit, whether by underground or open working or otherwise and includes any operation or activity incidental thereto, in, on or under the relevant mining area;"*

The definition of 'residue stockpile' includes materials that are common forms of mine waste and adds the qualification that these be "*stockpiled, stored or accumulated for potential re-use, or which is disposed of, by the holder of a mining right*". In other words, the material must be stored or stockpiled with a view to re-use or it must be disposed of. Disposal can mean either discarding or transferring of ownership (called 'alienation' in legal parlance). It is noted that in Section 11 of the act, the words 'disposed of' are used alongside 'alienated' and as a form of alienation when considering the transfer of a mining or prospecting right. In line with these definitions, it is likely that a mining right would be required to extract a mineral from mine waste, regardless of the downstream use. This would for instance apply in the case of the two-stage separation process to simultaneously recover value and remove ARD generating sulphide minerals from the processing of coal and sulfidic hard-rock ores. In such cases, an external party wishing to process the mine waste for environmental reasons would either need to do it under the current mine's mining right or wait until the mine closes and receives a closure certificate. At this point the mine's residue stockpiles become residue deposits and a mining right for the minerals can be applied for. Furthermore, should an entity be interested in recovering minerals from an existing residue deposit, a prospecting right will probably need to be applied for before prospecting at the site can begin, if no other entity holds a right or permit for the same mineral and land (S16). The definition of prospecting does, however, state that it is done: "*in or on any residue stockpile or residue deposit, in order to establish the existence of any mineral and to determine the extent and economic value thereof*". It thus stands to reason that incidental 'prospecting' could be done without a right, but it is not clear whether one would need a prospecting right to conduct the necessary calculations for profitability if the data is obtained from environmental monitoring operations. It should be noted that a prospecting right grants the holder the sole and exclusive right to apply for and be granted a mining right in respect of the mineral and land. Clearly, the process of applying for a mining right is administratively cumbersome and this requirement is a barrier for implementing processes entailing the pre-separation of minerals, such as the two-stage flotation process proposed by the University of Cape Town. Furthermore, it is not clear whether, or under what conditions, a mining or prospecting licence will be required in the event that the waste is used as feed for other applications without any prior separation or removal of specific minerals.

A potential solution, not currently considered under the MPRDA, would be to create a separate category of 'mineral' for which a mining right need not be applied. An example of creating a separate class of mineral can be found in the Minerals Act 50 of 1991 (now repealed), which states in S5(2b)

> *"the occupier of land who otherwise lawfully takes sand, stone, rock, gravel, clay or soil for farming purposes or for the effecting of improvements in connection with such purposes on such land, shall not require any such authorization and the provisions of this Act shall not be applicable in any such case".*

Schedule S5(3) of the same act states that

> *"Any person mining any mineral under a mining authorization may, while mining such mineral, also mine and dispose of any other mineral in respect of which he is not the holder of the right thereto, but which must of necessity be mined together with the first-mentioned mineral",*

clearly showing that creating separate classes of minerals is possible. Another alternative that has not been explored thus far is to consider mine waste such as tailings as a movable asset in terms of the law (De Beers Consolidated Mines Ltd vs. Ataqua Mining (Pty) Ltd and Others of 2007), which means that one could potentially process it without a mining right. This is a legally legitimate argument as a mining right technically only applies to taking material from the ground. However, applying this approach to mineral processing in general could open the possibilities for fraud and be in conflict with Section 5A of the MPRDA, if a right for an important mineral extracted is not obtained and the tailings is sold on to a processor who doesn't declare the materials. Such an argument is thus unlikely to hold water in a court of law.

D.1.2 Environmental legislation and regulations under NEMA

NEMA regulates all activities that may have impact on the environment and it has the purpose of minimising environmental damage and promoting environmental protection. It regulates, amongst other things, the granting of environmental authorisations as well as the content of Environmental Impact Assessments (EIAs), fleshed out in Environmental Impact Assessment Regulations, 2014, and Environmental Management Programmes (EMPs). Its focus appears to be pollution prevention and assigning responsibility for pumping of contaminated mine waters (S24N(7f)) (Humby, 2016).

According to NEMA (S24N(1A)), an environmental management programme (EMP) is required in cases where an EIA has been done before environmental authorisation can be granted. An EMP (S24N(2)) must show how environmental impacts identified in the EIA will be minimised throughout the lifecycle of the mine. Details of the specific activities that will be required, the individuals responsible for the activities as well as the monitoring regime must be included amongst other requirements. NEMA does not specify in the Act itself to what standards environmental harm is to be prevented or what standard of environmental neglect allowed in the EMP will lead to a refusal of environmental authorisation. It only states that the EMP must make clear how the holder of the right intend to "*comply with any prescribed environmental management standards or practices."* (S24N(2giii)). There are no standards specified in NEMA, so this probably refers to requirements in the Waste Act, Water Act, Air Quality Act, and their supporting regulations.

Similarly, rehabilitation requirements are unclear, since it specifies that land must but rehabilitated "to its natural or predetermined state or to a land use which conforms to the generally accepted principle of sustainable development" (S24N(2f)&(7e)). It also uses phrases such as "as far as reasonably practicable" (S24N(2f)&(7e)) in relation to site rehabilitation, which opens the Act to a wide range of interpretations and possibly therefore to large variations in the quality of rehabilitation plans. This was evident in the Environmental Management Plans and Programmes submitted under the MPRDA, before environmental regulation was placed under NEMA (Van Zyl et al., 2012). More details on site rehabilitation requirements are provided in the Financial Provisioning Regulations, that state in Appendix 4 (paragraph 3c(iv) and 3e(i)) that the final rehabilitated state should be set based on the final land use that is decided upon in consultation with stakeholders. This, once again, leaves the rehabilitation requirements open to interpretation. It has also been noted that a possible weakness of NEMA is that it states that the environment needs to be rehabilitated, but doesn't explicitly state that residue stockpiles and deposits need to be rehabilitated (Humby, 2016). These ambiguities and uncertainties make it difficult to justify implementation of environmental risk removal approaches that go beyond currently accepted standards, particularly where such approaches may entail additional capital or operating costs in the short-term or incur other risks of a reputational or legal nature.

Despite the lack of clarity in NEMA regarding site rehabilitation, directors of the entities that hold the mining or prospecting rights or permits are personally liable for environmental damage (S24N(8)). The clause states that they are liable for damage caused *"by the company or close corporation which they represent*", without limiting the time frame. Damage only discovered after the director's term could therefore still be prosecuted. The director liability may create support for technology to improve environmental characteristics of waste and reduce the volume of waste. Similarly, the risks of having to increase financial provision to remediate potential latent environmental damage associated with waste piles could also provide motivation for more pro-active approaches which avoid or minimise the amount of waste disposed to landfill. According to Section 24(1), financial provision for rehabilitation needs to be in place before the Minister grants environmental authorisation and the projected required financial provision must be reassessed annually (S24(3a)). This section makes provision for increasing the financial provision "*to the satisfaction of the Minister"*, but not for reducing the financial provision, and entitles the Minister to retain a part of the financial provision for remediating latent environmental damage (S24(5)). The main aim for the financial provisioning regulations is to specify how financial provisioning for site rehabilitation needs to be done. To do this, however, the subjects of annual rehabilitation plans; final rehabilitation, decommissioning and mine closure plans; care and maintenance plan; and environmental risk assessment reports are covered. From these, it seems that the final rehabilitated state of the mine is determined by the post-rehabilitation land use (Appendix 4 par2), supposedly set through stakeholder engagement (Appendix 4 par3(c(iv))). Once again the word "practicable" (Appendix 4 par3(d(iii))) makes the standards uncertain. A company also needs to explain why risks could not be managed (Appendix 5 par3(b(iii)).

D.2 Waste management legislation and regulations under the Waste Act

The Waste Act is of direct relevance to the re-purposing of mine waste as it explicitly focuses on waste management and de-risking. The Minister of Minerals and Energy is identified as the authority with regards to waste management activities related to prospecting, extraction and primary processing of mineral or petroleum resources as well as residue stockpiles and residue deposits in the Waste Act (S43(1A)). Residue stockpiles and residue deposits that contain hazardous components are also explicitly included in the definition of hazardous waste (Schedule 3, Category 1). This makes the stipulations regarding waste in the Act applicable to residue stockpiles and residue deposits as well. According to the Act, waste disposal must be licensed and may not pollute the environment or affect health (S26(1)).

In accordance with the definitions in the Waste act (below), the re-use or re-purposing of mine waste can be seen as recycling or both treatment and recycling, if the re-use involves a pre-separation step:

> ***"Recycle"*** *means a process where waste is reclaimed for further use, which process involves the separation of waste from a waste stream for further use and the processing of that separated material as a product or raw material*
>
> ***"Treatment"*** *means any method, technique or process that is designed to (a) change the physical, biological or chemical character or composition of a waste; or (b) remove, separate, concentrate or recover a hazardous or toxic component of a waste; or (c) destroy or reduce the toxicity of a waste in order to minimise the impact of the waste on the environment prior to further use or disposal;*

The definitions of recycling and treatment implies that recycling requires the act of 'further use' of the material, while the minimisation of environmental impact is an element of treatment. The definition does make clear, however, that treated waste can be further used. If the product streams from the two-stage flotation process are used, the process would probably need to conform to the requirements for recycling as well as treatment.

The Waste Act acknowledges the importance of recycling and re-using in the Preamble, but arguably makes recycling onerous by requiring that "the reduction, re-use, recycling or recovery of the waste – a) uses less natural resources than disposal of such waste; and (b) to the extent that it is possible, is less harmful to the environment than the disposal of such waste" (S17(1)). Waste management license and basic environmental assessment are also needed (Schedule 1, Category A (4)). In terms of Schedule 1, Category A, a basic assessment (S24(5)) would be required for a treatment facility that uses "biological, physical or physicochemical" methods and requires no demonstration that less natural resources is used in the process. This makes the treatment of hazardous waste legally less difficult than recycling, but the Act does not explicitly state how the use of treated waste should be handled.

Should the owner of the waste decide to stockpile rather than treat or recycle, there are requirements to be met as well. Construction of residue stockpiles require a waste management license and an EIA to be conducted (Schedule 1, Category B (4)&(5)). According to the act, "[r]esidue stockpiles and residue deposits must be managed in the prescribed manner" (S43A(1)). This requirement is fleshed out in the supporting Regulations Regarding the Planning and Management of Residue Stockpiles and Residue Deposits 2015. However, residue stockpiles and residue deposits is included in the definition of hazardous waste to the extent that they contain hazardous waste, which is defined below (Schedule 3, Category 1). Therefore, additional requirements are applicable to waste that is identified as hazardous.

> ***"Hazardous waste****" means any waste that contains organic or inorganic elements or compounds that may, owing to the inherent physical, chemical or toxicological characteristics of that waste, have a detrimental impact on health and the environment and includes hazardous substances, materials or objects within business waste, residue deposits and residue stockpiles*

Regulations regarding the planning and management of residue stockpiles and residue deposits 2015 specify practical issues regarding designing, constructing, operating and closing a residue stockpile. For example, it stipulates how to choose a site (Regulation 6), characterise the residue material (Regulation 4) and design a stockpile (Regulation 7). The regulations don't give definite requirements and references other acts for that. For instance, the requirements of the National Water Act, 1998 must be considered in the design of storm water systems. The legislation that must be taken into consideration according to the regulations is shown in Table D2.

Table: D-2 Legislation referenced in the Regulations Regarding the Planning and Management of Residue Stockpiles and Residue Deposits 2015

Aspect of residue stockpile	**Relevant legislation**
Storm water systems	National Water Act, 1998
Water purification standards	Government Notice or Regulation No. 991 of 18 May 1984
Pollution control barrier system	National Norms and Standards for Assessment of Waste for Landfill Disposal, 2013 National Norms and Standards for Disposal of Waste to Landfill, 2013
Dust	Mine Health and Safety Act, 1996 (Act No. 29 of 1996) National Environmental Management Air Quality Act, 2004 (Act No. 39 of 2004)

What these regulations make clear is that i) disposing of mining waste is not less burdensome than disposing of other waste and ii) the level of risk associated with the waste influences the measures that are required to be taken to construct and manage the facility. For instance, the requirement that the waste facility conform to National Norms and Standards for Assessment of Waste and for the Disposal of Waste to Landfill. *The National Norms and Standards for Assessment of Waste for Landfill Disposal 2013* classifies waste into categories 0 to 5 based on the total concentration and leachable concentration of certain key elements or substances in the waste. A classification of 0 is the most hazardous waste, while a classification of 5 denotes material that is benign. The document includes a list of elements and substances of interest as well as the concentration limits applicable to each. The methods for assessing total concentrations of elements are not specified, except that it must be reliable, accurate and repeatable. There are, however, detailed methods specified for the assessment of the leachable concentrations. *National Norms and Standards for Disposal of Waste to Landfill 2013* specifies four standard landfill designs for waste of class 1 to 5 (paragraph 4(1)). Waste of class 0 must be treated and reclassified before it can be disposed of in landfill (paragraph 4(1)). It also makes provision for the disposal of certain pre-classified waste types, such as domestic waste (paragraph 4(2)). These national standards stipulate that old waste disposal facilities may continue to be used, provided they were legal before the commencement of the National Norms and Standards for Disposal of Waste to Landfill, 2013, (paragraph 3(4)) but that any new waste disposal facilities need to be approved in terms of these National Norms and Standards (paragraph 3(3)). The new standards are significantly more stringent than the previous standards, which means that the construction and operation of new residue stockpiles will be significantly more expensive than in the past (Cullinan, 2015). Stricter and more expensive requirements for mine waste deposits provides incentive for management approaches that promote re-use and recycling of current arising. However, waste from a stockpile cannot be treated and placed on the same stockpile again. The 'new' waste would need to be placed on a stockpile that is prepared in terms of these regulations-a possible disincentive

An important development to be aware of is the fact that the Minister of Environmental Affairs intends to present the National Environmental Management Laws Amendment Bill, 2017 to parliament. This bill intends to bring the regulation of residue stockpiles and residue deposits under NEMA only, and remove them from the Waste Act (Diemont et al., 2017). This should ease the complexity of, for example, getting permission to backfill mines with mine waste (Diemont et al., 2017), and allow for less stringent pollution control barriers.

In January 2018, a new regulation (Government Gazette 41380, 12 January 2018) was also proposed by the Department of Environmental Affairs to allow for application for the exclusion of certain listed waste types from being defined as wastes, provided that such wastes were intended to be used for specific purposes.

D.3 Legislation and regulations for the protection of water resources under the Water Act

The Water Act looks at water resources comprehensively and deals with issues such as management of catchment areas, determination of the water reserve, dam safety and water use. Section 19 deals with pollution prevention. According to Section 19, the owner, manager or occupier of land must take precautions to prevent or stop pollution, defined below, from occurring (S19(1)). If they do not do so, the catchment management agency may direct them to do so and, failing compliance, step in and remedy the situation. In such a case a variety of persons or entities who were responsible for or involved in the pollution or potential for pollution will be jointly and severally financially liable for the steps taken by the catchment management agency (S19(5)). This means that mine owners can incur significant running expenses for the treatment of water affected by ARD that is generated while the mine is operating or thereafter. This legal approach has serious consequences for the creators of residue stockpiles and residue deposits, especially where inadequate pollution prevention measures are taken.

> ***Pollution****: the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it – (a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or (b) harmful or potentially harmful – (aa) to the welfare, health or safety of human beings; (bb) to any aquatic or non-aquatic organisms; (cc) to the resource quality; or (dd) to property;*

Waste water purification specifications are given in terms of indicators, such as pH, dissolved oxygen and chemical oxygen demand. Maximum values for specific elements and substances are also specified. Methods for testing water quality are also detailed.

Regulations for use of Water for Mining and Related Activities Aimed at the Protection of Water Resources specify practical issues related to water use in mining, such as the permitted location of mines and buildings in relation to water sources and permitted building materials. Also specified are the capacity requirements for clean and contaminated water systems. A special requirement is that no pollutants are permitted to enter water resources.

D.4 Legislation and regulations for the control of air pollution under the Air Quality Act

This act regulates issues such as air quality standards, authorities responsible for monitoring, declaration of priority areas and pollution prevention. As with NEMA, the Minister of Minerals and Energy is the responsible authority in case of the mining industry (S36(5e))(S40(3A)). Since flotation operations are not associated with air pollution as such, dust associated with residue stockpiles and residue deposits may be relevant.

National Dust Control regulations support the Air Quality Act with stipulations regarding the maximum permissible dust fallout limits as well as requirements for a dustfall monitoring programme, a dustfall monitoring report and measures for control of dust. It does not specify methods for dust control, but specifies that *“best practicable measures”* must be taken. These regulations add additional burden to environmental management plans, but are probably not so onerous to significantly motivate a company to implement measures to reduce the volume of waste that is produced.