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PHYTOREMEDIATION: AN ASSESSMENT OF THE POTENTIAL OF *CASUARINA EQUISETIFOLIA* IN ENVIRONMENTAL REHABILITATION IN THE MINING INDUSTRY OF SOUTH AFRICA.

Lucien James (949999)

Supervised by: Professor Mulala Danny Simatele

A dissertation submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science.

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DECLARATION

I, Lucien James declare that this dissertation is my own work. It has been submitted to the Faculty of Science of the University of the Witwatersrand, Johannesburg, for the fulfilment of the requirements to obtain a Master of Science in Geography, Archaeology and Environmental Studies degree. It has not been submitted to any other institution for examination prior to this submission.

Signed:

Lucien James Date: 21/07/21

ABSTRACT

For more than a century, mining has played an important role in the development of South Africa. At the same time, mining has also been instrumental in the degradation of the country's environment. It has become a priority that the mining industry of South Africa adopts a more sustainable approach to mining by practicing environmental rehabilitation. However, as the rehabilitation of mining sites can be approached using several methods with some being more effective than others. As a biological method, the use of plants for rehabilitation and phytoremediation has become an area of world-wide academic interest as an effective means to address environmental issues, even leading to the complete ecological restoration of degraded areas.

It was the aim of this study to assess *Casuarina equisetifolia* as a potential phytoremediation or rehabilitation tool for the mining industry of South Africa. A three-step data collection process was followed to investigate how mining companies in South Africa address rehabilitation. This included (1) a desktop study of large mining companies' ESG reports, (2) engagement with various professionals and (3) field visits to two mining sites. The specific methods used by the industry as well as their associated challenges and opportunities were assessed. Finally, through further engagement with professionals and a rapid appraisal of literature that considered past studies on *Casuarina equisetifolia*, the potential of the plant in the context of what was learned about rehabilitation in the mining industry was established.

It was learned that mining companies practice revegetation as their overarching rehabilitation strategy. Mining companies use a mix of different physical, chemical, and biological methods to prepare a site before planting indigenous trees for revegetation. As a resilient plant species able to withstand the conditions of raw mining tailings, *Casuarina equisetifolia* has the potential to be used as a direct revegetation method requiring little to no preparation of land before planting. Secondly, the plant is capable of fixing atmospheric nitrogen, encouraging the growth of indigenous plant species, and the subsequent re-establishment of plant communities. The plant is a hyperaccumulator of eight heavy metal contaminants and can be used for phytoremediation at gold and platinum mining sites.

Through this study, it has been established that *Casuarina equisetifolia* has the potential to be used by the mining industry to kickstart revegetation projects. Further experimentation is therefore encouraged to study the plant through long-term trials in practical situations.

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CHAPTER ONE

FRAMES OF REFERENCE

1.1. Background to the study

It is now widely accepted that humankind is living in the Anthropocene; a geological epoch characterised and shaped by human activity (Crutzen, 2006; Zalasiewicz *et al.*, 2008; Steffen *et al.*, 2011; Zalasiewicz *et al.*, 2018). As the driving force behind the evolution of this new epoch, unchecked socio-economic development has had serious effects on the natural environment and Earth's natural systems (Crutzen, 2006; Rockström *et al.*, 2009; Steffen *et al.*, 2015). Adding itself to an ever-expanding list of different human activities which affect the environment; mining is an important economic activity which has played a role in landscape transformation and land-use change (Price *et al.*, 2011).

Mining has an impact on the environment in a multitude of ways. While mining may have a direct impact on soil, both water and air are subsequently affected (Moore and Luoma, 1990; Dudka and Andriano, 1997; Tiwary, 2001; Akcil and Koldas, 2006). Furthermore, by affecting soil, water and air, mining indirectly affects the health and well-being of biota and humans. There has thus been a need to move towards sustainable mining practices which includes environmental rehabilitation during and after mining takes place (Mudd, 2007).

Through policy and corporate social responsibility, large mining companies have therefore taken it upon themselves to address environmental issues and report their efforts. This includes the expansive mining industry of Africa (Festin *et al.*, 2019). Recent studies have been conducted to assess environmental rehabilitation in the context of mining in Africa (Festin *et al.*, 2019). Although Festin *et al.* (2019) praise some environmental rehabilitation efforts made in Africa, Ogola *et al.* (2002) argue that complexity exists in the implementation of rehabilitation strategies in the continent. This complexity emerges through the specific methods and strategies employed for environmental rehabilitation. Because of the vast array of methods available to address even a single environmental issue, continuous evaluation and assessment of different options and strategies is necessary.

As the country's primary economic activity, mining is widespread across almost every province of South Africa. Coal, diamonds, platinum, and gold are among the most mined minerals in the country with large mining projects being undertaken by major mining corporations (Naicker *et* *al.*, 2003; Cawthorn, 2010; Durand, 2012). The country has a long history with mining being the activity which has contributed to the development of South Africa and several of its cities (Harrison and Zack, 2012). Because of its grandeur and extent, environmental management is addressed in different ways, through different approaches in the mining industry of South Africa. Therefore, the sentiments of Ogola *et al.* (2002) are most applicable to South Africa where mining has widespread impacts, with environmental management approaches and methods being numerous and potentially extensive. This eventually leads to misconceptions and misunderstandings about how environmental management is performed by the mining industry. These misunderstandings extend through to the environmental impacts mining companies identify as most pressing to address, and how they should be addressed.

1.2. Thematic considerations

South Africa's mining industry has had a near-immeasurable impact on the environment. Among many, one of the specific impacts of mining in South Africa worth mentioning is acid mine drainage. As an example of a secondary impact resulting from soil contamination, acid mine drainage is a testimony of poor or ineffective environmental management. It is through environmental issues such as acid mine drainage that the cracks and flaws within mining companies' environmental management plans and subsequently implemented strategies are exposed.

In as much as the South African mining industry aims to address and report on their sustainability and environmental management plans, there are still cases where rehabilitation is not being applied effectively to address long-term issues such as acid mine drainage. It is assumed that mining companies in South Africa have adopted environmental management plans according to past experience. However, these management plans include the adoption of dated environmental management or rehabilitation methods, some of which have not been well-documented or observed. Furthermore, novel methods and technologies are often overlooked.

Different rehabilitation methods can be grouped according to the form they take, or the instruments used. They can be either physical, chemical, or biological as per Festin *et al.* (2019). An example of physical methods is the placement of a topsoil layer over the area in need of rehabilitation otherwise known as cladding. Differently, chemical methods make use of chemically validated practices aimed to neutralise or counteract the harmful elements within contaminated soil and water. Finally, it has been noted that although mining companies have made use of physical and chemical methods, there is a lack of appreciation for the use of plants as a biological method used to address environmental degradation in many ways (Ogola *et al.*, 2002).

Plants can be used in different ways to address environmental rehabilitation. The broader term "phytotechnology" defines the use of plants for many different applications in environmental management. As part of phytotechnology, phytoremediation refers to the use of plants to address polluted environments (Pilon-Smits, 2005). This method is being increasingly used to rehabilitate mining areas (Sasmaz and Sasmaz, 2009; Barrutia *et al.*, 2011; El Aafi *et al.*, 2015). Furthermore, the use of plants for environmental rehabilitation has several advantages and benefits over physical and chemical methods, for example, allowing for ecological restoration and the re-establishment of former natural norms. However, as suggested by Župunski *et al.* (2018), there is once again a lack of knowledge on how different plant taxa may have potential to address different environmental issues.

A key inspiration of the current study was the use of *Casuarina equisetifolia* to restore and transform a degraded cement quarry into what is now a nature reserve. In 1971, efforts were led by René Haller to rehabilitate the degraded cement quarry located in Bamburi, Kenya. Various tree species, which included the Australian tree *Casuarina equisetifolia*, were planted across a 2km^2 area. *Casuarina equisetifolia* was identified to be tolerant to the conditions of the quarry and acted as a pioneer for other plants. The quarry was eventually transformed into a lush forest. *Casuarina equisetifolia* is still present among the indigenous vegetation now found at Haller Park nature reserve (Siachoono, 2010).

Therefore, it is worth investigating the different ways mining companies in South Africa address their impact on the environment. More can be learnt through observation and assessing specific methods currently being applied for environmental rehabilitation at large operations of major mining companies. Finally, it is worth investigating how mining companies make use of plants and what potential *Casuarina equisetifolia* may have in environmental rehabilitation of those natural environments negatively impacted by mining activities in South Africa. This study takes this focus as a point of its departure and investigation.

1.2.1. Research questions

In view of the above thematic considerations, the following research questions were a guide to the research process:

i. In what ways does the mining industry in South Africa address environmental rehabilitation?

ii. What are some of the rehabilitation methods used by the mining industry and to what extent are plants and phytoremediation used?

iii. What opportunities and challenges exist in the implementation of rehabilitation strategies using plants?

iv. In what ways can *Casuarina equisetifolia* be used for environmental rehabilitation at mining operations in South Africa?

v. What are the wider implications of the findings of this study, particularly in a mining context?

1.2.2. Research aims and objectives

The aim of this study was to assess *Casuarina equisetifolia* as a potential phytoremediation and environmental rehabilitation tool which can be used to address environmental degradation caused by mining.

In view of the above aim, the related objectives of the study were to:

i. Identify how rehabilitation is addressed in the mining industry of South Africa.

ii. Assess the different rehabilitation methods mining companies use and the challenges and opportunities related to environmental rehabilitation in South Africa.

iii. Establish the potential of *Casuarina equisetifolia* for phytoremediation or mine rehabilitation.

1.3. Research design

This study was conducted, keeping in mind the ideal that research is a "systematic process that leads to new knowledge and understandings" (Leedy and Ormrod, 2015: 19). In this regard, there are several considerations that a study of this nature had to address prior to commencing and during the research process. Firstly, the methods adopted would need to yield a generous amount of new insight and secondly, ensure a sound and replicable research design.

It is important to note that several limitations were encountered before and during the completion of this study. These limitations had to be considered, and the methodology of this study was therefore altered accordingly. Firstly, this study involved engagement with the mining industry. It was noted that many mining companies are not keen on sharing information on their workings and dynamics. Thus, data was collected from sources made readily available such as Environmental, Sustainability and Governance (ESG) reports. Secondly, *Casuarina equisetifolia* is considered a category 2 invasive plant species in South Africa. This limited work with the plant itself, including any field or laboratory experiments. Thirdly, the study was conducted during a period affected by the COVID-19 pandemic. This limited the number and nature of data collection methods. Therefore, a methodology and research design were implemented to circumvent these limitations.

A three-step research design was implemented for effective data collection and analysis. This was to address all the research questions, primary aim, and objectives of this study. The three steps part of this study's research design included (1) an initial desktop study of ESG reports, (2) engagement with the mining industry of South Africa through site visits and in-depth consultation with professionals and (3) a rapid appraisal of existing studies. As primary sources of information, literature, ground truthing and engagement with various professionals through interviews and questionnaires were vital for the completion of this study. It is important to note however that this study involved a large amount of qualitative research as well as made some use of quantitative information. Furthermore, content analysis was at the heart of this study and thus gave it an emergent form (Leedy and Ormrod, 2015).

1.4. Scope

This study is an assessment of the potential of *Casuarina equisetifolia* in the context of rehabilitation within South Africa's mining industry. To assess the potential of *Casuarina* *equisetifolia*, this study assesses rehabilitation practices of South Africa's mining industry. This study strays from concerns around the legal obligation mines have in terms of environmental legislation and the actual dynamics which drive rehabilitation efforts. Therefore, governance and policy are not touched in detail in this study unless it has implications on the opportunities and challenges involved with *Casuarina equisetifolia* itself. With regards to *Casuarina equisetifolia*, this study is an assessment of its practical potential. As research has already been done on how *Casuarina equisetifolia* interacts with different climatic and environmental settings of South Africa (Lubke *et al.*, 1996; Lubke and Avis, 1999), this study considers how the plant can be useful to address specific environmental impacts or issues as investigated within the mining industry. The focus of this study, therefore, are the viewpoints of South Africa's mining industry, how rehabilitation is currently being addressed and how *Casuarina equisetifolia* exhibits potential in specific situations.

1.5. Ethical considerations

As this study progressed, ethical considerations were key as engagement with professionals was necessary. According to the guidelines of the Human Research Ethics Committee (Non-Medical) of the University of the Witwatersrand, this study is of minimal risk to participants and society. Permission was given by the two mining companies engaged with to conduct research with them as the two representative mining companies of this study. However, names of participants or employees of the mining companies, operations and specific site locations have been omitted from this dissertation. This was done as per agreements with the two mining companies who provided conditional permission for the use of data collected at their sites and from their employees.

Probably the most important note to make on ethical considerations and limitations is that this study coincided with the COVID-19 pandemic of 2020. Necessary measures had to be taken during data collection to safeguard participants and the researcher. These included the postponement of any interviews or meetings as well as site visits. Some engagement was also performed remotely via online communication platforms. Furthermore, some visits and activities had to be abandoned completely as mobility was limited during the pandemic. Therefore, the methods of this study were adversely affected resulting in much of the study's methodology being altered.

This study was approved by the Human Research Ethics Committee (Non-Medical) of the University of the Witwatersrand on 21 August 2019 (See Appendix A for Ethics clearance certificate), from which point data collection could formally commence.

1.6. Structure of dissertation

This study is presented in the form of a dissertation and includes six main chapters. These six chapters are written according to general conventions used to report research. Each chapter consists of information, building up to the final findings and conclusion of this study.

As the first chapter of this dissertation, this chapter highlighted the various frames of reference considered for this study, as an introduction to the research conducted and findings thereof. It briefly highlighted the background of this study, the thematic considerations as well as provided a brief overview of the study's research design. This chapter also highlights the research questions, aim and objectives of this study. It also provides information on the scope of the study as well as ethical considerations made during research.

This chapter is followed by chapter two, which highlights the main theoretical considerations supporting this study in the form of a broad literature review. The literature review includes considerations of the context of South Africa's mining industry, highlighting its environmental impacts. Different approaches to environmental management, as well as specific environmental rehabilitation methods previously documented and studied are presented. Viewpoints on the use of plants for environmental rehabilitation are staged, particularly, considering case studies in Africa and South Africa. Finally, information related to *Casuarina equisetifolia* is presented, introducing the species as per past research.

The methodological approach of the current study is documented in chapter three. The value of the methodology chosen is argued considering the context of the current study as well as its opportunities and limitations. This chapter also presents the philosophical positionality of the study as well as the researcher themselves, providing further substantiation for the chosen research design. The three-step research design adopted for data collection and analysis is subsequently presented. A description of the sites visited as part of field work is provided. Sampling strategies and data collection tools are described, providing finer detail on how the findings of this study were gathered. Finally, how data was collected and analysed is described.

The results of the study are presented in chapter four. This chapter highlights findings from the three-step methodology followed in this study. In this regard, findings from the initial desktop study, engagement with the mining industry and the rapid appraisal of sources are presented in this order. This chapter includes all qualitative and quantitative findings relevant to the research questions and objectives of the study. Furthermore, this chapter includes an extensive range of figures, tables and images relating to findings and observations.

The findings presented in chapter four are then discussed in chapter five. This chapter provides an interpretation of the raw findings. Meaning is made of findings using literature and relevant results are highlighted. The results are therefore pieced together to answer the research questions of this study. It is in this chapter that the current study is related to the broader scientific body and past studies on similar areas of interest.

Finally, chapter six provides a conclusion to this study. As part of this conclusion, sentiments on the value of the current study are highlighted as well as prospects emerging from this study as a preliminary form of engagement with the subject matter. Some limitations, shortfalls and avenues for improvement are staged. The wider implications of this study are presented in relation to its contribution to the grander scientific body.

CHAPTER TWO

THEORETICAL CONSIDERATIONS AND LITERATURE REVIEW

2.1. Introduction

The impacts of mining, how these impacts can be addressed, and the potential of phytoremediation for environmental rehabilitation is covered by a vast literature base that will be reviewed in this chapter. Several documented case studies provide background information necessary to address the topic of the current study as well as contribute to the building of its rationale. This chapter will provide a synthesis and critique of literature and past studies to demonstrate why the current study is of importance to science and the scientific community.

Firstly, a summary of South Africa's mining history is necessary to initiate a review of the problem addressed by the current study. From as early as the 19th century, mining has been a fierce economic activity in South Africa. Harrison and Zack (2012) illustrate how the mining industry was instrumental in the building of the city of Johannesburg. This was mostly due to the discovery of gold in the 1880's (Adler *et al.*, 2007; Harrison and Zack, 2012). The mining industry of South Africa since then has grown to encompass the mining of a range of raw materials and minerals including coal, diamonds, gold, and platinum (Richardson and van Helten, 1984; Crowson, 2001; Wilson, 2001; McCarthy and Pretorius, 2009; Cawthorn, 2010; Durand, 2012). In some cases, mining in South Africa has also contributed to global development. An example of this is the mining of platinum, of which South Africa is the largest producer of the commodity in the world (Crowson, 2001; Cawthorn, 2010, Glaister and Mudd, 2010; Zientek *et al.*, 2014; Robinson, 2017).

As successful as the industry has been since its establishment, environmental concerns have plagued it. Several arguments have emerged considering the relationship between mining and environmental degradation. At the same time, environmental degradation caused by mining has been addressed in different ways. A more profound discussion of these issues, their solutions as well as subsequent considerations will be a key focus of this chapter. In this regard, this chapter will first consider the process of mining and its role in environmental degradation. The impacts of mining as well as some of the universal solutions to addressing these impacts will be discussed. Phytoremediation will also be discussed with particular focus on research done in South Africa. Finally, the plant in question, *Casuarina equisetifolia* will be presented.

2.2. The issue: tailings and environmental degradation

The processes involved in extracting minerals and raw materials are vast and complex. Firstly, an accessible mineral deposit must be discovered. Secondly, different mining methods are used to extract minerals depending on the nature of the deposit. Finally, the mining methods used, governed by the mineral deposit itself, demand specific resources as well as produce waste material. All three of these aspects or steps involve exploitation of the environment as argued by Bridge (2004).

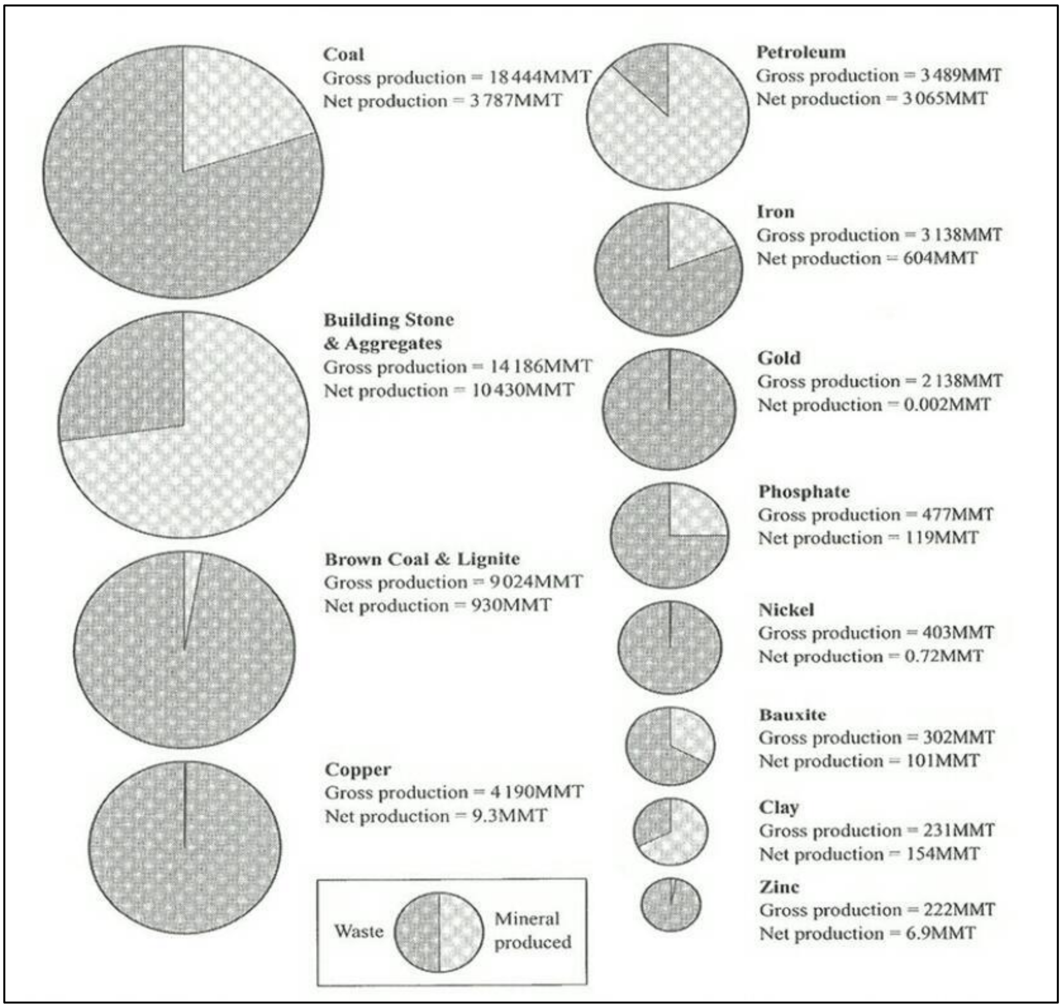

Figure 2.1. Diagram illustrating the ratio of waste generated to mined mineral yield (Douglas and Lawson, 2000).

Related to reaching mineral deposits, Bridge (2004) argues that a primary step to mining is earth moving. In this regard, large amounts of material need to be displaced and deposited during excavation. Bridge (2004) supports that this is a critical source of most environmental problems related to mining. Douglas and Lawson (2000) are of the same opinion, arguing that mining can be considered one of the most influential in transforming landscapes. Hendrychová and Kabrna (2016) support this argument stating that mining landscapes can be altered for centuries. This is put into better perspective through an illustration (Figure 2.1).

As in Figure 2.1, Douglas and Lawson (2000) demonstrate that, there is a great difference between the yield of ore or minerals in comparison to waste material. For example, for every 2130 million metric tonnes (MMT as abbreviated in the diagram) of waste material, only 0.002 million metric tonnes of gold are mined. Therefore, to be of more economic value, the more material or earth moved, the more often valuable commodities can be extracted.

Figure 2.1 is important as it alludes to a key theme of the current study, environmental management of tailings storage facilities. All the waste depicted in Figure 2.1 would be stored in the form of tailings. Tailings are considered by Bridge (2004) as a major point source of environmental degradation. Moore and Luoma (1990) support this by arguing that mine tailings affect many different aspects of the environment. Furthermore, Salomons (1995) is of the view that mine tailings, although covering a relatively small area of land-surface globally, account for large quantities of chemical pollution. Bridge (2004) is of the same opinion, suggesting that the dumping of mine tailings is only part of the larger problem. Furthermore, Moore and Luoma (1990) argue that pollution and contamination can be direct or indirect, affecting not only the immediate environment, but other aspects indirectly. Some of the aspects listed by Moore and Luoma (1990) form a critical point of assessment for the current study.

Bridge (2004) argues that waste material is also produced when mined material is processed and refined. Glaister and Mudd (2010) are of the same opinion, considering the processes and methods used while extracting platinum from mined material. As steps following excavation, grinding, separation and flotation are some of the conventional processes documented by Cole and Ferron (2002), Bulatovic (2010), and Mudd (2012) which are used to extract platinum and platinum group elements from rock and sediment mined. As part of these processes, more waste is generated and added to tailings.

In summary, Douglas and Lawson (2000), Bridge (2004) as well as Glaister and Mudd (2010) are among some who have attempted to quantify and assess the amount of environmental degradation mining can cause through its production of tailings. Although some such as Douglas and Lawson (2000) consider tailings as a source of pollution, Moore and Luoma (1990) argue that there is more to assess in relation to the amount of damage mine tailings and mining activity can incur on the environment. Starting from soil itself, leading to water, biodiversity and even human health, some of these will be discussed in the following sections.

2.3. Contextualising the literature on the impacts of mining on soil resources

The excavation of minerals, waste rock and sediment have a direct impact on firstly, the mined area as argued by Bridge (2004), but secondly, and more importantly, on the location where waste rock and sediment are stored as tailings. Dudka and Adriano (1997) argue that mining activity has a direct impact on the immediate landscape, however along with tailings from excavations and the processing of mined minerals, dangerous chemicals are introduced to the environment. The first aspect to be impacted is soil. Dudka and Adriano (1997) list some of the dangerous chemicals found in tailings. These include Copper (Cu), Lead (Pb), Zinc (Zn), Arsenic (As), Cadmium (Cd) and Nickel (Ni) as a few chemicals which are introduced to natural soil through the disposal or storage of mine tailings. This impact in the form of soil degradation is classified as a primary form of contamination by Moore and Luoma (1990).

The viewpoints above have been assessed in relation to the mining industry of South Africa. Rösner and van Schalkwyk (2000) discuss this point more closely in relation to gold mining in Johannesburg. They argue that tailings, when neglected, can lead to seepage of contaminants. Some of these contaminants can acidify topsoil which may complicate rehabilitation efforts. In contrast, van der Walt *et al.* (2012) argue the opposite is noted at platinum mines in the Rustenburg area. Waste associated with platinum mining can be alkaline and cause soil to become biologically sterile. This has also been argued by Maboeta *et al.* (2006) through their study of the interaction of soil microbiology and heavy-metal contaminants associated with platinum mining. Furthermore, Aucamp and van Schalkwyk (2003) argue that further degradation of soil is aided through erosion, expanding the impact of tailings on the environment.

2.4. Contextualising the literature on the impacts of mining on water resources

The means of erosion itself, being water or air are also susceptible to contamination. This brings into discussion one of the greatest concerns when considering how mining impacts the environment, that is, through water contamination and acid mine drainage. As a function or repercussion of soil contamination through the introduction of tailings, acid mine drainage has been a central focal point in assessing the impact of mining on water, particularly in South Africa.

Akcil and Koldas (2006) review acid mine drainage as a major impact mining has on water. They argue that mine tailings as well as pits and underground works are important sources of sulphides. When waste rock and mine tailings are left exposed, water which comes into contact with these by-products are rendered highly acidic. A detailed account of the process of oxidisation of heavy-metals and subsequent contamination of water is provided by Ackil and Koldas (2006). As an additional note, an earlier assessment of these processes was also conducted by Evangelou and Zhang (1995). At gold mines, Naicker *et al.* (2003) argue that the oxidation of pyrite (FeS_2) is the greatest contributor to water acidification. McCarthy (2011) supports that in South Africa, gold and coal mining in particular, are major contributors to the contamination of water. Kefeni *et al.* (2017) share this opinion. In contrast, Ackil and Koldas (2006) support that all forms of mining may contribute to acid mine drainage in different ways, depending on different situations. Following the processes described by Naicker *et al.* (2003), Ackil and Koldas (2006) as well as McCarthy (2011), Rösner and van Schalkwyk (2000) argue that contamination of water can reach aquifers and may lead to large-scale impacts relating to the groundwater table.

Acid mine drainage and the contamination of water sources in South Africa has been a major focal point of studies, suggesting that acid mine drainage is a precursor of other environmental issues. McCarthy and Humphries (2013) argue that acid mine drainage has also affected the water supply of towns in South Africa. Moore and Luoma (1990) support this view suggesting that natural water systems may be affected by acid mine drainage, leading to the contamination of water sources which are needed by humans and other biota. Moore and Luoma (1990) support that a link should be considered between soil and water contamination, suggesting that acid mine drainage is a form of secondary contamination. This viewpoint is critical when discussing how mining has an impact on water through soil degradation, which then has an impact on other environmental aspects.

Moore and Luoma (1990) suggest that water can also act as a means for contaminants to be mobilised. Aucamp and van Schalkwyk (2003) support this view when suggesting that erosion of tailings by water is one of the processes that is part of contaminant mobilisation. This is further supported by Tutu *et al.* (2008) who consider the chemical characteristics of contaminated groundwater near mine tailings and argue that water quality near mining sites is characterised by lower pH levels than that away from mining sites. Bell *et al.* (2001) argue that abandoned mines are an example of how, when not addressed, the impacts of acid mine drainage can become long-term. Mhlongo and Amponsah-Dacosta (2016) are of a similar opinion considering the impact of unaddressed and abandoned mine tailings. Therefore, tailings can have an impact on soil, but when exposed to erosion, this impact may spread affecting many other environmental aspects possibly for a long time.

2.5. Contextualising the literature on the impacts of mining on air resources

Moore and Luoma (1990) consider the impact of mining on air or the atmosphere as secondary contamination in a similar way as the impact of mining on water. As per Moore and Luoma (1990) argue, air quality is affected by mining through the processes such as smelting of ores. Kaonga and Kgadi (2011) argue further that air quality is affected by other mining processes such as crushing and blasting. However, the viewpoint of Ojelede *et al.* (2012) is key when discussing the relationship between mining and air. They argue that mine tailings and waste itself are sources of dust, dust storms and have the capability of contaminating air.

de la Campa *et al.* (2011) are of a similar opinion as Ojelede *et al.* (2012), arguing that although smelting has contributed to air pollution in the past, many different heavy-metal contaminants are introduced to the atmosphere through the suspension and resuspension of particulate matter from mine waste in the form of tailings. This is supported by Csavina *et al.* (2012) who argue that dust from mines can easily be transported. Furthermore, de la Campa *et al.* (2011) argue that the contamination produced by abandoned mines may be present in the atmosphere for longer than anticipated. Castillo *et al.* (2013) are of the same opinion as de la Campa *et al.* (2011), however they suggest that concentrations of particulate matter related to mining activity decrease moving away from mine tailings deposits. de la Campa *et al.* (2011) as well as Castillo *et al.* (2013) suggest that heavy-metal contaminants such as Cu, As and Zn are some of the contaminants observed in mine waste polluted air. These contaminants are the same as those listed by Dudka and Adriano (1997) when discussing acid mine drainage. In this regard, Castillo *et al.* (2013) argue that the mobilisation of particulate matter may further contribute to soil and water pollution where particulates are deposited. Ojelede *et al.* (2012) supports this viewpoint suggesting that mines are a source of aeolian emissions which could affect plants, animals, and humans, yet again adding to the impacts mining has on the environment.

2.6. Contextualising the literature on the impacts of mining on biodiversity and ecosystems

Bridge (2004) argues that as mining affects soil, water and air, new environmental conditions are introduced to ecosystems, flora, and fauna. As a result of soil and water contamination, many plant and animal species are affected by changing conditions. Bridge (2004) further argues that small environmental changes can have serious impacts on ecosystems.

Dudka and Adriano (1997) argue that, at a micro scale degradation leads to soil being rendered inhabitable to microbiology such as fungi and bacteria. Fungi and bacteria are necessary for promoting nutrient cycling in soil. Liao and Xie (2007) support this idea, demonstrating that soil microbiology is affected by the heavy-metal pollutants introduced to soil through tailings. Ramsey *et al.* (2005) are of the opinion that other processes such as soil respiration are also affected by heavy-metal contamination, implying that contaminated soil limits the growth of plants.

It has been suggested by van der Walt *et al.* (2012) that several natural processes such as infiltration and nutrient cycling are affected by soil contamination with the well-being of plant communities subsequently being affected. This point is illustrated well by Hernandez and Pastor (2008) who, through their experiments, conclude that plant life is affected by heavy metal contaminants in soil. Furthermore, they highlight a link between plant life and other biota such as larger fauna. Supporting this viewpoint and even expanding it, Pandey *et al.* (2014) suggest that air pollution from mining activity further affects plant communities. Pandey *et al.* (2014) argue that plant species diversity is limited due to mining activity and result in changes to ecosystems themselves. Donato *et al.* (2007) supports this point providing the conclusion that wildlife may thus also be affected by heavy-metal contamination.

Parsons (1977) is among the first to argue that acid mine drainage affects aquatic life. Following Parsons (1977), Marques *et al.* (2001) argue that chemicals previously discussed such as Cu, Pb and Fe play an important role in the alteration of aquatic ecosystems. According to Marques *et al.* (2001), acid mine drainage and water flowing from mine tailings are important sources of heavy-metal contaminants which alter aquatic ecosystems. Erasmus *et al.* (2020) demonstrate that even more recently, aquatic ecosystems are still affected by mining. Erasmus *et al.* (2020) argue that macroinvertebrates are vulnerable to heavy-metal contaminants introduced to water systems through platinum mining in South Africa. This further supports the argument of Moore and Luoma (1990) who argue that the effect of mining on biodiversity is a function of the impact mining has on soil, water and air.

2.7. Contextualising the literature on the impacts of mining on human health

All the above highlighted impacts of mining culminate to one last impact: the impact of mining on human health. Once more, the viewpoint of Moore and Luoma (1990) helps place into context the impacts of mining on human health. Moore and Luoma (1990) argue that mining can affect human health through the contamination of soil, water, and air. Additionally, the impact of mining on biodiversity also has an impact on human health.

Mining can introduce harmful pollutants to food sources because of the impact of mining on biodiversity. Li *et al.* (2006) argue that farming can be affected by mining, leading to potential health risks. Xu *et al.* (2013) support this view arguing that vegetables farmed in the vicinity of mine waste are exposed to unhealthy amounts of heavy-metal contaminants. Yang *et al.* (2009) further expands on this opinion suggesting that some vegetables can accumulate heavy-metal contaminants which are then ingested by humans, posing a health risk. Liao *et al.* (2016) argue that a source of these contaminants can be the soil itself or water affected by acid mine drainage.

The impact of mining on air quality also has an impact on human health. Respiratory diseases are often associated with mining activity and mine waste. Aeolian emissions, as argued by Ojelede *et al.* (2011), are also considered a hazard to human health. Nkosi *et al.* (2015) expand on this by considering links between mine waste and respiratory diseases among adolescents living near mine tailings. An important disease mentioned by Nkosi *et al.* (2015) is asthma. Additionally, Moore and Luoma (1990) argue, that cancer could also result from exposure to different contaminants. Lee *et al.* (2006) supports this argument suggesting that contaminants such as As may cause cancer through exposure. Nkosi *et al.* (2015), although linking respiratory diseases to the occurrence of mine tailings in certain communities, suggests that further research should be conducted to better understand this link. Following these viewpoints, a key argument to consider is that of Maseki *et al.* (2017) who support that mine tailings is an important source of heavy-metal contaminants being introduced to communities.

2.8. Sustainable mining: from business as usual to addressing the issues

Considering all the impacts of mining and mine waste, the grandeur of the environmental issue is uncovered. Like other human activities, more sustainable approaches to mining have been considered to minimise impacts. As part of early environmental movements, Perez and Sanchez (2009) suggest that mining companies began sustainability reporting, indicating how their companies have addressed mining under the ideals of environmental sustainability. de Villiers *et al.* (2014) are of the same opinion, arguing that South African mining companies also engaged in sustainability reporting through the influence of global environmental movements. Presently, sustainability reporting is addressed through the ESG reports large mining companies prepare annually. These reports will be further discussed in Chapter 3 as they play an important role in the methodology of the current study.

Sustainability reporting, as Perez and Sanchez (2009) argue, requires that mining companies comply with sustainability practices and report this. However, Kirsch (2010) is of the opinion that different mining companies have engaged with the concept of sustainability in different ways. The viewpoint arises here that environmental issues are addressed through different approaches as there is no one-size-fits-all model for sustainable mining and subsequent reporting. This is supported by Festin *et al.* (2019) who argue that mine pollution, such as tailings dams, have been addressed by mining companies, however, each issue is addressed in different ways.

There is therefore a void left in the understanding of how mine tailings is addressed by mining companies thus adding to the rationale of the current study. This viewpoint has also provided some like Kirsch (2010) the potential to argue that sustainability is not addressed by the mining industry through practical methods altogether. The current study is therefore key in this regard; to better understand the underlying methods and strategies used to address mine tailings as a source of many impacts mining has on the environment. However, before considering some of the methods used, an appraisal of the overall approaches in relation to perceived end-goals is necessary.

2.9. The R4: Environmental Restoration, Reclamation, Remediation and Rehabilitation

Discussing the approaches through which environmental issues are addressed in a post-mining situation, Festin *et al.* (2019) briefly define four terms. Each term, restoration, reclamation, remediation, and rehabilitation are defined differently by Festin *et al.* (2019), however, they each relate to larger approaches to improving degraded environments. Lima *et al.* (2016) defines these approaches further, collectively calling them the R4. Borišev *et al.* (2018) argue that these approaches differ and that each represents a specific end-goal for the environmental issue which they address. As Festin *et al.* (2019) suggest, restoration, reclamation, remediation, and rehabilitation each include different methods to achieve their respective end-goals, supporting the argument of Borišev *et al.* (2018). In this regard, Borišev *et al.* (2018) as well as Festin *et al.* (2019) support that efforts made to counter or reverse the adverse effects of mining often address environmental matters differently. The R4 is therefore, considered a pinnacle consideration when assessing novel approaches to environmental management.

Restoration can be described, as per Cooke and Johnson (2002), as the goal to re-instate a mining area to former, natural conditions before mining had begun. Hu *et al.* (2012) expand on this idea by suggesting that an ecological approach is often attached to restoration, emphasising the need to engage with restoring the natural ecosystems of an area. Cooke and Johnson (2002) further argue that restoration involves ecosystem reconstruction. Lima *et al.* (2016) describe restoration to be an ambitious approach as it requires the dedication of resources and time to re-instate the flora and fauna of a degraded environment. Borišev *et al.* (2018) support Lima *et al.*'s (2016) viewpoint, suggesting that restoration is time consuming. Jackson *et al.* (1995) argue further that successful ecological restoration depends on four different aspects, namely, values, social commitment, ecological circumstances, and judgements. Finally, restoration, according to Župunski *et al.* (2018), also requires planning.

Hu *et al.* (2012) presents a case study of the ecological restoration of abandoned mines in China. Expressed as part of this case study, is the idea that a plan needs to first be implemented for successful ecological restoration. As an example, Hu *et al.* (2012) argue that the ecological restoration of coal waste piles requires a three-stage process of analyses, evaluation, and implementation of strategies to address the problem.

Lima *et al.* (2016) argues that when restoration is not a feasible option, reclamation may be a more appropriate choice. Župunski *et al.* (2018) is of the opinion that reclamation is guided by ecological principles; however, it is more focused on repairing the environment and its ecosystems rather than restoring them. In addition, Lima *et al.* (2016) suggests that efforts of reclamation may result in the replacement of the pre-existing ecosystem. Lima *et al.* (2016) further argues that reclamation involves targeting one aspect to recover a particular ecosystem service. These aspects may include addressing water and soil pollution, leading to the repair of a single natural system damaged through environmental degradation.

Feng *et al.* (2019) exemplify reclamation in the context of addressing degraded soil. In their review, Feng *et al.* (2019) highlight how surface coal mining affects soil quality, thus showing that focused efforts on improving soil quality is necessary. These sentiments echo those of Lei *et al.* (2016) who argue that addressing soil quality through reclamation may lead to the eventual ecological restoration of a degraded environment. Lima *et al.* (2016) is also of the view that reclamation and restoration may appear similar to each another. However, unlike restoration, Feng *et al.* (2019) argue that reclamation has little focus on the implication applied methods would have on large-scale and long-term ecological restoration.

Remediation, the third concept of the R4 is described by Festin *et al.* (2019) as an effort for correcting or halting an environmental issue. Furthermore, Festin *et al.* (2019) consider the root of the word remediation, stemming from the world “remedy”, therefore associating remediation with fixing or rectifying an issue. Lima *et al.* (2016) argue that remediation is similar to reclamation as one environmental aspect, problem or impact is addressed or targeted through intervention. Lima *et al.* (2016) define remediation as an approach involving different processes or methods to decontaminate or remove pollutants from the environment. More importantly, Lima *et al.* (2016) regard the approach of remediation as the specific physical, chemical or biological methods used in this regard. Therefore, the word “phytoremediation” can be linked to the same idea as will later be discussed.

Xu *et al.* (2015) review remediation methods used to remove mercury from soil as a heavy contaminant. They list several different strategies to compare different options for the remediation of mercury contamination caused by natural and anthropogenic factors. Xu *et al.* (2015) argue that each site in question may require a different remediation strategy. Furthermore, it is the opinion of Festin *et al.* (2019) that remediation should be considered part of restoration itself. However, Xu *et al.* (2015) disagree and support that the implementation of remediation measures requires an understanding of the issue to be addressed as well as the opportunities and challenges associated with the measures considered.

The point that Xu *et al.* (2015) highlight becomes an important factor when discussing rehabilitation. Rehabilitation, the last of the R4, is argued by Lima *et al.* (2016), as the consideration of issues beyond the effectiveness of a remediation measure or implemented method. Lima *et al.* (2016) are of the opinion that different costs and benefits related to addressing an environmental issue are considered under the concept of rehabilitation. Festin *et al.* (2019) argue that restoration and rehabilitation can be viewed as synonymous as both encompass a wider solution to an environmental issue. However, Bradshaw (1984) presents an interesting assessment of how rehabilitation differs from restoration. Unlike restoration, Bradshaw (1984) is of the opinion that the complete re-instatement of a pre-existing ecological condition is not expected through rehabilitation. This has been further illustrated by Bradshaw (1984), who shows that different from replacement or neglect, rehabilitation strives towards restoration, however, takes a more sustainable approach when addressing environmental issues (*Figure 2.2*).

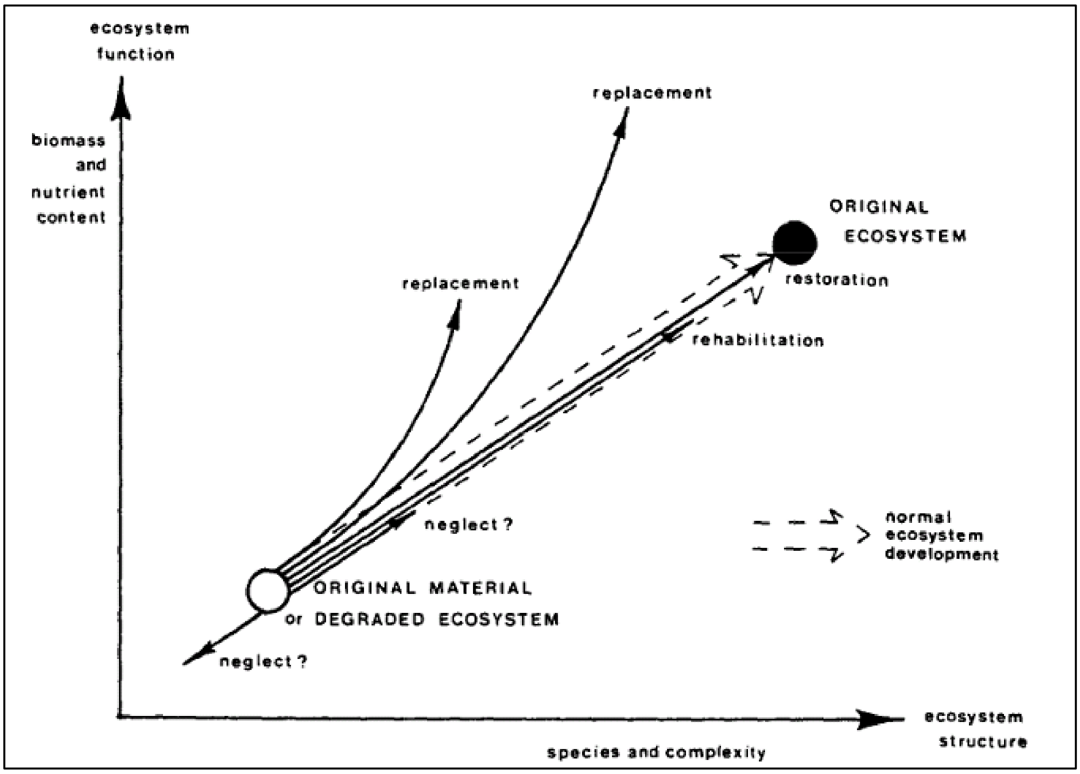

Figure 2.2. A diagram illustrating the difference between restoration, rehabilitation, complete replacement or neglect (Bradshaw, 1984)

Using Figure 2.2, Bradshaw (1984) argues that the most crucial aspects of natural ecosystem development are ecosystem function and ecosystem structure. Ecosystem function refers to biomass and nutrient content of the ecosystem. Ecosystem structure refers to species complexity. In this regard, Bradshaw (1984) argues that both restoration and rehabilitation respect normal ecosystem development, unlike ecosystem replacement or neglect. However, ecosystem function and structure may not reach that of the original ecosystem through rehabilitation. This is because rehabilitation as argued by Bradshaw (1984), is a partial restoration process. This is therefore illustrated in Figure 2.2 with an arrow that indicates a movement towards the original ecosystem, but does not reach it.

Attached to each of the R4 are specific methods and strategies. These methods will be discussed in the context of rehabilitation as the most optimal viewpoint of the current study. Other factors apart from the ability of each method to address an environmental issue will also be compared.

2.10. Contextualising the literature on environmental rehabilitation methods

Festin *et al.* (2019) identify many rehabilitation methods and argue that these can be grouped into three main categories, physical, chemical, and biological methods. In more recent work, all three have been considered equally in the implementation of larger rehabilitation plans (Bramley-Alves *et al.*, 2014; Feng *et al.*, 2019). Luptakova *et al.* (2012) support that each of these three methods can be applied to different environmental issues. However, Li and Zhang (2012) support that each can be applied to different problems and scenarios considering their own advantages and disadvantages.

Wang *et al.* (2017) claim that physical rehabilitation methods can be described as solidification, covering, or dumping. These physical methods are further argued by Wang *et al.* (2017) as the implementation of a technology to address a problem. The use of covering has been argued by Festin *et al.* (2019) as a physical rehabilitation method often used in the mining industry. Nandillon *et al.* (2019) suggest that there exists a knowledge gap when considering the applicability of covering and the use of technosols. Hence, the use of technosols and topsoil to improve soil quality is efficient however, their long-term capacity and effects are yet to be understood (Asensio *et al.*, 2013; Asensio *et al.*, 2019, Nandillon *et al.*, 2019).

Different from physical methods which are often described as easier to implement as per Wang *et al.* (2017), are chemical methods which are more complex. Prominent examples of chemical rehabilitation methods found in literature include chemical washing and thermal treatment (Moutsatsu *et al.* 2006; Yang *et al.*, 2012; de Sales *et al.*, 2013). These methods aim to neutralise or eliminate the heavy metals and chemical pollutants by introducing other chemicals to the soil or water. As Li and Zhang (2012) claim, the use of chemical methods for environmental rehabilitation are still experimental and are yet to be implemented on a larger scale.

Physical and chemical methods have been argued as “traditional techniques” by Wang *et al.* (2017). Additionally, Ali *et al.* (2013) corroborate yet argue that these methods have been considered costly and labour-intensive. In contrast, biological methods have been argued to be more readily available and cost-effective and are currently being used for environmental rehabilitation (Balba *et al.*, 1998; Mench *et al.*, 2003; Liphadzi *et al.*, 2005; Vymazal and Sklenicka, 2012; Rungwa *et al.*, 2013; Gastauer *et al.*, 2018; Odoh *et al.*, 2019). Biological methods, as less traditional alternatives can also be used alongside traditional physical and chemical methods (Imfeld *et al.*, 2009; Barbosa and Fernando, 2018).

Vidali (2001) expresses support for the use of plants as a biological rehabilitation method. As an emerging technology at the time, Vidali (2001) claimed that it was a promising solution to solving many environmental issues. Phytoremediation and the use of plants for environmental rehabilitation are key focuses of the current study. Having considered the opportunities and challenges associated with physical and chemical rehabilitation methods, it is therefore important to highlight the opportunities and challenges associated with phytoremediation.

2.11. Contextualising the literature on Phytoremediation and its application in environmental rehabilitation

Described as a multidisciplinary approach to environmental rehabilitation, phytoremediation has gained interest because of its effectiveness to address multiple environmental issues (Jadia and Fulekar, 2009; Borišev *et al.*, 2018; Odoh *et al.*, 2019). As a biological approach, phytoremediation employs the use of plants for various applications as part of rehabilitation (Jadia and Fulekar, 2009; Zhang *et al.*, 2013; Barbosa and Fernando, 2018). Susarla *et al.* (2002) argue that it is often viewed as an ecological and green solution to environmental issues. Furthermore, literature also suggests that phytoremediation has been used in different environments, from addressing issues related to aquatic ecosystems, to environmental issues which are anthropogenic in nature (Ebel *et al.*, 2007; Rai, 2008; Rahman and Hasegawa, 2011).

Jadia and Fulekar (2009) suggest that plants can be used for different purposes when applied to environmental rehabilitation. While phytoremediation can be used to address issues related to water contamination, Wang *et al.* (2017) support that “phytostabilization”, “phytoextraction” and “phytovolatilization” are important uses of phytoremediation in the context of soil contamination and environmental degradation through mining. Wang *et al.* (2017) use a simple diagram (Figure 2.3) to illustrate how a plant is involved with these three uses as will be discussed.

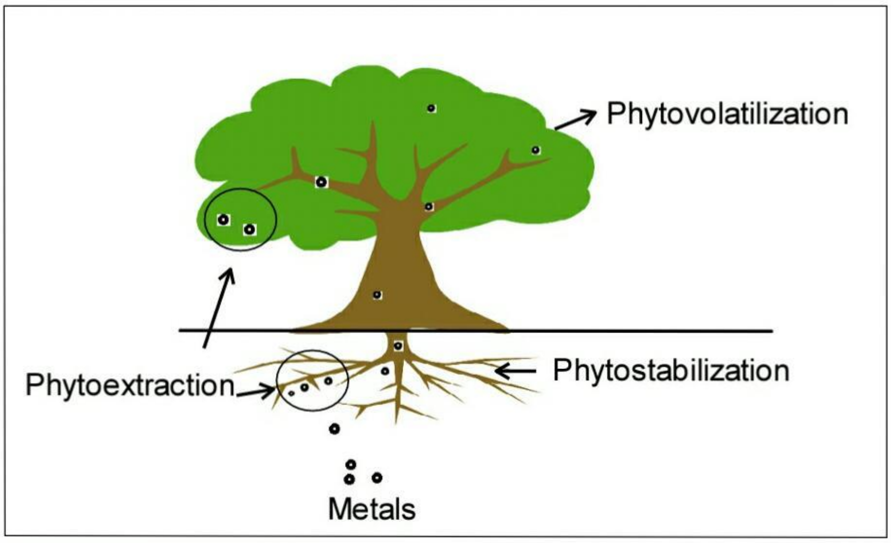

Figure 2.3. The types of soil phytoremediation (Wang et al., 2017).

A large number of efforts related to the use of phytoremediation focus on the use of specific plants for phytostabilisation (Kumpiene *et al.*, 2009; Galende *et al.*, 2014; Lee *et al.*, 2014; Parra *et al.*, 2016; Ciarkowska *et al.*, 2017; Tapia *et al.*, 2017). Phytostabilisation has been described by Cunningham *et al.* (1995) as well as Brunner *et al.* (2008) as the use of plants to restrict the mobility or spread of contaminants or leachates. Lee *et al.* (2014) argues that for phytostabilisation, plant roots and their root systems become the important focal point of methods and measures put into place as illustrated in Figure 2.3. In the case of phytostabilisation, plants act as anchors for the contaminants being addressed. Ciarkowska *et al.* (2017) further argue that plants have been used as barriers to stop the spread of salts, heavy metals, and contaminants. Furthermore, the study of Parra *et al.* (2016) demonstrates that experiments on different plants have been done to determine the potential use of different plant species since different plants’ root systems may be more effective in phytostabilisation.

Certain plant species have more potential being used for phytoextraction than they do being used for phytostabilisation. Bhargava *et al.* (2012) claim that phytoextraction refers to the ability of plants to absorb heavy metals and chemical contaminants. Lasat (1999) is of the opinion that plants considered for phytoextraction must be identified as hyperaccumulators. This is further argued by Wang *et al.* (2017) who illustrate that much more of a plant is involved in phytoextraction as compared to phytostabilisation (Figure 2.3). Bhargava *et al.* (2012) support that for phytoextraction, plants can extract heavy metals in addition to the essential metals naturally found in the soil which plants require for their growth. Lasat (1999) argues that plants identified with the qualities associated with hyperaccumulators have become a key interest in the use of phytoremediation for the uptake of contaminants. Furthermore, Juárez-Santillán *et al.* (2010) and Sheoran *et al.* (2010) argue that the use of hyperaccumulator plant species has also been of interest for phytoremediation of mining environments.

As some heavy metals cannot be stored or accumulated in plants without threatening their well-being and natural life, Jadia and Fulekar (2009) argue that these contaminants need to be addressed through phytovolatilisation. Phytovolatilisation is argued by Ghosh and Singh (2005) as the uptake of heavy metals and contaminants by plants. However, plants of interest are able to transform heavy metals into a less harmful elements. This is once again illustrated in Figure 2.3 by Wang *et al.* (2017). Many have stated that this transformation results in the emission of less harmful elements through transpiration (Moreno *et al.*, 2004; Tangahu *et al.*, 2011; Jeevanantham *et al.*, 2019). However, like hyperaccumulators, Jadia and Fulekar (2009) claim that not all plants are able to volatilise heavy metals. Furthermore, Jeevanantham *et al.* (2019) argue that the heavy metals and contaminants in need of volatilisation should be understood in relation to their reaction to plants as they may not be volatilised into less harmful elements. In this regard, Selvakumar *et al.* (2018) support that the considerations required in relation to phytovolatilisation can make it complex and difficult to achieve.

Previous studies demonstrate that phytoremediation has been applied to different scenarios for the rehabilitation or the cleaning up of different heavy-metal contaminants which may be present in soil or water (Wang and Freemark, 1995; Chaney *et al.*, 1997; Susarla *et al.*, 2002; Ali *et al.*, 2013; Cristaldi *et al.*, 2017). It is therefore important to highlight that phytoremediation has been used for other purposes apart from addressing soil degradation. Jadia and Fulekar (2009) highlight three other uses of phytoremediation, namely, rhizofiltration, phytodegradation and phytostimulation.

The use of phytoremediation to rehabilitate environments degraded by mining activities is becoming an option that many stakeholders and interested parties are engaging with around the world (Fernández *et al.*, 2017; Desai *et al.*, 2019; Midhat *et al.*, 2019). More importantly, Galende *et al.* (2014) argue that phytoremediation is a cheaper and more effective alternative to physical and chemical methods of rehabilitation. In Africa, while many of these efforts are not in the context of mining, Odoh *et al.* (2019) argue that some do address the potential of phytoremediation for environmental rehabilitation of degraded landscapes.

2.12. Phytoremediation in Africa: the case study of Haller Park, Kenya

Africa has suffered greatly from past and present cases of exploitation, particularly in relation to mining and mineral extraction (Ogola *et al.*, 2002; Agena, 2007; Ikenaka *et al.*, 2010; Durand, 2012). Many studies have shown that a vast number of efforts has been made to rehabilitate some of the degraded environments and landscapes of Africa affected by the negative effects of human activity (Cooke and Johnson, 2002; Tetteh *et al.*, 2015; Saichoono, 2010; Festin *et al.*, 2019; Odoh *et al.*, 2019). Odoh *et al.* (2019) argue that as part of rehabilitation efforts, the use of phytoremediation in the African mining industry is slowly developing.

A key example of phytoremediation in Africa is the case study of Haller Park, Bamburi, Kenya. The history and transformation of Haller Park from a cement quarry to a nature reserve has been documented by Siachoono (2010). Siachoono (2010) argues that reclamation of the degraded quarry began in 1971 with 26 different tree species being planted. After a six-month period, all but three species, *Cornocarpus lancifolius*, *Cocos nucifera* and *Casuarina equisetifolia*, had not survived the conditions of the quarry. Of the three, Siachoono (2010) supports that *Casuarina equisetifolia* adapted to the quarry's conditions the fastest. In addition, the tree grew fast and because it dropped foliage often, the tree was able to introduce a layer of humus to the soil.

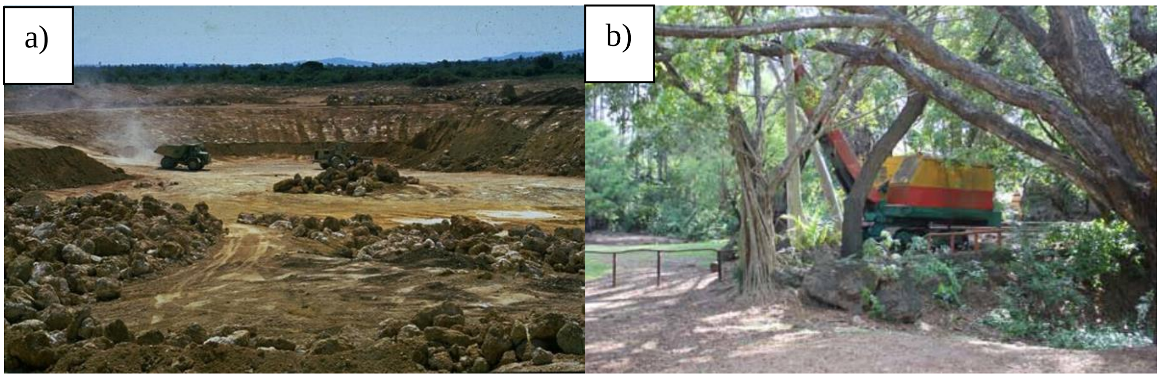

Figure 2.4. An image of (a) a cement quarry alongside an image of (b) the transformed and rehabilitated Haller Park ((a) Siachoono (2010) and (b) Knoop et al. (2012)

After several years, it was noted that *Casuarina equisetifolia* had allowed for more than 300 indigenous species to inhabit the landscape. Figure 2.4 is an important illustration of how Haller Park was transformed from a cement quarry to a nature reserve. In this regard, an image of a cement quarry, provided by Siachoono (2010), is placed alongside an image of Haller Park itself, provided by Knoop *et al.* (2012).

The story of Haller Park in Bamburi, Kenya has inspired and is the motivation of the current study. This story encompasses the ideals of the R4 as Lima *et al.* (2016) and Festin *et al.* (2019) suggest, demonstrating how rehabilitation efforts can lead to ecological restoration. This case study also exhibits the potential of *Casuarina equisetifolia* for environmental rehabilitation in the mining industry. The current study thus seeks to establish *Casuarina equisetifolia*'s potential in South Africa where phytoremediation studies are yet to further develop in the context of its mining industry.

2.13. Phytoremediation in South Africa

Odoh *et al.* (2019) argue that phytoremediation as a method has not further developed in South Africa due to different reasons. Regulation and enforcement are some of the reasons highlighted, however, according to Odoh *et al.* (2019), a poor understanding of different plant species and their potential as tools for phytoremediation is a key reason for why phytoremediation in South Africa has not developed further. Except for some species, this knowledge gap persists.

Berkheya coddii, a South African indigenous plant, has been of interest for its ability as a hyperaccumulator, both internationally and in South Africa itself (Robinson *et al.*, 1997;

Brooks *et al.*, 2001; Przybylowicz and Mesjasz-Przybylowicz, 2001; Davies and Mundalamo, 2010; Orłowska *et al.*, 2011). Through experimentation, the study of Robinson *et al.* (1997) was one of the earliest to consider the plant as a hyperaccumulator of nickel. From initial experiments, Mesjasz-Przybylowicz and Przybylowicz (2001) further studied the plant to evaluate its potential at mining sites in South Africa. As suggested by Brooks *et al.* (2001) and Orlowska *et al.* (2011), *Berkheya coddii* is presently more considered for its capability to absorb nickel for phytomining purposes rather than phytoremediation. Furthermore, Davies and Mundalamo (2010) argue that the intended use of the plant for phytoremediation in the mining industry has been limited but is developing into a rehabilitation method.

Wilson *et al.* (2017) consider another plant that has gained interest in recent years as a tool for phytoremediation in South Africa is *Tamarix usneoides*. Dye *et al.* (2017) argue that the plant has been of interest as a hyperaccumulator of salt and consequently able to extract heavy-metal contaminants. Additionally, Dye *et al.* (2017) claim that studies of *Tamarix usneoides* have been supported by the Mine Woodlands Project of the University of the Witwatersrand and Anglogold Ashanti Ltd. The Mine Woodlands Project is a key example showing initiative towards the development of phytoremediation strategies and methods for the mining industry of South Africa as suggested by Dye *et al.* (2017).

2.14. Different plant species in rehabilitation context

A common theme when discussing studies such as that of Dye *et al.* (2017), is the necessity to establish the potential specific plant species have in relation to phytoremediation. The study of Dye *et al.* (2017) is a recent example of efforts made to span the knowledge gap which Odoh *et al.* (2019) argue for. As it has already been pointed out, different plants have been used differently for phytoremediation purposes. Furthermore, different studies argue how the potential of different plant species can be evaluated in phytoremediation context.

Wang *et al.* (2017), referring to the study of Afzal *et al.* (2014) argue that plants contribute to the amelioration of soil through two different ways. Firstly, Wang *et al.* (2017) are of the opinion that plants can be used to address heavy-metal contamination through some of the uses of phytoremediation such as phytovolatilisation. Secondly, Wang *et al.* (2017) are of the same opinion as Afzal *et al.* (2014), suggesting that a plant’s biomass production is also important. Afzal *et al.* (2014) justify their view by stating that increased biomass may allow for increased endophytic bacterial activity which may aid to degrade pollutants. Borišev *et al.* (2018) argue further that trees which produce biomass may be able to contribute to the production of various plant-based commodities such as paper or fuel.

Another aspect which has been argued to be important when selecting plant species for phytoremediation is the plant's role in ecological succession. In this regard, Borišev *et al.* (2018) argue the importance of studying and comparing different tree species. As part of their study, Borišev *et al.* (2018) provide a table of different tree species which can be used for ecological restoration and their suitability to different contexts. According to Borišev *et al.* (2018), there are several different methods which can be implemented to encourage plant recolonisation of mine tailings areas, for example. One of these is argued by Borišev *et al.* (2018) as the use of pioneer species.

The plant in question for the current study, that is, *Casuarina equisetifolia*, is also among the plants listed by Borišev *et al.* (2018) which may be successful in achieving ecological restoration. As the plant species in question of this study, it is therefore worth presenting it as a potential tool which could be used by the mining industry of South Africa.

2.15. *Casuarina equisetifolia*: description of species, uses and potential

Adding itself to the growing list of plants studied for their potential to be used for environmental rehabilitation is *Casuarina equisetifolia*. Known by the common names "whistling pine", "whistling tree", "coast sheoak" or "horsetail sheoak", *Casuarina equisetifolia* is native to Australia as according to Boland *et al.* (2006). Part of the casuarinaceae family, it is described as a small to medium tree which can grow 8-16 meters tall. *Casuarina equisetifolia* is found mostly along coastlines, or growing very close to water bodies, on the banks of rivers or on beaches. This is particularly observed in Australia as illustrated by Boland *et al.* (2006) (Figure 2.5). Potgieter *et al.* (2014) show that the tree can grow in a range of different environments and is observed in many countries including South Africa, Kenya, Brazil, India, Taiwan, Sri Lanka and China. Boland *et al.* (2006) describe the appearance of *Casuarina equisetifolia* as resembling both conifers and willow trees.

Boland *et al.* (2006) are of the opinion that casuarina tree species are known to occur early in the ecological succession of an environment. This has been supported by Parrotta's (1999) study in relation to the reforestation of degraded landscapes. In this regard, Parrotta (1999) suggests that *Casuarina equisetifolia* can be considered a tree which will enable other species to inhabit areas that have become otherwise unfavourable. Because of its natural lifecycle, Parrotta (1999) supports that *Casuarina equisetifolia* is a tree which may effectively aid in the rehabilitation of forests, particularly those including many native species of plants.

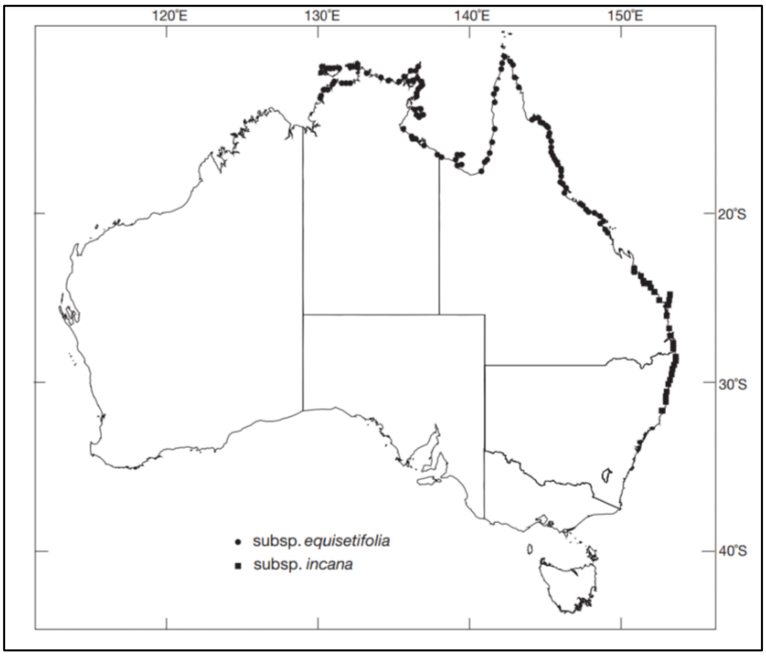

Figure 2.5. Map of Australia showing the distribution of Casuarina equisetifolia and subspecies incana. Note that the tree is only found along the coastline of the country (Boland et al., 2006).

Contrary to Parrotta's (1999) argument is the consideration of *Casuarina equisetifolia's* relation to allelopathy. In this regard, Batish *et al.* (2001) argue that *Casuarina equisetifolia* limits the growth and germination of understorey vegetation. Suresh and Rai (1988) are of the same opinion as Batish *et al.* (2001), arguing that *Casuarina equisetifolia* limits the growth of vegetation growing near or under it. Batish *et al.* (2001) further argue that *Casuarina equisetifolia* produces allelochemicals that affect the soil through leaves and cones that fall on the ground. Although allelopathy is seen as a negative impact on the growth of vegetation, Suresh and Rai (2012) argue that the allelopathic properties of *Casuarina equisetifolia* are not as restricting as those of other plants. Furthermore, Rizvi *et al.* (1999) argue that allelopathy of agroforestry species such as *Casuarina equisetifolia*, may be beneficial in different ways for control and the provision of specific services to the environment, therefore, adding to the uses of agroforestry species.

Probably the most important use of *Casuarina equisetifolia* in the context of the current study is its application in dune stabilisation in Richards Bay, Kwa-Zulu Natal, South Africa.

Rehabilitation strategies have been put into place since 1977 to mitigate the adverse effects of dune mining by the Richards Bay Minerals mining company (Lubke *et al.*, 1996; van Aarde *et al.*, 1996; Lubke and Avis, 1999). Dune mining, as Lubke *et al.* (1996) argue, requires a site to be cleared of all vegetation before mining, exposing the topsoil to wind.

A physical rehabilitation method, that is the use of a topsoil layer, highlighted by van Aarde *et al.* (1996), is applied to address the area affected by surface mining. This topsoil includes a rich seed bank of indigenous and native vegetation. In addition, indigenous trees such as *Vachellia karoo* are introduced to the area. Areas affected by dune mining are also revegetated as forest plantations. This is an important point as one of the trees grown at plantations is *Casuarina equisetifolia*. In addition to being used for dune stabilisation, the wood produced by the plantations helps surrounding communities (van Aarde *et al.*, 1996).

Considering the various uses and qualities of *Casuarina equisetifolia*, it is important to note that even though it is being actively used at Richard's Bay for dune stabilisation and forestry projects, South Africa still considers *Casuarina equisetifolia* as an unwanted category 2 invasive plant species. It is thus worth asking what opportunities and challenges exist in South Africa's mining industry related to the use of *Casuarina equisetifolia*. Does the plant have potential as a phytoremediation tool for South Africa's mining industry? How else can *Casuarina equisetifolia* be used for environmental rehabilitation by the mining industry, particularly to address some of the different impacts of mining?

2.16. Gaps in knowledge

The areas covered in this literature review includes a summary of the importance of South Africa's mining industry and how it contributes and has contributed to environmental degradation. As the main issue, tailings storage facilities have been argued as the most influential aspect of mining, which continues to affect the environment (Bridge, 2004). Tailings have several impacts on the environment, with their impact on soil being argued as a primary impact (Moore and Luoma, 1990). Furthermore, soil contamination leads to secondary impacts, including the infamous environmental issue, acid mine drainage (Akcil and Koldas, 2006).

Mining companies in South Africa engage with these environmental issues and report on their practices (de Villiers *et al.*, 2014). However, so much uncertainty and obscurity exists related to sustainability reporting in the mining industry that some such as Kirsch (2010) argue that sustainability is not practiced by the mining industry altogether. This sentiment is further complicated as several approaches are available to mining companies in terms of environmental management. Mines can elect to restore, reclaim, remediate or rehabilitate degraded areas and often, this is not explicitly expressed when mining companies report their efforts. The terms above, otherwise known as the R4, are critical when considering some of the methods which can potentially be applied for environmental management.

While physical and chemical methods are used as some of the strategies towards environmental rehabilitation, the application of plants through phytoremediation has garnered a lot of praise in the scientific community. Plants have been studied for their ability to address heavy metal contamination in the form of phytostabilisation, phytoaccumulation and phytovolitilisation as three main potential uses (Wang *et al.*, 2017). Plants have been used in projects around Africa and South Africa. One example was the use of *Casuarina equisetifolia* for the restoration and rehabilitation of the present, Haller Park in Bamburi, Kenya.

Casuarina equisetifolia, the object of Haller Park's success story, has shown potential in other applications, be they different from phytoremediation. However, direct application or enquiry of the plant's potential in South Africa's mining industry is yet to be seen. Furthermore, it must be noted that, by law, *Casuarina equisetifolia* is classified as a category 2 invasive species as per the Alien and Invasive Species Lists of the National Environmental Management: Biodiversity Act (No. 10 of 2004). This study, therefore, evaluates the potential of *Casuarina equisetifolia* for environmental rehabilitation and phytoremediation, considering the current dynamics, focuses, challenges and opportunities related to environmental management in South Africa's mining industry.

The current study therefore addresses gaps in the knowledge and literature base, providing more insight on environmental management across South Africa's mining industry, while taking into account the opinions and reported information of large mining companies themselves. Furthermore, it presents new information on the rehabilitation and phytoremediation potential of the plant, *Casuarina equisetifolia* with other findings in mind to present a better picture on the challenges and opportunities related to using the plant in the mining industry.

CHAPTER THREE

METHODOLOGICAL CONSIDERATIONS

3.1. Introduction

Any scientific endeavour needs to follow a chosen and justifiable means in which to address a research problem. Leedy and Ormrod (2015) demonstrate that in the past, this was described as “the scientific method”. The scientific method was a rigid structure followed by any researcher without which, their research would not be considered scientific. In short, Leedy and Ormrod (2015) describe the scientific method involving four steps. Firstly, a problem is identified by the researcher and a research goal is selected. Secondly, the researcher poses a hypothesis which may solve the problem. Thirdly, the researcher gathers data to prove or disprove the hypothesis. Finally, data is analysed and interpreted by the researcher who addresses the posed hypothesis. This rigid and dated method has been contested over the years as research can be conducted in many ways with justifiable outcomes. This has therefore given rise to the idea that research can be conducted according to a “methodology” defined by the researcher themselves which may or may not follow a rigid structure similar to that of the general scientific method.

It has therefore become imperative that any scientific work should clearly illustrate its chosen and followed methodology. A methodology, as per Leedy and Ormrod (2015:26) is the “general approach the researcher takes in carrying out the research project”. This is given further depth by Kothari (2004:8) who suggests that a methodology is a “way to systematically solve the research problem”. Simply put, Crotty (1998:3) describes a methodology as a “plan of action, process or design lying behind the choice and use of particular methods”. Kothari (2004) continues by arguing that an adopted methodology is dependent on the specific research problem and thus, each methodology is different and unique. Kothari (2004) demonstrates therefore that it is important for a researcher to clearly articulate their methodological approach as this would demonstrate the logic followed when addressing their research problem as well as justify the choice of specific techniques used for the collection, analysis, and interpretation of data.

The specific techniques used by the researcher is therefore described as “methods” and these methods are not the same as the methodology. Kirsch and Sullivan (1992:2) argue that while methods are the techniques used to gather evidence, methodology differs as it is “the underlying theory and analysis of how research does and should proceed". Therefore, the two terms cannot be used interchangeably. However, Kothari (2004) would argue that any methodology should describe the methods adopted as well as consider the logic behind choosing said methods. A methodology should also explain why the chosen methods were used in contrast to others.

This chapter describes the methodology of the current study. The structure of this chapter follows an initial discussion of the methodology of the study, followed by an overview of the methods chosen and their relevance. Following this introduction, the underlying philosophical positionality of the researcher and the research is described. An outline of the research design which governed data collection and analysis is then presented. Next, the methods used for sampling and gathering data are illustrated and discussed. Subsequently, the chosen data collection tools are listed and described in the context of the methodology. In conclusion, the methods used to analyse data are highlighted.

3.2. Philosophical positionality

Before describing the research design of this study, its philosophical positionality should be highlighted as this has had a bearing on the specific methodology followed. Research can be conducted through different approaches or seen through different "theoretical lenses" as suggested by Creswell (2007). As Creswell (2007) argues, it is important to explicitly illustrate the viewpoint or position which underpins the researcher and the research in question. However, as will be demonstrated and argued, constructivism was considered the most valuable philosophical positionality, underpinning the methodology and research design of this study.

It is therefore important to highlight what constructivism is, what its key tenets are and how it influenced the research process. As Crotty (1998) argues, through the constructivist view, "meaning" is not discovered but constructed. Unlike other philosophical positionalities which have long dominated the scientific method, Crotty (1998) suggests that through constructivism, the researcher and social actors are key to acquiring new insight. Fosnot (2013) further suggests that social activity, discourse and debate are important elements to constructivists. Because of its engagement with social actors, Creswell (2007) defines this position differently as social constructivism.

Constructivism is a vast philosophical positionality which has underpinned innumerable scientific endeavours. Crotty (1998) even suggests that it may be a positionality that is slowly changing the way traditional science is viewed. Defining different philosophies related to epistemology, Crotty (1998) defines the key tenets of constructivism. The first key tenet of constructivism is the idea that knowledge is derived as the researcher engages with the world. In this regard, Crotty (1998) states that a constructivism accepts that there is no meaning in the world without consciousness of said meaning. Therefore, it is the responsibility of the researcher to go out and find meaning and information related to their specific research problem. A constructivist values their observations as well as the observations of others who they may engage with. This may include other researchers as well as other members of society.

As a constructivist, the researcher valued their own observations and the observations of others as will be demonstrated in the description of the current study's research design. Furthermore, the views of past researchers and professionals working in the mining industry of South Africa were important sources of information without which this research could not be completed. Qualitative data was therefore used extensively throughout the research process, allowing for the researcher to make sense of current events and deduce a conclusion in this regard.

Although constructivism holds that "meaning" is not found within the objects of science but rather in the understanding drawn by the researcher, Crotty (1998) highlights that through constructivism, meaning is not created, but rather constructed. This refers to the importance of interpretation as the second key tenet of the positionality. Interpretation is viewed as a cornerstone of the positionality with some such as Tracy (2012: 40) categorising constructivism as an "interpretive paradigm". Crotty (1998) supports that constructivism embraces both objectivism and subjectivism. In this regard, it is important for the researcher to make sense of what meaning may be embedded within the observed objects of enquiry. Furthermore, the perspectives and interpretations of the individuals and actors which the researcher engaged with were equally important in the current study.

Without the interpretation of the researcher, the data collected would hold very little to no meaning. Furthermore, the viewpoints and perspectives of social actors engaged with were crucial for the researcher to understand the data gathered. Therefore, constructivism as the philosophical positionality of the current study strongly upheld the interpretations and understandings of the researcher as they engaged with different social and environmental actors who possessed their own perspectives which needed to be taken into account. The value the current study rendered to content analysis is an example of how this tenet of constructivism was upheld. At the same time, it must be remembered that this presents bias in how the information gathered was understood and how conclusions were ultimately made.

An acknowledgment of the biases associated with constructivism is yet another key tenet of the philosophical positionality in question. Leedy and Ormrod (2015) state that constructionists are required to be "upfront" about any potential bias that may arise from prior assumptions before conducting the research as well as their interpretations of the data collected. Tracy (2013) supports this argument by suggesting that because constructivism relies on interpretation, any identifiable bias be addressed through a study's research design.

As for the current study, several methods are employed as part of the research design to triangulate findings and secure their reliability and validity. Therefore, the ideals of constructivism are deep-rooted in the chosen methodology of the current study. Highlighting any possible bias and addressing them allows the current study to maintain reliable information using more than one data source.

An important point to mention is that this study could be approached through other philosophical positions. Some of these include postpositivism, pragmatism, or transformative movements. None of the mentioned were considered as appropriate as constructivism. For example, this study could be approached through postpositivism. Creswell (2007) states that as a philosophical position, postpositivism is at the core of empirical science. It values the need to test causes through measurement, observation, and experimentation. Experimentation with the plant was not seen as potentially beneficial for data collection. Although first considered, a pot experiment would not be sufficient in itself to assess the potential of *Casuarina equisetifolia* as this would not assess all possible uses of the plant. A broader approach was necessary to address multiple aspects related to the use of the plant. Therefore, constructivism is of more value, making use of already available information and other methods to paint a bigger picture illustrating the potential of *Casuarina equsetifolia* as a tool for the mining industry.

This study could also be addressed through the position of a transformative movement. Transformative movements, as described by Creswell (2007), are often inspired by groups such as Marxists, feminists as well as other critical theorists. Such movements, as Creswell (2007) argues, supposes that research be linked to an action agenda to address current policy. The researcher in this regard, could assume the positionality of an environmental activist who wishes to address political or social issues within the mining industry of South Africa. However, this was considered to do more harm than good to the current study. In contrast, the constructivist positionality chosen for this study offers more research possibility as the researcher assumes the role of a learner, gaining more insight as data is collected. Therefore, a philosophical positionality inspired by transformative movements would not yield as much data and new insight as a research design based on constructivism.

3.3. Research design

Two key points of enquiry were identified while planning the research design and selecting an appropriate methodology. Firstly, it was noted that to answer the research questions, it was imperative to engage with the mining industry of South Africa. This would yield information on the ways rehabilitation is addressed as well as what challenges and opportunities exist when using plants for rehabilitation purposes. Secondly, it was noted that as *Casuarina equisetifolia* was a key subject of the current study, as not only does it relate to a specific research question, it also relates to the overall aim. Any and all forms of information or data sources which have and currently engage with *Casuarina equisetifolia* were thus necessary to consult. Therefore, the research design of this study considered the mining industry of South Africa and *Casuarina equisetifolia* as key points of enquiry.

Three obstacles were encountered from commencement of this study to its later stages which further influenced the research design. These three obstacles relate to (1) limitations related to gathering data from the mining industry, (2) *Casuarina equisetifolia's* status in South Africa, and finally, (3) the adverse effects caused by the COVID-19 global pandemic.

As the study was initiated, it was realised that mining companies were not comfortable providing information on their approaches to environmental management as they were afraid of any legal implications it may have on their activity. Therefore, six mining companies save two, refused to participate in this study. The two mining companies offered tours of their active operations and tailings storage facilities. Selected professionals also offered more information on their work and opinion in the form of formal discussions or semi-structured interviews. The methodology of this study was therefore modelled to optimise data collected from these visits and engagement with professionals.

This study aimed to assess the phytoremediation potential of a plant which is currently considered a category 2 invasive species. For this reason, no experimentation or controlled tests would have been possible to assess the plant's phytoremediation potential without a permit. Rapid detection and response programs have been put in place to effectively remove *Casuarina equisetifolia* trees from much of the area they grow naturally in, further limiting the collection of plant samples. In this regard, to assess *Casuarina equisetifolia's* phytoremediation and rehabilitation potential, this study employed a research design which benefitted from collecting data from the scientific body, previous studies as well as select professionals currently working with and studying *Casuarina equisetifolia*.

As a final, and most critical obstacle, this study was conducted during the COVID-19 global pandemic. Any further field work would not have been possible during the pandemic. Therefore, online media and information accessible from home were the only options available for collecting any additional data following field visits. The methodology of this study was thus adjusted to make use of online information and services, including ESG reports, online literature and social platforms for interviews and questionnaires.

With the above considerations in mind, a three-step research design was adopted for this study (Figure 3.1). These steps include (1) a preliminary desktop study on the mining industry of South Africa, (2) Field work and engagement with professionals and finally (3) a rapid appraisal of published studies to establish *Casuarina equisetifolia*'s potential to be used for rehabilitation in the mining industry. These steps, therefore, involved the collection of data through desktop research, field observations and engagement with different professionals.

As a first step, an initial desktop study was undertaken. This involved an assessment of available ESG reports, annually published by mining companies listed on the Johannesburg Stock Exchange (JSE). The use of ESG reports have been useful in other studies (Doni *et al.*, 2016; Lokuwaduge and Heenetigala, 2017) and offered the opportunity for the current study to gather information from the mining industry as a whole without needing to engage with individual companies for information readily available. ESG reports would provide more information on South Africa's mining industry and their general practices. Furthermore, the desktop study allowed for information on the entirety of South Africa's mining industry to be collected remotely. This step was a critical part of this study, steering subsequent methodological steps into a specific direction.

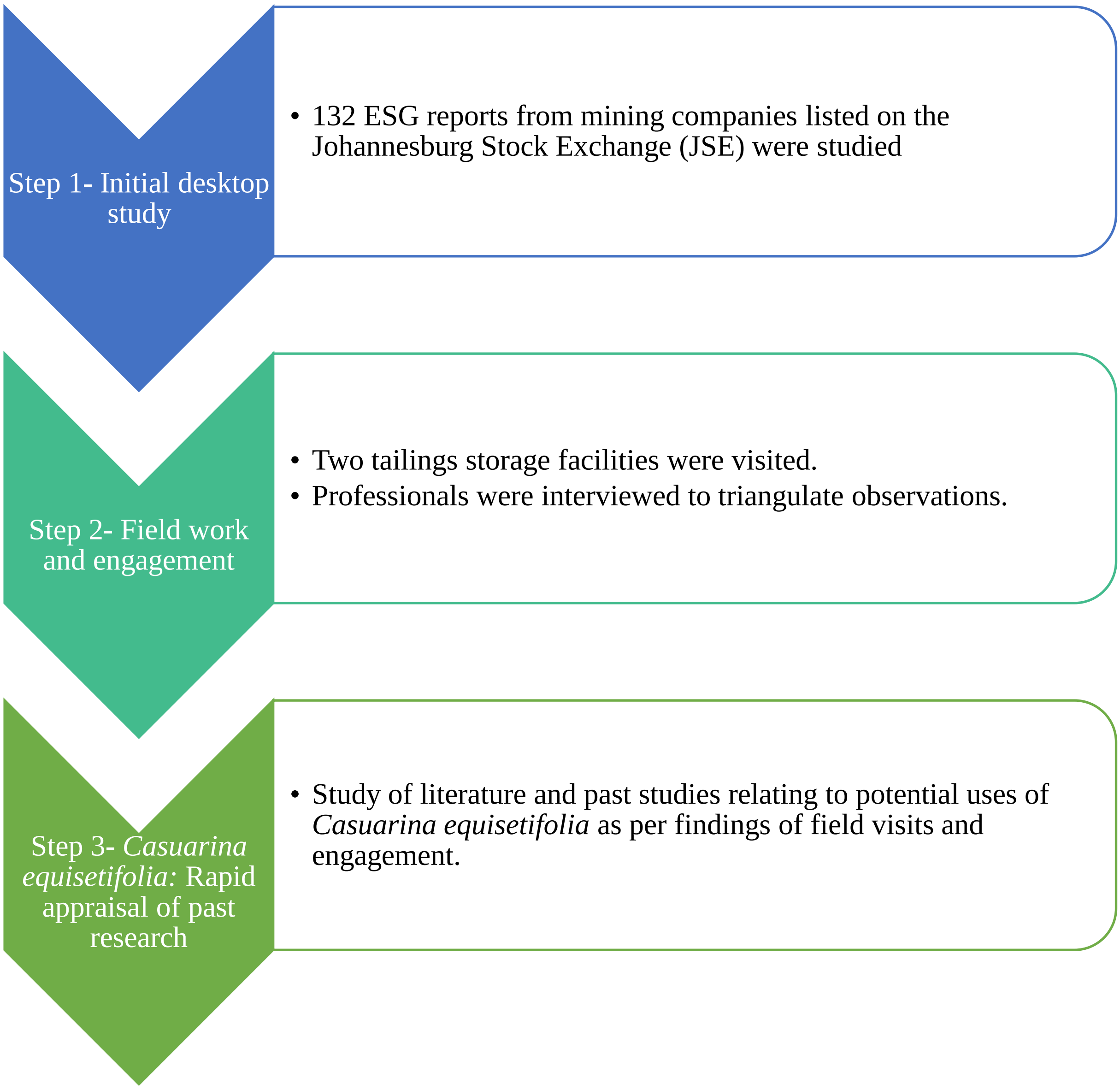

Figure 3.1. The three steps part of this study's research design.

Following the initial desktop study, two tailings storage facilities were visited. This was for observational purposes; to better understand the dynamics of mine tailings storage and rehabilitation. The data gathered through observation was to compliment the initial desktop study of ESG reports, placing findings in a more practical context. As part of this step, new insight on how companies manage tailings storage facilities could be gathered. Furthermore, mine rehabilitation, as practically performed in South Africa, could be observed to better situate possible use-cases of *Casuarina equisetifolia* in the context of these or similar facilities. Field visits offered an exclusive means of engaging with the mining industry to better understand their work without making assumptions about the nature of rehabilitation.

Further engagement with the mining industry was achieved through interviews and online questionnaires. Several environmental professionals were interviewed or asked to complete an online questionnaire. Some of these professionals worked at the sites visited while others were identified as potentially important information sources. These professionals included a mix of academics and environmental managers. Their viewpoints were important to triangulate information gathered through desktop and field research. This step also offered the opportunity to learn more about the opinions of professionals on mine rehabilitation in South Africa and the potential use of *Casuarina equisetifolia*.

Finally, following the initial desktop study, field visits and engagement with professionals, a rapid appraisal of literature was performed. This appraisal considered findings from previous steps and made use of past studies to establish the potential of *Casuarina equisetifolia*. In this regard, not only was the plant's phytoremediation potential established, other uses of *Casuarina equisetifolia* as a phytotechnology were considered and assessed.

The research design of this study held fast to the ideals of constructivism, while considering key points of enquiry and circumventing limitations. It is also important to note that an "emergent" research design as described by Leedy and Ormrod (2015) was adopted. In this regard, as information was collected through the various steps, further research was conducted to better analyse the data acquired. Each step had an impact on the information gathered in subsequent steps. Therefore, data collection had a bearing on data analysis, which in turn had a bearing on the nature of data collection in the next step of the research design. This emergent research design played an important role on the way sampling as well as data collection and analysis were performed.

3.4. Study population and sampling procedure

As the population of interest would include the entire mining industry and its dynamics as well as other institutions, a sampling strategy was employed to gather enough data in a less time-consuming and efficient way. The three-step research design favoured a sampling strategy which Maxwell (2009) describes as purposeful sampling. Purposeful sampling is argued by Maxwell (2009) as an effective sampling strategy used for qualitative research where particular persons, settings, events, and material are deliberately selected as they hold important information pertaining to the greater population. As data collection progressed, different companies, operations and eventually professionals were identified.

Purposeful sampling took place during the initial desktop study of ESG reports. In this regard, purposeful sampling was helpful to identify and collect data from mining companies who have a potentially large footprint in South Africa's mining industry. This eliminated the need to evaluate an unnecessary amount of smaller mining companies who may not even have the information sought. Furthermore, engaging with ESG reports eliminated the need to contact all identified mining companies for data already publicly available. Therefore, ESG reports of mining companies were an important source used to gather data from South Africa's mining industry.

ESG reports are prepared and made public by mining companies who have many stakeholders and investors involved with their operations. ESG reports offer stakeholders an opportunity to review the well-being of a company. ESG reports normally include information on the extent of environmental rehabilitation efforts put in place by respective mining companies or how they address rehabilitation altogether. In this regard, mining companies listed on the JSE formed a critical sample for this step as they are assumed to be the largest in the country. Additionally, ESG reports aided in identifying the two large companies who would eventually provide tours of their facilities and engagement with professionals working for them.

All ESG reports were accessed online via the websites of the mining companies identified. As an additional sampling measure, no reports older than 10 years old were considered in the study sample. These reports were downloaded, stored and studied on the personal computer of the researcher. No physical copies of the reports were printed or made. After all information of interested was extracted, reports were subsequently deleted from the computer they were stored on. Only reports which were downloadable as PDF documents were considered as part of the instrumentation used for the desktop study. Reports which were only available in web or HTML format were omitted as these could later be altered by the website managers themselves.

A total of 53 mining companies were listed on the JSE. Of these 53, five were excluded from this study as all their operations were internationally based. This brought the total number of mining companies studied during the desktop study to 48 mining companies engaging in active mining across the country. A table was created to include all the data used to report information gathered from ESG reports (See Appendix B).

ESG reports were available for 65% of the 48 mining companies. This accounted for 31 mining companies for which reports were available. A total of 132 ESG reports were gathered and studied from the 31 mining companies. Reports could not be found for the other 35% and so, these companies were therefore removed from the desktop study.

Companies with available reports were classified and grouped according to the type of mining they engaged in. Nine different types of mines were identified. These included platinum, gold, iron, coal, diamond, chrome, aluminium, copper, and mines which were involved with the mining of multiple minerals and resources. Figure 3.2. illustrates the different groupings and presents the percentage each group covered of the total number of mining companies studied. As illustrated, gold and platinum mining accounted for a cumulative total of 52% of the mining companies studied. A further 13% represent companies who mine multiple minerals which include platinum and gold. Therefore, a substantial amount of the sampled mining companies included those which mine platinum and gold.

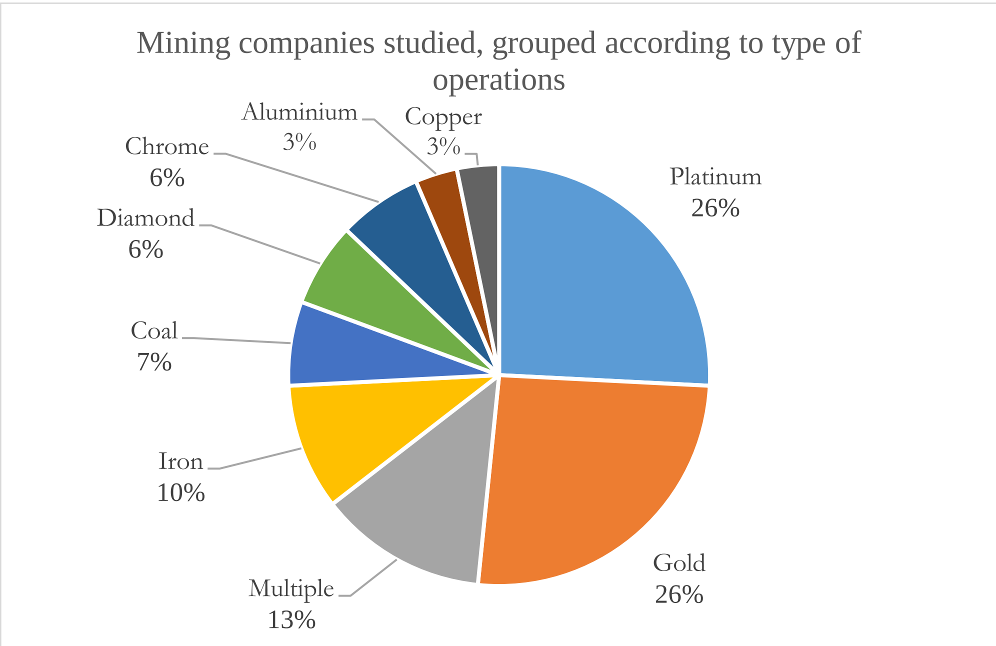

Figure 3.2. Categorisation of mining companies according to the type of mining they engage in.

Data collected from ESG reports were recorded on a Microsoft Excel 365 spreadsheet and included both descriptive details and other information related to aspects of interest. The same spreadsheet was used to create charts and perform other statistical tests when analysing data.

In addition to Microsoft Excel 365 was also used to analyse data gathered through the initial desktop study.

After the initial desktop study of ESG reports, several mining companies of interest who continue active rehabilitation and tailings management were contacted. A total of six different mining companies were contacted via interviewed professionals and academics. Of the six, two mining companies agreed to further engage with this study through offering tours of their tailings storage facilities and permission to engage with professionals working for them. Two tailings storage facilities, one of each mining company, were visited.

The First tailings site visited, labelled in this paper as Site A, is an example of an active tailings storage facility located in one of South Africa’s most active platinum mining areas, that is, the Rustenburg mining area. A guided tour was conducted by the site supervisor who provided more information on the site itself. The tailings storage facility included four different tailings dams managed by a separate company in charge of tailings and environmental management. The oldest tailings dam of the site has been in operation since 1978. Although the dams store the tailings of platinum mining activity, the dams are also used to store the tailings of chrome mining activity in the same area. A team of mine experts is involved with the management and maintenance of the site on a 24-hour basis.

The second site visited, labelled as Site B, is an active tailings storage facility located in the Ekurhuleni area of the Gauteng province. The area has a rich history of gold mining; Site B itself, is an iconic part of that history as one of, if not the largest, gold tailings storage facilities in the world. The site is part of a grand network of mining activity in the Ekurhuleni, East Rand and Johannesburg areas. A guided tour was offered by an environmental manager of the site who provided information on the facility and answered all questions part of the formal interview.

The tailings storage facility includes a single dam spanning an area of 11 to 14 km^2. The extent of the site is so great that its perimeter extends far into the horizon (Figure 3.3). The facility was commissioned no later than 1985. Active tailings deposition and rehabilitation was observed at the site. The dam stores both gold and platinum tailings. The tailings stored at the dam includes tailings from other storage facilities being re-mined or cleared up. Like Site A, Site B is an active site where tailings are still being stored and managed on a 24-hour basis as pictured in Figure 3.4.

Figure 3.3. A photograph taken before the catwalk, at the top of Site B's tailings storage facility.

Figure 3.4. A cyclone depositing new tailings at Site B.

Field visits as a form of ground truthing was an important means of validating and adding to findings from the initial desktop study as supported by Leedy and Ormrod (2015). Observations were made during field visits and allowed for more information relating to the dynamics of tailings storage and rehabilitation to be collected.

Purposeful sampling was coupled with snowball or chain sampling as per Wright and Stein (2005) to identify different professionals, who through their work, could provide qualitative information to triangulate observations and provide additional insight. Several professionals were identified through contact with the two companies who provided permission to visit their operations. Other professionals were identified through the researcher's academic institute and the international institute, the Technical University of Mombasa (TUM).

A total of eight individuals were identified and subsequently interviewed. Included in this sample were the two environmental managers of each site visited, the site supervisor and assistant site manager of Site A. A soil scientist working at a different mining company than the two engaged with was also contacted as well as an environmentalist who actively engages with the sustainability of mining companies. The environmental manager of Haller Park in Bamburi, Kenya and an academic who has studied *Casuarina equisetifolia* and its relationship to South Africa's environment were also engaged with.

In more detail, the eight individuals were contacted and subsequently engaged with in different ways and through different means. This was dependent on each professional's availability, schedule, time allowance and other factors including emerging social restrictions following the COVID-19 pandemic as well as internet or data limitations. In many cases, the identification and engagement with one individual led to contact with another, emphasising the snowball or chain sampling procedure the current study embraced. As a starting point, several professionals were identified with the help of the researcher's supervisor. In this regard, the environmentalist and soil scientist were the first to be contacted. The environmentalist referred the researcher to Site B's management, who were contacted through their relevant offices. In a similar way, the soil scientist referred the researcher to Site A's management, who were likewise contacted through their relevant offices.

The management of both mining companies permitted the researcher to visit their sites and speak to relevant professionals or the environmental managers of the sites themselves. The environmental manager of Site A referred the researcher to their contractors and employees for further engagement. The employees engaged with in this regard included the assistant site manager and the site supervisor of Site A. These two employees, along with the two environmental managers, the environmentalist and the soil scientist accounted for all the professionals engaged with relating to the mining industry.

Two internationally based professionals were also contacted to learn more about *Casuarina equisetifolia*, its phytoremediation or phytotechnological potential as well as its relationship to the ecology of South Africa. This included the environmental manager of Haller Park in Bamburi, Kenya and the academic now based in Canada. This academic provided invaluable help in establishing contact between the researcher and Haller Park. As a success story in Africa, Haller Park is an example of how *Casuarina equisetifolia* could be implemented as an environmental management or rehabilitation strategy. Through engagement with the environmental manager of the park, the researcher drew insight from this case study. The environmental manager also shared their valued opinion on implementing similar strategies in the mining industry in South Africa. Finally, the academic based in Canada was contacted by the researcher directly. Contrary to the information sought from Haller Park, the researcher sought information from the academic on the possible adverse effects *Casuarina equisetifolia* could have on South Africa’s ecology as an invasive plant species. At the same time, the academic was invited to share their opinion on the potential of *Casuarina equisetifolia* as an environmental management or rehabilitation strategy.

Professionals were offered the opportunity to share their opinions and viewpoints, either during field visits, through a formal in-person interview, via an online interview or online questionnaire. Two professionals, including the site supervisor of Site A and the environmental manager Site B, provided information while guiding field visits. The assistant site manager of Site A participated in a formal in-person interview. The environmentalist and the academic participated in online interviews and three professionals, namely the soil scientist, the environmental manager of Haller Park and the environmental manager of Site A, completed online questionnaires. More detail will be provided on the nature of engagement as this differed per professional as to acquire specific insight relating to their own work for better understanding the dynamics of rehabilitation in the mining industry as well as the potential of *Casuarina equisetifolia* in the same context.

A rapid appraisal of existing studies and literature was conducted to assess the potential of *Casuarina equisetifolia* considering what was already learnt from the mining industry and the various professionals interviewed and engaged with. Through a rapid appraisal, information and specific case studies related to the use of *Casuarina equisetifolia* for environmental management could be identified and studied in the context of the current study. This rapid appraisal followed similar processes as other studies such as that of Ganann *et al.* (2010) and Featherstone *et al.* (2015). In this regard, a rapid appraisal is different from a systematic review as it includes the benefit of collecting important information in less time, with the least amount of tedious work (Featherstone *et al.*, 2015). This rapid appraisal involved searching selected academic databases for relevant material, grouping material according to primary and secondary themes, and finally, analysing the content of individual literature sources for information to address the research questions.

Literature sources were gathered from six academic databases. These databases were chosen as they return search results from multiple peer-reviewed journals and academically accepted publishers. Sources of interest included journal publications, chapters and books, dissertations, and theses. Sources were accessed online via the university library website. The search engines of each database were used to find sources of interest.

Specific key words were used to find sources on the various databases. This primarily included the key words "*Casuarina equisetifolia*". Advanced search tools were applied to refine database searches to find sources with the key words "*Casuarina equisetifolia*" appearing in their title or abstract. Other key words used to find relevant sources included any of the R4 terms as per Lima *et al.* (2016). This included the key words "restoration", "reclamation", "rehabilitation" and "remediation" appearing anywhere in sources. This refined searches to identify studies which make mention of *Casuarina equisetifolia* in the context of environmental management. The total returned results per each of the R4 terms were recorded on a dedicated spreadsheet. Once the number of returned results were recorded, individual sources were analysed for their content.

Table 3.1. provides the total number of results returned by search engines of the six databases. Of the returned results, a total number of 69 literature sources were identified as relevant to the current study. As the content of sources were analysed, those identified as relevant to the current study were grouped according to themes. Each relevant source was associated to two themes, one being their primary theme or focus, the other being a secondary theme apart from their focus. Table 3.2. provides a list of all the primary and secondary themes identified, under which relevant sources were grouped. Some themes occurred as primary as well as secondary themes across the relevant sources as observed in Table 3.2.

Table 3.1. Number of returned search results per academic database.

	Search criteria or Keywords				
Academic databases	***Casuarina equisetifolia* + Rehabilitaton**	***Casuarina equisetifolia* + Restoration**	***Casuarina equisetifolia* + Reclamation**	***Casuarina equisetifolia* + Remediation**	**No. of relevant sources**
Elsevier	19	13	7	4	9
JSTOR	85	84	83	83	8
Proquest Central	83	84	78	77	28
Springerlink	98	163	117	35	6
Taylor & Francis	31	59	30	8	9
Wiley Online	42	87	2	3	9
Totals	358	490	317	210	69

Table 3.2. List of all primary and secondary themes used to categorise relevant sources.

Primary themes	**Secondary themes**
Biology	Biology
Chemistry	Ecology
Ecology	Mining
Ecosystem services	Nitrogen fixing
Nitrogen fixing	Nutrient cycling
Nutrient cycling	Resilience
Phytoremediation	Soil amelioration
Resilience	Water
Soil amelioration	Wind
Water	

Content of individual sources were then analysed to identify important information and case studies relating to the use and potential of *Casuarina equisetifolia* for environmental management in different contexts which included mine rehabilitation. The findings of this rapid appraisal were linked to the other findings gathered from the mining industry as well as from professionals engaged with.

Altogether, the 132 relevant ESG reports, two sites visited, eight professionals engaged with, and the 69 literature sources gathered during the rapid appraisal formed the sample of the current study. Data gathered through this sample were used to address the research questions, aim and objectives. This sample not only represented the mining industry, but the scientific body who have already engaged with relevant topics and areas from which the current study could draw information from to construct an argument in relation to its aim. Furthermore, as this was a qualitative study, the content provided by the various data sources were of most importance rather than a sheer number of sources within the sample. Therefore, the described sample was adequate to address the current study.

3.5. Data collection tools

To collect data from the various sources part of the sample, three main data collection tools were used. These three data collection tools included observation, interviews, and rapid appraisal. All three tools were used throughout the data collection process, being used at different stages as the study progressed. These three tools are therefore considered the primary instruments used to conduct the current study and were at the heart of its methodology. Although this study could have been approached using other tools, the selected three had their own advantages relating to the qualitative nature of the data sought and collected. The advantages of each selected tool will be further discussed in this section.

3.5.1. Observations

Observation was an important tool for data collection used throughout the current study's research design and formed an important part of the methodology adopted. Denzin and Lincoln (2018) argue the importance of observation as a necessary part of research which has been refined and perfected throughout history. In this regard, Denzin and Lincoln (2018) state that observation is used in both quantitative and qualitative studies under several paradigms or positionalities including more rigidly structured studies following the previously considered "scientific method". However, Leedy and Ormrod (2015) express their opinion that in qualitative studies, observation is more free-flowing or flexible and therefore, more valuable. Observation allows a researcher to collect data from a range of sources, particularly when a study follows an emergent research design as Leedy and Ormrod (2015) suggest. In the context of the current study, observation allowed the researcher to gain an understanding of the state of environmental management in the mining industry of South Africa and subsequently assess challenges and opportunities. Observation allowed the researcher to gain first-hand experience in the mining industry through site visits and through learning from professionals.

During the two field visits, observation was critical for the collection of adequate data. In this regard, all important information on the dynamics of tailings storage and rehabilitation thereof were documented by the researcher during the two field visits. Some important considerations made during field visits and site observations were, (1) what impacts mines addressed, (2) in what ways they addressed these impacts, (3) what were some of the challenges and opportunities observed in relation to the implementation of rehabilitation methods and (4) what is the role of plants or how are plants used for environmental management at the sites.

Notetaking and photography were means of recording and eventually presenting observed data. Field notes were recorded in the researcher's personal field journal. Although photographs were taken at Site B, the managers and staff of Site A prohibited the taking of photographs during the visit. During both site visits, protective gear was necessary. Both field visits were a day long at each mining operation.

3.5.2. Interviews

Along with observations, interviews allowed for additional data to be collected relating to what was observed and what might not have been apparent. Merriam and Tisdell (2016) cite Patton (2015) who argue that interviews are necessary to gather information which cannot be acquired through direct observation. Merriam and Tisdell (2016) describe interviews as being either "highly structured" or semi-structured". The current study elected to maintain a semi-structured approach to interviews and engagement with professionals. In this regard, the current study followed the ideals of Leedy and Ormrod (2015) who argue that interviews in a qualitative study should resemble that of a friendly chat. Therefore, through the interviews of this study, it was not the intention of the researcher to only draw information through a straightforward and rigid question-answer session. Instead, the researcher sought to engage with professionals to learn more about their work, communicating its perceived relation to the current study in the hope that professionals would share even more.

The semi-structured and less rigidly defined method of interviewing employed by the researcher allowed for interviews and questionnaires to be tailored to the specific professional being engaged with. As will be discussed, although a general format was adopted for both interviews and questionnaires alike, questions and points of enquiry differed per professional. The intention, therefore, of engagement was to acquire focused and qualitative data for the purpose of data triangulation. Following the definition of Roulston and Choi (2018), triangulation refers to the use of multiple data sources, which may include interviewing a number of different individuals who may have their own viewpoints and information to share related to the same phenomenon in question. Therefore, the different viewpoints of the professionals engaged with were considered together with information gathered from other data sources to gain insight on specific areas of interest.

Interviews were performed in person and through online platforms or media. Except for three interviews, the other five were conducted making use of mediatory tools. Important mediatory tools used were online questionnaires as well as social platforms such as Zoom and Microsoft Teams. The use of “mediated interviews” are argued by Tracy (2013) to be an effective means of collecting interview data in situations where geographical limitations exist, or the individual is otherwise unavailable. These “mediated interviews” in the form of online questionnaires and online interviews were considered collectively with the traditional in-person interviews as data gathered through engagement.

A 45-minute time limit was observed when conducting both in-person and online interviews. Questionnaires were drafted to allow for professionals to complete them in 15 minutes. In some cases, interviews were conducted during field visits to maximise data collection in a small amount of time. A more flexible and casual nature of interviewing was chosen to ensure that professionals were comfortable and adequately conversed with. Since many of these professionals can be related to the operations they work at, their anonymity is protected throughout this study. However, professionals were made aware that their corporate or professional title would be used, which may compromise their anonymity. All interviews were carefully recorded through notetaking, with additional noting of direct quotes. Direct quotes were noted as no voice recording was performed to allow the professional to feel more comfortable.

An interview guide (see Appendix C) was drafted and used to guide all interviews and to draft the respective questionnaires of the current study. Interviews and questionnaires included three main question categories. In brief, the three categories addressed were (1) the professional themselves and what they do, (2) further exploring the work the professional is involved with and how it relates to the current study, the mining industry as well as *Casuarina equisetifolia* and finally, (3) their opinion on the use of *Casuarina equisetifolia* and phytoremediation in the context of South Africa's mining industry considering the case study of Haller Park in Bamburi, Kenya.

The following is a breakdown of the structure of each question category which was used to guide the researcher's flow of enquiry. As part of the first category of questions, the professional was asked about their role, what it entailed and the dynamics of their work. In some cases, this section was omitted if this information was already known. This data was crucial to clearly illustrate the background from which the professional comes and how this may affect their view, their involvement and knowledge on environmental rehabilitation in the mining industry.

The second category was an extension of the first, delving deeper into the detail of the work professionals are involved with. Professionals were asked about the rehabilitation strategies used in the mining industry. Furthermore, professionals were also asked about the R4 as per Lima *et al.* (2016) and their relationship to rehabilitation goals. Professionals were invited to discuss which strategies and methods were most effective in their opinion and if other options would be worth exploring. Additionally, professionals were asked about the various aspects of mining that were in particular need of rehabilitation and remediation. Where chemical pollution was mentioned as a particular issue in need of rehabilitation, professionals were asked which chemical contaminants were of concern. In the case of the ecologist, this section was completely omitted as they did not work with rehabilitation in the mining industry. This category was important as it opened up discussions of the challenges and opportunities involved with various rehabilitation strategies and environmental rehabilitation in the mining industry as a whole.

The third and final category of questions related to *Casuarina equisetifolia* directly. The case study of Siachoono (2010) and the use of *Casuarina equisetifolia* at Haller Park was communicated to professionals. Professionals were asked if they had heard of this case study and what their opinion was on its relevance to South Africa's mining industry. Questions relating to *Casuarina equisetifolia*'s current status as an invasive species in South Africa and its potential in the mining industry followed. Since the academic could provide more detail on this section, additional elaboration questions were asked. This category focused mainly on acquiring the opinion of professionals on the potential of *Casuarina equisetifolia* and opened up discussions of how the use of the plant may have been discredited due to its other qualities such as allelopathy. This would thus be related to the current strategies implemented at mining operations and if *Casuarina equisetifolia* could have potential uses.

Between ten to eleven main questions, four or five questions for further elaboration, ice-breaker questions and cooling-off questions all formed part of each interview or questionnaire. This interview guide was drafted as per the guidance of the researcher's supervisor.

During in-person and online interviews, the researcher strictly followed the interview guide, taking particular care to ask questions relating back to the three main categories. Although some conversations required the researcher to ask questions in a different order than planned, these questions were asked where and when possible. Discretion and attention were necessary in situations where several questions requiring answered by professionals required further elaboration. As part of each of the main categories, however, a plan for the type of information each category would yield was kept in mind.

The questionnaire included questions of the second and third category as highlighted above. To make the questionnaire easier to answer, a number of questions were made multiple choice, including selectable answers and an option for the professionals to add additional notes. Multiple choice options were formulated taking into account the observations made during site visits and other information gathered. Another option accommodated for any possible limitation related to the selectable answers. Questionnaires were created using Google Forms and required very little internet data to access compared to online interviews themselves. A full draft of the online questionnaire is provided in the Appendix D.

3.5.3. Rapid appraisal

In addition to observations and interviews, rapid appraisal was another tool used to gather qualitative data from literature sources. These sources include ESG reports considered during the initial desktop study as well as during the study of existing literature on the use of *Casuarina equisetifolia* for environmental management. Often referred to as rapid review, this tool is a form of systematic review. Systematic review is a method which engages with multiple studies through published sources to outline areas where research has been abundant, while highlighting areas where there are research gaps. The current study performed a "rapid" review or appraisal instead of a full systematic review as described by Crowther *et al.* (2010). Ganann *et al.* (2010) argue for the value of a "rapid review" in place of a systematic review stating that, in some cases, valuable data can be collected in a shorter amount of time. In this regard, important sources were analysed for their content, without imposing a set of rigid criteria or questions as a systematic review would have required. Rapid appraisals or reviews are performed for many purposes, including gathering data for stakeholder decision-making or policy makers (Crowther *et al.*, 2010; Ganann *et al.*, 2010).

Performing a rapid appraisal was considered the most effective means of gathering data related to the themes of the current study keeping in mind the different obstacles which limited other potential methods. Regarding the collection of data from the mining industry, time constraints were most important as consulting with all the different mining companies studied as part of the initial desktop study would not have been possible. Furthermore, as seen with the companies contacted, only two of the six responded. Therefore, to engage with the mining industry of South Africa through a method which would best represent it, the appraisal of ESG reports was a valuable point from which further engagement for triangulation purposes could then follow.

The use of rapid appraisal or review as a data collection tool is no less apparent than as part of the third step of the current study's research design effectively called a rapid appraisal of literature. As a method selected to gather information on *Casuarina equisetifolia* and its potential to be used for environmental management, the rapid appraisal of past research had several advantages over other possible data collection tools. Compared to other methods, a rapid appraisal allowed for information to be gathered from the already established wealth of literature on the subject matter in question. Since the rapid appraisal involved engaging with several literature sources, the data collected was not limited to a specific topic and therefore covered a wide range of considerations in relation to the potential of *Casuarina equisetifolia*. The rapid appraisal also offered the researcher the ability to analyse specific case studies which held important information related to the research questions and objectives of the current study. Data collected through the rapid appraisal was then triangulated with data collected through interviews with professionals where possible.

3.6. Data analysis

A separate data analysis strategy was adopted for the specific data collected in each step of the research design. Findings from each step ultimately affected the data collection and analysis in the next. It is important here to argue the importance of content analysis as a vital tool used to analyse data and gather relevant information. Content analysis can be described as finding and highlighting important elements and characteristics within the data collected (Leedy and Ormrod, 2015). While the research problem was initially broad, an "open-minded perusal of the data" as per Leedy and Ormrod (2015) is an adequate way of describing how content analysis of qualitative data was conducted.

Content analysis formed the first step to analysing data gathered from ESG reports. A set procedure to analysing each ESG report was followed (Figure 3.5). This procedure was applied to all ESG reports gathered during the initial desktop study. Collectively, ESG reports were analysed as data relating to each respective mining company who prepared and published them. In this regard, where multiple reports were collected per company, the content of all reports analysed would render a better understanding of environmental practices of that company.

Several areas were of interest when studying ESG reports. These included, (1) the type of mining the company engaged in, example, gold mining, platinum mining, iron mining, etc., (2) the environmental impacts they addressed through environmental management, (3) rehabilitation strategies companies used, example, physical, chemical or biological, (4) the purpose of implementing said strategies and finally, (5) if the company makes use of phytoremediation.

An additional note was made of companies who practice biodiversity offsetting. Biodiversity offsetting is the setting up of a protected area which acts to compensate for the environmental impact an operation has. This is considered a rehabilitation strategy often used to address a company's impact on biodiversity. This would, therefore, not be considered a method employed to address the actual impact an operation has on the environment.

The last note made was the response a company had towards alien invasive plant species. Some companies are known to eradicate these species as part of their efforts to mitigate their impact on biodiversity. As *Casuarina equisetifolia* is an invasive species, companies who practice such would possibly show hostility to using the plant for rehabilitation purposes. Therefore, the sentiments of mining companies in this regard were important to note.

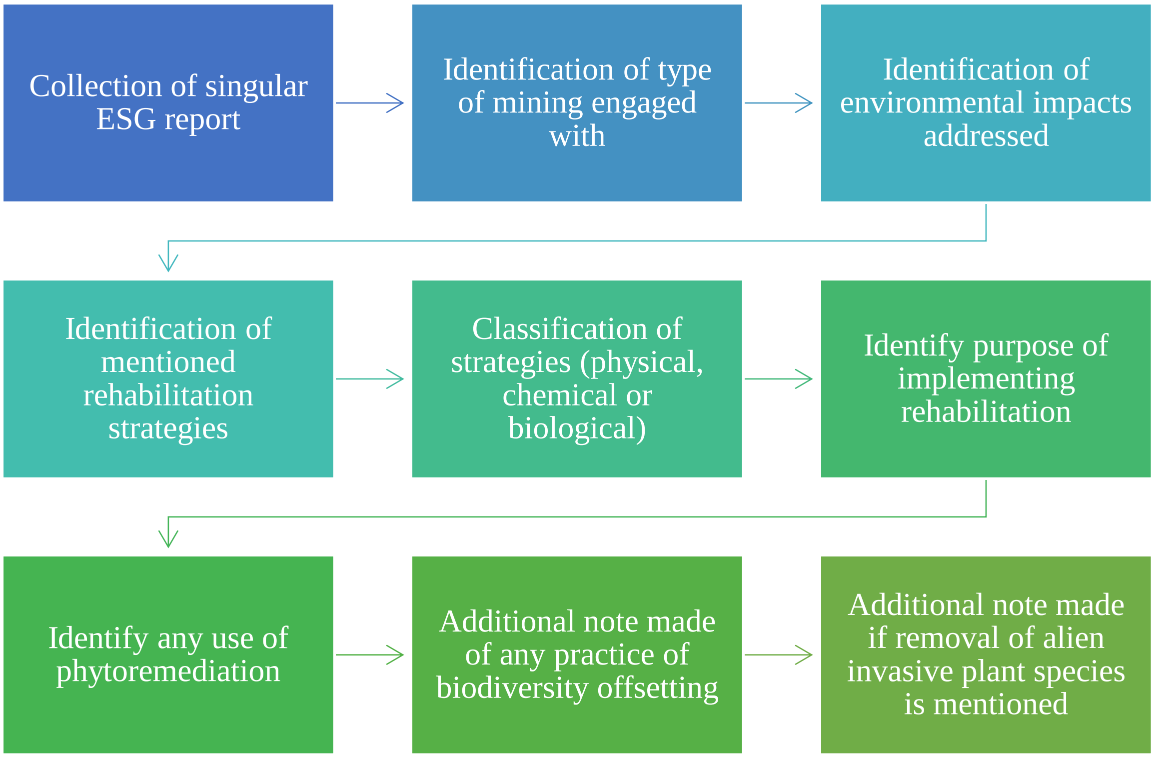

Figure 3.5. Flow chart illustrating the procedure followed when analysing individual ESG reports.

The data collected per mining company was quantitatively recorded in Microsoft Excel to then be compared with the findings from other mining companies. An absence/presence binary code was used to record findings related to everything except the type of mining a company engaged in and the purpose and reasons they implement rehabilitation. A scoring system of 0 or 1 was used as part of the binary code. The use of an absence/presence binary code represented by either 1 or 0 allowed for easy calculation of percentages and subsequently easy comparisons. For example, where a company noted the use of physical rehabilitation, the company was allocated a score of 1. In contrast, where the company did not use physical rehabilitation methods, the company was allocated a score of 0.

The absence/presence binary code was used for five different categories. The first category considered the different environmental impacts addressed, these included, impacts on soil, water, air and biodiversity. The second category assessed the rehabilitation approaches used, physical, chemical and / or biological. The third category assessed whether a company took specific measures against alien plants. The fourth category examined if a company practiced biodiversity offsetting. Finally, the fifth category examined whether a company mentioned use or interest in phytoremediation. For the first and second category, all environmental impacts and rehabilitation approaches were listed as stated above as part of the spreadsheet. Where a company addressed multiple impacts or used more than one different rehabilitation approach, the presence of these were recorded.

Totals were calculated for each binary category. This allowed for a cumulative total to be established for each category which could subsequently be compared to other items in the same category, for example, comparing different rehabilitation strategies. These totals were then used to create graphs and figures to compare items and categories. All figures, graphs and charts were created in Microsoft Excel 365.

All binary data relating to the five different categories described above were imported into Past 4 statistical software. Two-way correlation tests were performed in Past 4 to better understand if there was a relationship between the environmental impacts mining companies address and the rehabilitation methods implemented. For example, a correlation test was conducted to compare if there was a relationship between companies who address their impact on soil and companies who make use of physical rehabilitation methods. This would aid in understanding if specific rehabilitation strategies were more common among companies who address specific environmental impacts.

Data collected in the second step was qualitative and not quantitative as with the initial desktop study. These data included the observations made during field visits and information gathered from engagement with professionals. Both observations and data collected through engagement were combined and analysed together. Content analysis was important when assessing these data and played a critical role in how these data could be related to each other as well as provide important insight which would guide the rapid appraisal of the final step of the research design.

Individual interview reports were prepared for each interview conducted or questionnaire answered, noting the most important statements and comments made by professionals (Appendix E). Attention was paid to details observed as well as the words and concepts used by professionals interviewed. Explanations provided by professionals of observations made in field were recorded according to the observations themselves. For example, any use of phytoremediation observed was related to what professionals said about the same.

Interview reports were subsequently summarised and studied to extract specific information. This included information relating to rehabilitation strategies used to address environmental impacts, any opportunities and challenges faced relating to rehabilitation and all additional comments on the potential of *Casuarina equisetifolia*. The information in prepared reports were then compared with themes related to environmental management, rehabilitation and the dynamics of mining. For example, mentions of cultivating slopes were compared to revegetation; a practice which is part of mine rehabilitation.

The online questionnaires were created such that they were easier to analyse. The multiple-choice answer options provided for each answer related to specific themes as mentioned above. Reports were compiled including answers as they were. Where professionals provided longer explanations, these were compared with themes as mentioned above.

As with the initial desktop study, different literature sources identified during the rapid appraisal were analysed for their content. After searching academic databases for literature, relevant sources were identified and individually recorded on a Microsoft Excel spreadsheet. The title, date, author, and geographical setting of each source was recorded. After analysing their content, a primary theme and secondary theme was assigned to each source. These themes would then be the basis through which further statistical analyses would be possible.

The different primary and secondary themes of relevant sources were then collected and given a numerical code. These codes were then used to create charts and graphs for comparison to identify the most frequent or common themes among literature sources.

Data collected from engagement with the academic who studied *Casuarina equisetifolia* and the environmental manager of Haller Park were presented as per their content. Relevant information was identified from the answers provided, considering the findings of the rapid appraisal of literature. All information which related to the findings from other steps of the research design was therefore communicated.

CHAPTER FOUR

EMPIRICAL EVIDENCE

4.1. Introduction

To define what is meant by empirical evidence, a few definitions and concepts must firstly be discussed. The current study can be defined as an example of “empirical research” as according to Bhattacharya (2008). Empirical research values empiricism, or the idea that for research to be conducted, different forms of experience of the world is required (Paley, 2008). Experience in this regard can take the form of observation or engagement. Finally, “evidence” is defined by Clark (2008) as “the knowledge and principles that substantiate claims to wider truth”.

Following the overview and in-depth description of the current study’s methodological considerations, this chapter is dedicated to presenting the empirical evidence gathered. Empirical evidence in this regard includes all observations as well as data gathered through engagement with professionals and literature.

4.2. Mining and rehabilitation in South Africa

Table 4.1 provides a summary of the key findings or empirical evidence associated with this section and its associated research question. Sources from which findings were drawn are likewise listed.

Table 4.1. A summary of the empirical evidence related to the first research question and their sources.

Empirical evidence	**Source**
Mining companies report addressing their impact on different environmental components or aspects.	ESG reports
Mining companies engage with biodiversity offsetting as a form of addressing their impact.	ESG reports and observations at Site A.
Main purpose of rehabilitation is for the revegetation of mined landscapes.	ESG reports, observations at the two sites visited, questionnaire answered by the environmental manager (Site A)

Revegetation is strongly linked to the end-goal of a mining site and is part of ongoing efforts to stabilise environmental conditions.	Observations at the two sites visited, interviews with environmentalist assistant site manager and site supervisor (Site A), questionnaires answered by soil scientist as well as environmental manager (Site A).

From the data gathered, it was ascertained that mining companies across South Africa report being involved in different rehabilitation projects. All the companies assessed during the desktop study reported undertaking rehabilitation at their operations. As per ESG reports, most of the rehabilitation projects companies were involved in relation to how they address their impact on different environmental components. The four main environmental concerns companies reportedly address is their impact on (1) soil, (2) water, (3) air and (4) biodiversity.

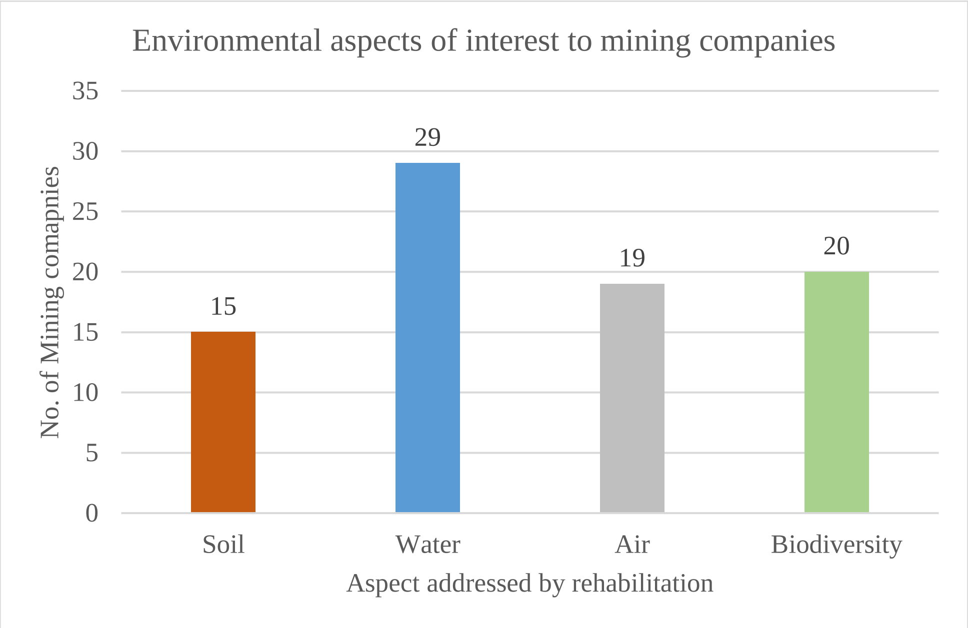

Figure 4.1. A comparison of the different impacts of mining addressed in reports.

While studying the ESG reports, the different environmental components addressed by individual mining companies were recorded and subsequently compared. This was done to better understand the main concerns related to mining companies' rehabilitation efforts. As illustrated in Figure 4.1, 29 out of 69 mining companies report addressing their impact on water as the most reported employment of rehabilitation efforts. The least addressed is mining companies’ impact on soil, with only 15 out of 69 companies reporting soil rehabilitation in their ESG reports.

Mining companies also report practicing biodiversity offsetting which should not be considered as directly addressing environmental issues. Biodiversity offsetting can be described as the balancing of a biodiversity loss as a result of environmental degradation with a biodiversity gain at a different location (Apostolopoulou and Adams, 2017). This means that the actual impact is not addressed through rehabilitation.

In contrast to the use of biodiversity offsetting as a form of rehabilitation, it was noted that mining companies initiate rehabilitation to revegetate degraded landscapes. This was noted from the empirical evidence gathered through the initial desktop study of ESG reports and through observations made during field visits. The responses of several professionals provided confirmation of the implementation of rehabilitation strategies at mining operations for the purpose of revegetation.

As the ESG reports were studied, any reasons reported for implementing or initiating rehabilitation projects were noted. Although some companies did not specify any reasons for rehabilitation, five reasons were observed as the most prevalent reported by mining companies in their ESG reports. The different reasons reported by mining companies were recorded and then compared. Figure 4.2 provides a breakdown and comparison of the overall sample and their reported reasons for implementing rehabilitation at their operations.

Majority of mining companies report implementing rehabilitation strategies for the purpose of revegetation; this accounted for 39% of all mining companies in the study sample. A further 19% report implementing rehabilitation for revegetation along with other purposes. Altogether, 58% of mining companies report implementing rehabilitation for the purpose of revegetation. Only 10% of all mining companies report implementing rehabilitation to address pollution and contamination. Even fewer report implementing rehabilitation to control dust or for surface rehabilitation.

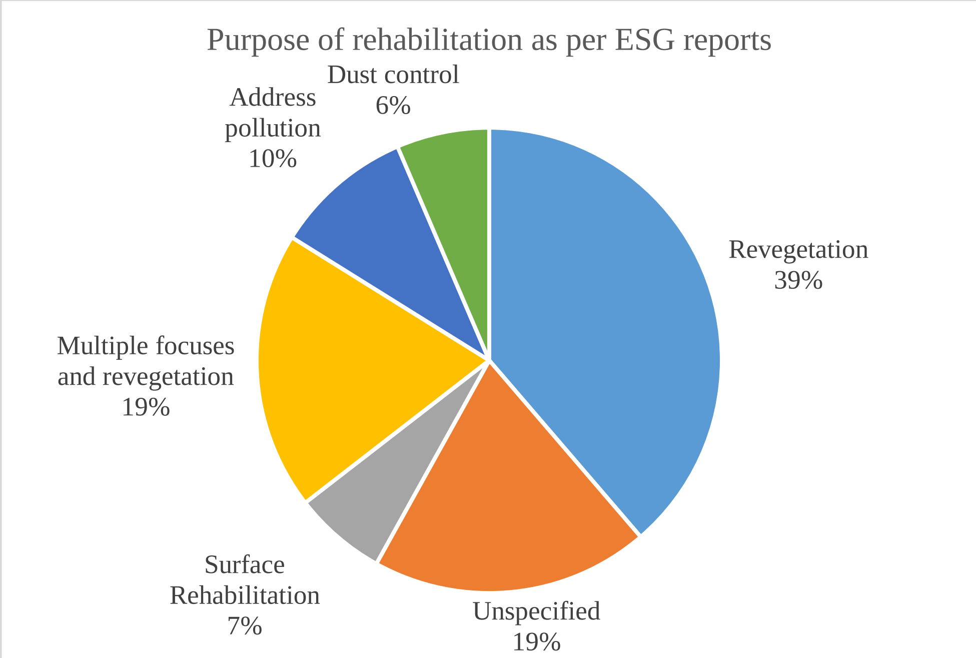

Figure 4.2. Companies grouped according to the main purpose of rehabilitation they report.

Revegetation was observed at both sites visited and confirmed by some of the professionals as an important form of rehabilitation. At Site A, revegetation was observed as the only implementation of rehabilitation at the tailings facility visited. The entire site was covered in vegetation (Figure 4.3). The perceived importance of revegetation was confirmed by the environmental manager of Site A, who identified revegetation as one of the most pressing matters needed to be addressed at the tailings facility visited. Similarly, revegetation was also observed at Site B and will be discussed in further context as it is an integral part of rehabilitation strategies. Furthermore, the soil scientist confirmed that revegetation was an important part of rehabilitation at their mining company stating that "re-establishment of ecosystems and indigenous vegetation" was a pressing matter which needed to be addressed at their operations.

Figure 4.3. A final picture taken before ascending the Site A tailings facility itself.

Although revegetation was observed as a pressing matter mining companies address, it forms part of a greater environmental plan of mining operations. In this regard, the environmentalist provided more insight on what rehabilitation is for mining companies or what rehabilitation means in the context of their respective environmental management plans. Referring to Sutton and Weiersbye (2007), the environmentalist emphasised that rehabilitation at mining operations is strongly linked to the end-goal of the site itself. Furthermore, the environmentalist stated that, "mines cannot do concurrent land rehabilitation if the end-use is not known". In this regard, mining companies establish, early in their environmental management plan for the site, an end-goal for the site to address the future use of the environment in a sustainable way. In some cases, the environment is restored to pre-mining conditions, while in other cases, the mining site can be repurposed for other uses.

According to the environmentalist, the purpose of rehabilitation at most mining companies is to stabilise environmental conditions during activity while approaching the eventual end-goal. This has been confirmed through observations during field visits and through engagement with professionals. It was observed at both sites that measures are put in place to address potential environmental issues during activity. This will be further discussed when presenting the empirical evidence on the rehabilitation methods used in the mining industry. Furthermore, the environmental manager of Site A confirmed that the focus of environmental management of the site is "stabilisation and remediation".

While describing the end goal of rehabilitation in the context of their own work, the soil scientist expressed their involvement in, "proper planning to ensure that the final rehabilitated mine is sustainable". More information provided by the soil scientist further suggested that the environmental stability of mining operations is a primary concern of rehabilitation:

> *"the end goal would be partially reached. The work done has ameliorated some of the negative conditions but thing (sic) could be done much better!!!"*

Related to the visited sites, it is further affirmed that stabilisation and remediation are the primary uses of rehabilitation. However, the nature of stabilisation and remediation highly depends on the foreseen end goal.

4.3. Mine rehabilitation methods, use of plants and practice of phytoremediation

After having assessed the ways the mining industry of South Africa addresses rehabilitation, the current study delved deeper into evaluating the specific methods used for rehabilitation. Additionally, the extent to which phytoremediation or plants are used for rehabilitation was of particular interest. Table 4.2 provides a summary of the key findings or empirical evidence associated with this section and its associated research question. Sources from which findings were drawn are likewise listed.

The different rehabilitation strategies or approaches used by mining companies were assessed and compared through the information reported in ESG reports. 20 of the 48 companies report using biological rehabilitation strategies to address the environmental impacts of concern. At the same time, 15 of the 48 companies report using physical rehabilitation strategies. Only six of the companies studied report using chemical rehabilitation strategies. A comparison of these findings is illustrated in Figure 4.4. It is important to note that these results represent companies who report using different strategies concurrently, for example, biological and physical strategies at the same time to address the same environmental impact.

Table 4.2. A summary of the empirical evidence related to the second research question and their sources.

Empirical evidence	**Source**
Out of the three approaches, mining companies make use of biological rehabilitation methods most, followed by physical methods and least of all, chemical methods.	ESG reports
All three approaches are often implemented together as part of one environmental management or rehabilitation plan.	ESG reports, observations at the two sites, questionnaire completed by soil scientist, site supervisor and environmental manager (Site A), environmental manager (Site B)
Mining companies follow guidelines which direct their rehabilitation efforts and dictate their choice of methods.	Interview with environmentalist, observations at Site B.
Indigenous plants are used extensively for rehabilitation, and for the sole purpose of revegetation or ecosystem restoration.	Observations at the two sites, interview with environmental manager (Site B), interview with site supervisor (Site A).
Phytoremediation is practiced at a few mining companies, however, the mining industry does not exhibit specific interest in the use or potential of phytoremediation.	ESG reports, Observations at the two sites, interview with the environmentalist.

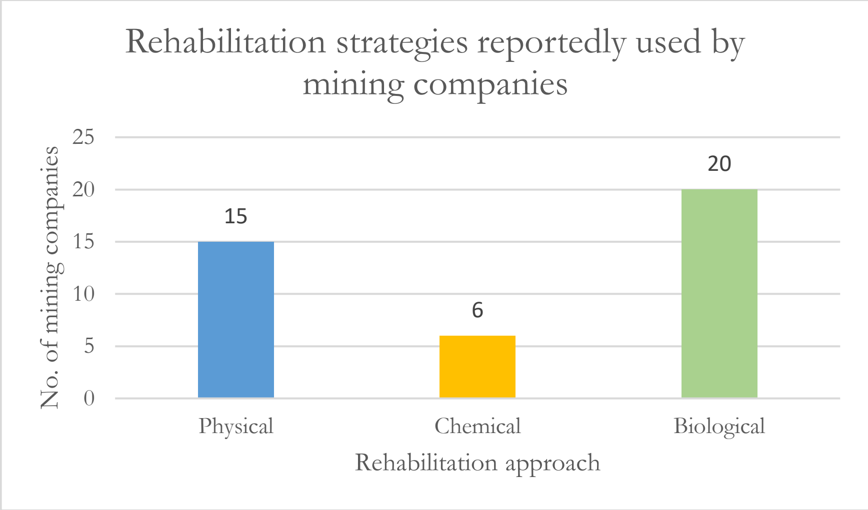

Figure 4.4. A comparison of the different rehabilitation approaches reportedly used by mining companies.

Through further investigation, it was noted that all three approaches are often used together as part of a larger rehabilitation or environmental management plan. The best description of this phenomenon in the mining industry was provided by the soil scientist who described the nature of rehabilitation approaches at the mining company they worked at as:

> *"Physical plus biological for rehab: use of mine water for irrigation you may consider to be "chemical"".*

The above was further substantiated during field visits and engagement with other professionals. During the tour of Site A, the site supervisor described the process through which rehabilitation was initiated at the tailings facility:

> *"The tailings that come from the plant are mixed with chemicals. Seeds are also added before deposition."*

This would indicate that chemical treatment of the tailings is being performed. In addition, a seed bank is then added to the tailings soil to facilitate revegetation, which confirms the use of biological methods. Furthermore, the environmental manager of the site described rehabilitation methods as "physical methods" which would include covering, displacement and soil amelioration. This indicated that over and above what was observed during the tour, rehabilitation also involves physical methods.

The use of physical, chemical and biological approaches was also observed at Site B. Physical rehabilitation strategies were observed in the form of covering or cladding, soil amelioration and wind control using netting. Biological rehabilitation measures were observed through revegetation efforts. The use of chemical rehabilitation was also confirmed by the environmental manager who stated that chemical treatment of tailings was used for dust suppression. The observations made at Site B were also important as they shed light on some of the factors which dictate the nature and choice of rehabilitation methods in the mining industry.

Before visiting Site B, the environmentalist who referred the researcher to Site B's management, provided further reference to a document called "*Guidelines for the rehabilitation of mined land*" prepared by Tanner and Möhr-Swart (2007). The environmentalist emphasised that many mining companies follow this document when performing rehabilitation as several methods and processes are listed. Physical and biological methods are documented in the guidelines. The steps and processes illustrated and listed as part of the guideline document were identical to the practices observed at Site B. This included the use of cladding, subsequent revegetation and use of netting for wind control.

Cladding was observed as an initial step taken to rehabilitate an area of the tailings facility walls. Highlighted by the environmental manager as an important implementation leading to the eventual revegetation of dam walls, cladding is a clear example of physical rehabilitation efforts being made at Site B. The processes involved was described by the environmental manager and photographed during the explanation and tour.

The first step in cladding requires that the dam wall be prepared and its angle of inclination be reduced to 18º (Figure 4.5a). This is to accommodate for revegetation measures which follow. The environmental manager also stated that a cladding material is prepared of "60% soil, and 40% dolerite" at an on-site plant (Figure 4.5b). The cladding material is then used to cover the prepared land (Figure 4.5c). Following cladding, a seed bank of indigenous trees and grasses obtained from a local nursery, or the nursery on site is sowed into the covered ground as an initial step towards revegetation and eventual ecological restoration of the area. Special attention is given to the use of grasses for revegetation. Prior to the tour, cladding and revegetation at the site was confirmed by the environmentalist, who stated that Site B engages with strategies to, "level the land and prepare it for grassing."

Figure 4.5. A photograph taken from the top of a slope being prepared for cladding.

Netting along with chemical treatment is used to control wind and dust fallout at the top of the site (Figure 4.6). Nets are placed according to wind direction at strategic locations. The environmental manager also provided more detail on the measures used to control wind and potential dust fallout. It was stated that an entire team maintains the netting who have to make sure the nets are aligned and placed properly.

Figure 4.6. Netting used to prevent dust fallout as a result of wind.

The environmental manager of Site B expressed that the efforts made at the site relate to the end goal of one day allowing the site to be re-integrated into the surrounding environment. The above-described rehabilitation methods were observed being practiced in different areas around the tailings facility. As an example of the eventual end-goal of the site, strides towards successful ecological restoration were observed following revegetation and rehabilitation of areas at the lower elevations of the tailings facility. For example, slopes were well-grassed with vegetation very similar to the surrounding environment. Small fauna such as birds have also re-inhabited the area. Nesting birds were observed in trees at medium elevations along the dam wall.

The observations made at Site B further emphasised the importance of plants for the revegetation, stabilisation, and eventual ecological restoration of mining operations. At both, Site A and B, the importance of indigenous plant species resonated through what was observed during field visits as well as during interviews and engagement with professionals. It was therefore important to identify the various plant species being used at the mining sites visited to lead into a discussion on the status of phytoremediation in the mining industry. The empirical evidence gathered relating to the opportunities and challenges associated with using plants for rehabilitation can subsequently be presented.

During the tour of Site A, it was observed that the walls of all four tailings dams of the mining plant were well vegetated. Indigenous plant species were identified as part of this vegetation. Plants identified on site are listed in Table 4.3 below. The plants identified were further studied using various field guides. Table 4.3 includes some of the information gathered about each plant after the field visit. The site supervisor confirmed observations that the vegetation composition growing on the tailings dam walls were no different than that growing in surrounding areas.

More information on the plants used for revegetation at Site B's tailings facility was provided by the site's environmental manager. A list of the plants mentioned by the environmental manager as well as other plants identified during the tour is provided in Table 4.4. In a similar way as with Site A, more information was gathered about the different plant species and this is also included in Table 4.4.

Interest in different grass species was indicated by the environmental manager who stated that indigenous grasses including *Eragrostis curvula*, *Eragrostis tef* and *Cynodon dactylon* were planted at Site B. The comments of the environmental manager indicated that some plant species identified at the site were valued more than others by the mining company. For instance, *Cynodon dactylon* was praised by the environmental manager as an important species used for rehabilitation. Additional information was also provided on *Chrysopogon zizanioides* or vetiver which was observed growing on site. The environmental manager stated that environmental governing bodies originally recommended the planting of *Chrysopogon zizanioides* for revegetation and stabilisation, however, this recommendation was shortly retracted. The mining company was then prompted to remove the plant. The environmental manager argued for the use of *Cynodon dactylon* instead of *Chrysopogon zizanioides* as it was noted that the root system of latter was not as extensive to address stabilisation.

Table 4.3. A list of the most prominent plant species identified and noted at Site A.

Taxon	**Use at the site**	**Additional comments**
Aristida bipartita	Indigenous grass species found growing naturally in the area. Same species grows on tailings and in surrounding areas.	Indigenous grass species which grows on sandy, loamy, stony and clayey soils. Thrives in overgrazed and disturbed landscapes. (Fish *et al.*, 2015)
Eragrostis curvula	Natural grass species found in the area. Same species was observed growing in surrounding areas.	Another indigenous grass species that grows on sandy or acidic to loamy soil. Known to grow in disturbed, degraded and badly managed areas. (Fish *et al.*, 2015).
Searsia lancea	Tree species observed growing on tailings as well as in surrounding areas. A species used as part of revegetation purposes.	Small to medium tree. Occurs in a wide range of habitats across most of southern Africa. A plant involved in a number of phytoremediation projects and studies across South Africa. Tolerates chemically polluted areas and is known to accumulate heavy metal contaminants (Dye *et al.*, 2008; Ndou *et al.*, 2020)
Vachellia burkei	Thorny tree species observed on site identified by its fruit. Typical of the area. Unclear if part of natural vegetation or revegetation work.	Medium to large tree. Another of the many vachellia species indigenous to the region. Grows on sandy soil. (van Wyk and van Wyk, 2013)

Vachellia erioloba	Tree species observed growing on tailings as well as in surrounding areas. A species used as part of revegetation purposes.	Described as a medium to large tree. Several specimens seen on site were large. Grows on deep sandy soil and along watercourses in arid areas. (van Wyk and van Wyk, 2013)
Vachellia erubescens	Small tree species observed growing on the tailings as well as in surrounding areas. A species used as part of revegetation purposes.	A larger species of acacia which grows naturally in the area. Known to grow on rocky ridges forming impenetrable thicket as observed at lower levels of the tailings facility. (van Wyk and van Wyk, 2013)
Vachellia nilotica	Additional thorny tree species identified on site by its fruit. Typical of the area. Most probably part of the surrounding vegetation and not distinctly used for revegetation.	A more difficult vachellia species to identify as it resembles others. Known to grow in gravelly soils. Yet another tree known to grow in the area. (van Wyk and van Wyk, 2013)
Vachellia tenuispina	Small tree or shrub species observed growing on the tailings as well as in surrounding areas. Identified by its fruit. A species used as part of revegetation purposes.	Similar to other acacia species with very slight physical differences. Shares traits with *V. Karroo*. Another tree part of the vegetation in the area. (van Wyk and van Wyk, 2013).

Table 4.4. A list of the most prominent plant species identified and noted at Site B.

Taxon	**Use at the site**	**Additional comments**
Casuarina cunninghamiana	Observed growing in a grove near the on-site nursery. Older trees which seen to have been planted many years ago.	One of the two most prevalent species of Casuarina growing in South Africa; the other being *C. equisetifolia* itself. Commonly known as "beefwood". Like *C. equisetifolia*, this tree is native to Austraila. Typical of the Highveld, Gauteng area. Commonly used as windbreaks on cultivated land to prevent erosion or for dune stabilisation. (van Wyk and van Wyk, 2013; Potgieter *et al*., 2014)
Chrysopogon zizanioides	Observed growing at the lower levels of the tailings facility.	A grass species which is widely used and applauded for its phytoremediation potential. (Fish *et al.*, 2015)
Cortaderia selloana	Observed growing at the lower levels of the tailings facility along with *Chrysopogon zizanioides*.	An exotic grass, naturalised in South America. Commonly known as "pampas grass". Grows in seasonally wet areas. Well-studied around the world as well as in South Africa for its phytoremediation potential. (Couto *et al.*, 2012; Basílico *et al.*, 2013; Fish *et al.*, 2015)
Cynodon dactylon	Grass species used for rehabilitation and revegetation of the tailings facility.	A grass species which has been studied for its phytoremediation potential. (Fish *et al.*, 2015)

Eragrostis curvula	One of the grass species of which seeds are used to revegetate the tailings facility.	A grass species that grows in disturbed and nitrogen rich areas. Can become a problematic weed which spreads fast. (Fish *et al.*, 2015)
Eragrostis tef	Another grass species used for revegetation.	A grass species that grows in weedy areas. Planted to prevent erosion and rehabilitate road reserves. Naturalised in Ethiopia. (Fish *et al.*, 2015)
Eucalyptis sp.	Large tree species cultivated at the on-site nursery and used for revegetation and rehabilitation.	A very large tree native to Australia. Considered an invasive in many parts of South Africa. Part of phytoremediation studies in South Africa and around the world. (van Wyk and van Wyk, 2013; Rasafi *et al.*, 2020)
Olea europaea subsp. africana	Another large tree species cultivated at the on-site nursery and used for revegetation and rehabilitation. This tree is not common in the surrounding area.	An indigenous olive tree species used for medicinal purposes in South Africa. Known to be a hardy plant which grows in a number of different environments. (van Wyk and van Wyk, 2013)
Searsia lancea	Large tree species used for revegetation of the tailings facility. Observed growing around the tailings facility together with *Vachellia karoo*. Not clear if its phytoremediation potential was considered when deciding to use the tree for rehabilitation.	Small to medium tree. Occurs in a wide range of habitats across most of southern Africa. A plant involved in a number of phytoremediation projects and studies across South Africa. Tolerates chemically polluted areas and is known to accumulate heavy metal contaminants (Dye *et al.*, 2008; Ndou *et al.*, 2020)

Vachellia karroo	Tree species observed growing around the tailings facility. Part of the plant species of which seeds are planted for revegetation.	Small to medium tree. One of the indigenous vachellia trees in South Africa. Grows in gravelly areas. (van Wyk and van Wyk, 2013)

Figure 4.7. On-site nursery at Site B.

The Site B management also grows different tree species at an on-site nursery (Figure 4.7). These tree species include *Olea africana*, *Searsia lancea*, *Eucalyptus sp.* and *Vachellia karoo*. These are then planted after cladding and the preparation of soil has been completed. The sole purpose of these trees is for the use of revegetation and stabilisation.

Although the mining industry does exhibit interest in the use of plants for rehabilitation, the use of plants is limited to being part of revegetation and stabilisation initiatives. Empirical evidence suggests that there is a lack of interest in the use of plants for phytoremediation or as a phytotechnology to address specific environmental issues. This was noted during the initial desktop study, during field visits, and when engaging with professionals. Furthermore, it was observed that the lack of interest in phytoremediation can be linked to certain challenges which will be discussed later.

After studying the ESG reports of the different mining companies of the study sample, it was evident that no particular interest is shown towards the use of plants for anything more than a means of revegetating degraded environments. Any mention of the use of plants to address specific environmental issues was recorded when assessing ESG reports. The empirical evidence gathered through the initial desktop study demonstrated that 16% of all companies report making use of, or showing interest in phytoremediation. This accounted for five mining companies of the 31 who display interest, have attempted using or have current projects related to phytoremediation.

The five companies who mention phytoremediation are among the largest in mining corporations in South Africa. Included among them is Site A's company, who at a mining operation in the past, made use of *Chrysopogon zizanioides* to successfully rehabilitate a degraded area. One other company also reported making use of the grass species for phytoremediation purposes. *Pennisetum purpureum* was used to address chemical pollution in this case. Two of the companies who report making use of plants for phytoremediation are participants in a project called the Mine Woodlands Project. This project has produced a significant amount of research output relating to experimentation with indigenous tree species including *Searsia lancea*, *Combretum erythrophyllum* and various *Eucalyptus* trees (Dye *et al.*, 2008; Regnier *et al.*, 2009; Dye *et al.*, 2016; Dye *et al.*, 2017).

Several phytoremediation projects around South Africa were also mentioned by the environmentalist interviewed. One example was the use of a plant, *Tamarix usneoides*, for salt uptake at tailings storage facilities. This project was reported by the fifth company who, in their ESG reports, made mention of their use or interest in phytoremediation. The same project is further documented in the study of Wilson *et al.* (2017). Another example provided by the environmentalist was the use of *Cortaderia selloana* to address mine residues by a different mining company. Finally, the environmentalist provided other case studies including the use of bamboo, and exotic reeds. Furthermore, the environmentalist maintained that many mining companies have explored the use of phytoremediation, however, "uptake on this is slow".

4.4. Opportunities and challenges associated with the use of plants for rehabilitation

Empirical evidence collected during this study also provided insight on the different opportunities and challenges associated with the use of plants by the mining industry. Following the comments of the environmentalist, it was necessary to gain more insight on why the use of phytoremediation was "slow" in development. Table 4.5 provides a summary of the main points gathered in relation to the opportunities and challenges associated with the use of plants for rehabilitation in the mining industry.

Table 4.5. A summary of the empirical evidence related to the third research question and their sources.

Empirical evidence	**Source**
The specific end-goals of mining companies encourage the use of other rehabilitation approaches instead of phytoremediation.	Observations made at the two sites, interview with environmentalist
Mining companies implement the most cost-effective and risk-free rehabilitation strategies	Observations made at the two sites, interview with environmentalist and interview with academic
Exotic plants have been noted as more effective for rehabilitation purposes than some indigenous options which are not suited for rehabilitation.	Interview with environmentalist
Mining companies are open to exploring the use of plants for rehabilitation, provided costs and risks are minimal.	Interview with environmental manager (Site B), Questionnaires answered by environmental manager (Site A) and soil scientist.
Mining companies practice the removal of exotic plants, making it difficult to recommend or experiment with the use of different plant species.	ESG reports, Observations at Site B.

As noted during field visits, it was apparent that phytoremediation or the implementation of phytotechnology would not fit into the current environmental management plan of the two operations. The two mining companies did not exhibit interest in addressing specific environmental problems during the implementation of rehabilitation. Furthermore, considering their end-goals were observed as re-integrating the sites into the surrounding environment, revegetation and stabilisation during activity appeared to be the most effective implementations. This was further confirmed by the environmentalist who stated that mining companies prefer to continue using their tried and tested methods of rehabilitation without experimenting with new options.

Through observation, it was noted that the rehabilitation methods put in place are not costly. For example, plants used for revegetation include fast spreading grass species found in the surrounding area. At both sites visited, revegetation involves allowing the surrounding vegetation in the area to naturally grow on the tailings facility walls without complex intervention. This was confirmed by the environmentalist who stated that cost is a very big concern for mining companies as they implement rehabilitation at their sites. The academic who was interviewed also showed concern that implementing phytoremediaton strategies at mining operations may not be easy depending on the amount of maintenance needed. This was particularly mentioned by the academic in relation to exotic plant species.

As seen through some of the examples above, exotic plant species are more effective and present more potential in relation to phytoremediation. The environmentalist emphasised this point stating that, after a number of experiments and tests, indigenous plants are not as resilient to the harsh conditions at mining sites. Except for some important plants such as *Tamarix usneoides*, *Berkheya coddii* and *Searsia lancea*, the environmentalist stressed that most other indigenous plant species do not survive or are “totally ineffective” as rehabilitation tools. An example provided by the environmentalist was the use of indigenous reed beds, supposedly used as a means to address water quality. The reed beds were not effective enough to address the environmental concern at the operation implemented. The environmentalist also provided detail on a small project that involved the planting of three specimens of *Ziziphus mucronata*. The plants did not sustain growth in the harsh environment. Furthermore, the environmentalist supported that soil amelioration is a must when attempting to use plants for rehabilitation. This further supports an argument for the use of exotic plant species for phytoremediation instead of indigenous plants species.

Although the environmentalist supported that mining companies do not wish to experiment with new options, engagement with the environmental managers and the soil scientist returned positive feedback in relation to the current study. While the environmental manager of Site B confirmed that their mining company would be interested in learning more about the benefits of different phytotechnologies or phytoremediation strategies, the manager of Site A welcomed possible future projects around the current study. They stated that:

> *“the [current] study will help the industry and trials of more than 24 - 48 months should be done in order to see the success of restoration.”*

The trials mentioned here are referring to tests and experiments involving the plant species studied, *Casuarina equisetifolia*. The soil scientist also showed interest in being open to exploring new options for their own mining company. They stated that it is worth exploring how different plants could help rehabilitate even the most seriously degraded sites. They even suggested investigating how invasive species such as black wattle, or *Acacia mearnsii* could be used as a means to address such sites.

This positive feedback or response from the professionals engaged with does not reflect, however, the current practices in the industry or the viewpoint of the entire companies themselves. In this regard, mining companies still view invasive and exotic plants as a threat to the well-being of the biodiversity present at their site. As part of rehabilitation efforts, mining companies engage in the removal or eradication of invasive plant species. This was noted as part of the empirical evidence gathered through the initial desktop study of ESG reports and through observation at Site B. A record of all companies of the desktop study sample who eradicate invasive plant species at their operations was made. A comparison was then performed to ascertain how many mining companies in the sample engage in this activity as part of rehabilitation efforts. 29% of all mining companies in the study sample report eradicating invasive plant species. It was thus taken that the other 71% do not engage in this, however, it was never explicitly made clear within these companies' reports. This was an important finding also related to the fourth research question and will therefore be discussed in more detail later on.

The eradication of invasive plant species was observed at Site B, verifying that companies do perform this activity. During the tour of the site, the environmental manager pointed out that alien invasive plant species are eradicated as part of the activity towards protecting biodiversity. A wilted specimen of *Solanum mauritianum* or bugweed was pointed out as an example of the chemical control measures applied to invasive plants found on-site.

4.5. Potential of *Casuarina equisetifolia* for rehabilitation in the mining industry

Following an investigation on the dynamics of rehabilitation in the mining industry as well as an assessment of associated opportunities and challenges, the plant, *Casuarina equsetifolia* was placed in the context of the discussed empirical evidence to yield more findings. These findings would be related to the plant itself and would thus be used to argue for *Casuarina equisetifolia*'s potential. Table 4.6 provides a summary of the main points relating to the empirical evidence gathered. Literature on past research formed a key source in this regard. The viewpoints of the different professionals interviewed complemented these findings.

Table 4.6. A summary of the empirical evidence related to the fourth research question and their sources.

Empirical evidence	**Source**
Not enough research has been done in South Africa until now to verify why *Casuarina equisetifolia* is considered a category 2 invasive nor is the mining industry fully aware of the potential of the plant.	Engagement with different professionals of the mining industry and interview with academic.
Casuarina equisetifolia has been studied within different contexts and under different themes exhibited that the plant shows great potential.	Rapid appraisal of literature
Casuarina equisetifolia is a resilient plant species, able to withstand harsh conditions.	Rapid appraisal of literature, questionnaire answered by environmental manager of Haller Park.
Casuarina equisetifolia has been studied for its ability to ameliorate soil conditions.	Rapid appraisal of literature, questionnaire answered by environmental manager of Haller Park.
The potential of *Casuarina equsetifolia* is most noted when grown with fungal species of *Frankia* for the encouragement of mychorrhiza.	Rapid appraisal of literature, interview with academic, questionnaire answered by environmental manager of Haller Park
Casuarina equisetifolia has the potential to initiate revegetation.	Questionnaire answered by environmental manager of Haller Park
Casuarina equisetifolia is also a hyperaccumulator of several heavy metals and contaminants.	Rapid appraisal of literature
Casuarina equisetifolia also has other uses through its biomass in the form of wood.	Questionnaire answered by environmental manager of Haller Park.
As a plant with much potential, *Casuarina equisetifolia* is worth further studying.	Interview with academic, questionnaire answered by environmental manager of Haller Park.

After engaging with the mining industry, it was clear that *Casuarina equisetifolia* had not been previously considered as a potential phytoremediation tool. Of the different professionals, only the environmental manager of Site B and the environmentalist indicated that they had previously heard about *Casuarina equisetifolia*. However, neither of the two professionals had heard of the case study of Haller Park, where the plant was used successfully for ecological restoration.

However, the academic provided an example of the use of *Casuarina equisetifolia* by Richard's Bay Minerals, a mining company on the east coast of South Africa. The plant was used for dune stabilisation and revegetation, but not deliberately selected as a tool to address specific environmental issues. *Casuarina equisetifolia*, in the case of Richard's Bay Minerals, is planted as forests which offer further uses for surrounding communities through its biomass. Therefore, Richard's Bay Minerals is the only company in South Africa which has experience with the plant. Because of limitations presented by the global COVID-19 pandemic, more information was difficult to gather from Richard's Bay Minerals themselves.

Despite being planted as forests in Richard's Bay, *Casuarina equisetifolia* is still considered a category 2 invasive species. This further complicates the initiation of potential experiments or projects, as previously discussed in the context of the current study. Interestingly, the academic suggested that the decision to categorise *Casuarina equisetifolia* as a category 2 invasive plant species was not made under specific premises. However, they did state that *Casuarina cunninghamiana*, the other species of Casuarina found in South Africa, was known to consume large amounts of water. Both species are known to seed and spread fast, therefore making them a danger to indigenous species and ecological water supply. It was further suggested by the academic that more research is necessary to justify *Casuarina equisetifolia*'s categorisation as an invasive species, however, they did state that due to *Casuarina cunninghamiana*'s impact on water and difficulty to be controlled, moving the plant to category 1 invasive species status was considered.

Although *Casuarina equisetifolia* may still be considered an invasive species in South Africa, however, quoting the environmental manager of Haller Park:

> *"There are more benefits to casuarina than challenges."*

Empirical evidence gathered through the rapid appraisal of past studies suggested that *Casuarina equisetifolia* has potential in many different contexts. As seen in Chapter 3, sources gathered from academic databases were categorised according to primary themes and secondary themes. The different sources per primary and secondary theme were quantified and compared to better understand the focus of most studies on *Casuarina equisetifolia*. Figure 4.8 provides a chart comparing the number of sources per primary theme. Figure 4.9 provides a chart comparing the number of sources per secondary theme. Seven themes were observed as primary themes in some sources, while in others, secondary. Sources which were categorised under these respective themes were quantified altogether and frequencies were compared. This comparison is illustrated in Figure 4.10, highlighting the overall most frequent themes observed during the rapid appraisal.

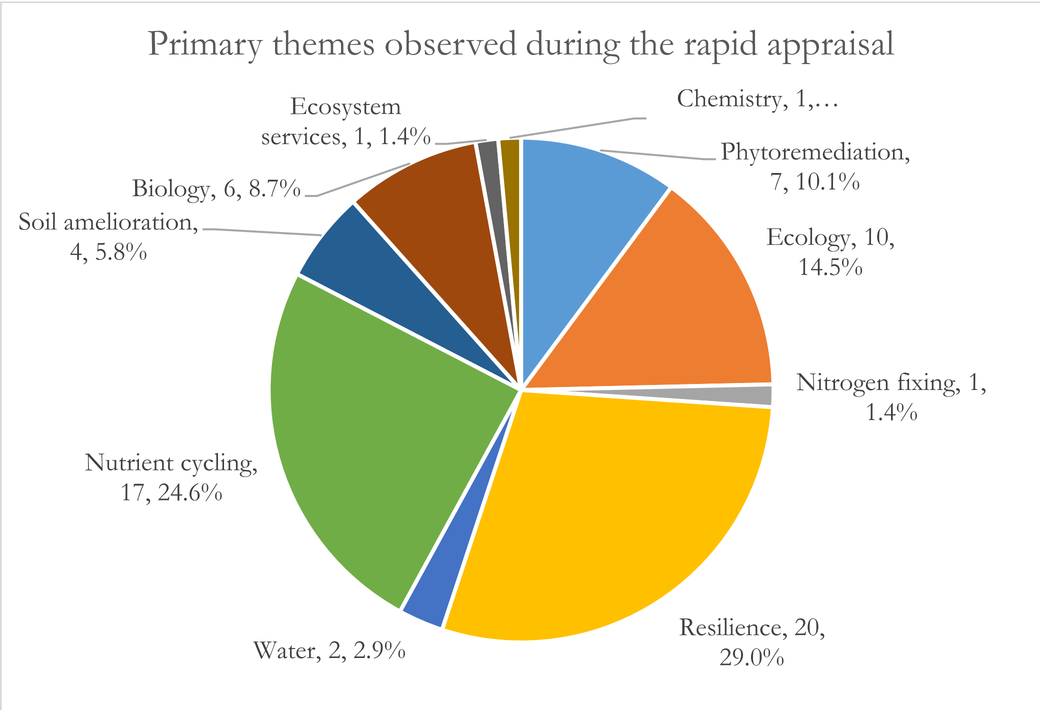

Figure 4.8. A comparison of the different primary themes of sources observed.

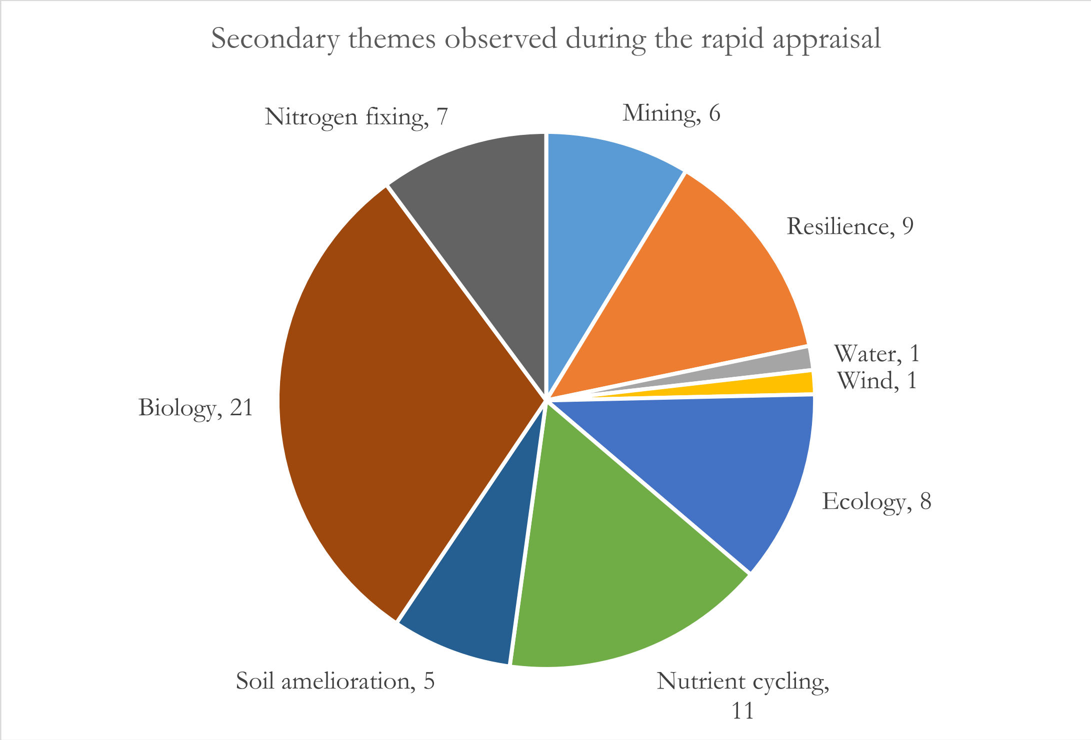

Figure 4.9. A comparison of the different secondary themes of sources observed.

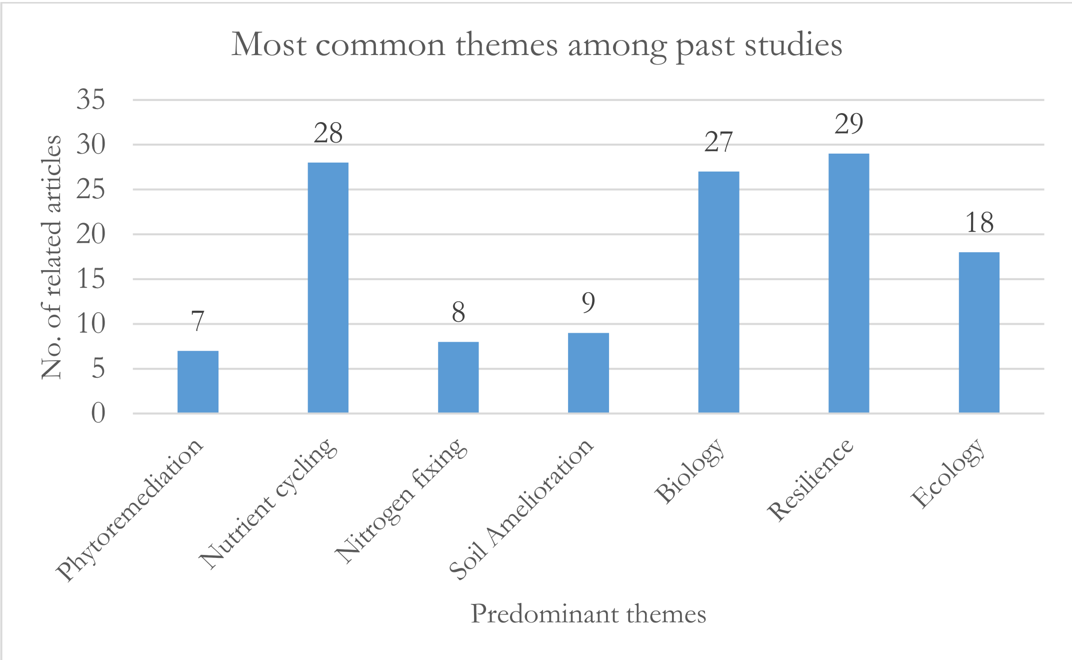

Figure 4.10. Cumulative frequency of themes among sources.

The most common primary theme observed was resilience with 20 sources. This accounted for 29% of all the literature studied during the appraisal. The theme resilience included all past studies of *Casuarina equisetifolia*’s ability to tolerate different environmental conditions or stressors. In particular, several of these sources assessed how well *Casuarina equisetifolia* performed in sodic or saline soil.

As the most common primary theme encountered in past studies, *Casuarina equisetifolia* has been identified and studied as one of the most resilient to saline conditions. Several studies involved experiments with multiple plant taxa and conclude that *Casuarina equisetifolia* is one of the most resilient to salt stress (Tomar *et al.*, 2003; Hussain and Alshammery, 2008; Djighaly *et al.* 2018). Furthermore, *Casuarina equisetifolia* has built a reputation in this regard with studies being conducted on its resilience to salinity from as early as 1987 to as recent as 2020 (Ng, 1987; Edrisi *et al.*, 2020). *Casuarina equisetifolia*’s resilience to saline conditions has also been explored in the context of mining environments (Wehr *et al.*, 2006; Karthikeyan *et al.*, 2009). As an important point in the context of the current study, *Casuarina equisetifolia*’s potential to successfully revegetate saline mining landscapes was considered (Karthikeyan *et al.*, 2009). *Casuarina equisetifolia*’s ability to withstand saline conditions has also been studied in Africa with positive results (Djighaly *et al.*, 2018). The resilience of *Casuarina equisetifolia* has been remarked on by the environmental manager of Haller Park. Specifically, the environmental manager stated that *Casuarina equisetifolia* was able to “survive in the saline waters”. This triangulated the findings from the rapid appraisal.

Other studies included assessments of *Casuarina equisetifolia*’s tolerance to waterlogged areas, cold stress and ability to aid in ecological restoration (van der Moezel *et al.*, 1989; Lee *et al.*, 1997; Zhou and Chokkalingam, 2010; Li *et al.*, 2017; Li *et al.*, 2018; Singh and Lal, 2018; Djighaly *et al.*, 2020). While a number of studies support that *Casuarina equisetifolia* is resilient to drought and dry conditions (Lee *et al.*, 1997; Ahriwal *et al.*, 2016; Chen *et al.*, 2018), Singh and Lal (2018) support that the plant is also resilient to waterlogging. However, the plant requires modification in order to withstand cold conditions (Li *et al.*, 2017; Li *et al.*, 2018).

The second most common theme among literature was nutrient cycling with a total of 17 sources or almost 25% of the total number of studies assessed during the appraisal. Included as part of this theme were all sources documenting studies of *Casuarina equisetifolia*’s relationship with soil nutrients. *Casuarina equisetifolia* is noted as very effective in nutrient consumption as well as re-nourishing soil. Several past studies consider the plant's usefulness in restoring soil quality through its litterfall and biomass production as sources of nutrients (Dutta and Agrawal, 2001; Hata *et al.*, 2012; Uma *et al.*, 2014).

The above must be presented along with findings related to *Casuarina equisetifolia* and nitrogen fixation. Although very few sources address nitrogen fixation as a specific theme, many of the sources which include the theme nutrient cycling address nitrogen fixation as well. Past research has been focused on assessing *Casuarina equisetifolia*'s ability to ameliorate soil conditions through nitrogen fixation (Guerrero *et al.*, 2009; Karthikeyan *et al.*, 2009; Sayed, 2011; Mishra *et al.*, 2014; Seenivasan *et al.*, 2016). Starting with early research on the plant's potential, it has been accepted that *Casuarina equisetifolia* contributes to soil amelioration as a nitrogen fixing species (Ng, 1987; Sougoufara *et al.* 1990; Marriotti *et al.*, 1992). Nitrogen fixation has an important role to play in relation to establishing plant communities and will be discussed in the next chapter. Altogether, *Casuarina equisetifolia* has been studied to be efficient in both nutrient cycling and nitrogen fixation, contributing to soil amelioration (Ng, 1987; Sougoufara *et al.* 1990; Marriotti *et al.*, 1992; Guerrero *et al.*, 2009; Karthikeyan *et al.*, 2009; Sayed, 2011; Mishra *et al.*, 2014; Seenivasan *et al.*, 2016).

The environmental manager was able to provide an example case where soil amelioration was observed at Haller Park. Firstly, it was emphasised by the environmental manager that *Casuarina equisetifolia* is "useful in jump-starting soil formation". In this regard, the plant's ability to cycle soil nutrients was praised because of its role in ecosystems. The environmental manager stated that the plant attracts a millipede species (*Epibolus pulscripes*) which feeds on the leaf litter, producing humus for soil nourishment. In a similar way, the litter acts as fodder for wildlife of Haller Park, allowing for further nutrient cycling. In a similar way, the environmental manager also stated that *Casuarina equisetifolia* is able to fix atmospheric nitrogen for improving soil quality.

Two important themes observed during the rapid appraisal of literature sources were biology and ecology. These themes were noted among past studies which involved research on *Casuarina equisetifolia*'s physical properties as well as the plant's relationship with other organisms or ecosystems. As gathered from the rapid appraisal of literature, *Casuarina equisetifolia* shares an important relationship with another organism, that is, different species of the fungus, *Frankia*. A number of these sources study the relationship between *Casuarina equisetifolia* and fungal species with interest in mycorrhiza (Sidhu *et al.*, 1990; Srivastava and

Ambasht, 1995; Hahn *et al.*, 2003; Muthukumar and Udaiyan, 2010; Karthikeyan *et al.*, 2013; Karthikeyan, 2016; Diagne *et al.*, 2018; Djighaly *et al.*, 2018; Zhong *et al.*, 2019). Mycorrhiza is the study of symbiosis between a fungal species and a plant. In the case of *Casuarina equisetifolia*, the different sources present evidence to suggest that mychorrhiza enhances the plant's nitrogen fixing capability (Pape *et al.*, 2018; Zhong *et al.*, 2019). Both the academic and the environmental manager of Haller Park were able to provide confirmation that encouraging mychorrhiza has become a widely studied theme regarding *Casuarina equisetifolia*. Furthermore, the environmental manager listed *Casuarina equisetifolia*'s nitrogen fixing capability as one of the benefits of using the plant for rehabilitation.

The environmental manager of Haller Park was able to provide one other point relating to *Casuarina equisetifolia*'s relationship with other plants and its ecological benefits. As earlier noted, *Casuarina equisetifolia* was described as able to "jump-start soil formation". The environmental manager continued by stating that:

> *"Casuarina is only used [by Haller Park] as a pioneer species for initial planting, later interplanted with other species to speed up restoration exercise (sic)."*

This suggests that *Casuarina equisetifolia* is able to facilitate revegetation. It was also suggested by the environmental manager that because of the plant's ability to seed itself and spread, the revegetation of degraded and bare landscapes can be addressed with *Casuarina equisetifolia*. This was a key finding and will be discussed in Chapter 5.

About seven sources, or 10% of the total number of studies assessed were categorised under the primary theme phytoremediation. *Casuarina equisetifolia* has been studied in the context of phytoremediation in many different environments (Sun *et al.*, 2004; Ram *et al.*, 2008; Vidya *et al.*, 2011). However, some sources provided information on the performance of *Casuarina equisetifolia* and its potential in the mining industry (Shanker *et al.*, 2005; Baycu *et al.*, 2015; Chirakkara *et al.*, 2016; Salas-Luévano *et al.*, 2017). In particular, studies in Mexico highlight *Casuarina equisetifolia*'s potential to accumulate heavy metal pollution such as As (Carrillo-González and González-Chávez (2006) cited by Salas-Luévano *et al.* (2017)). Traces of As were observed in sampled shoots of *Casuarina equisetifolia* indicating that the plant could accumulate the contaminant. Additionally, *Casuarina equisetifolia* has been noted as one of the best tested hyperaccumulators of Cd while the plant does accumulate Pb, Zn and Cu in small quantities.

A similar study was performed in Cyprus confirming *Casuarina equisetifolia*'s ability to hyperaccumulate Cd (Baycu *et al.*, 2015). As part of the same study, traces of Fe, Ni, Cu and Pb were also observed in samples of *Casuarina equisetifolia*, however, when compared to other plants, the quantity of these contaminants is small. Additionally, *Casuarina equisetifolia* can be a notable hyperaccumulator of Cr (Shanker *et al.*, 2005). Modification of the plant can result in better hyperaccumulation of Cr (Vidya *et al.*, 2011).

Besides for its rehabilitation potential, as highlighted above, the academic and environmental manager of Haller Park suggested that because of *Casuarina equisetifolia*'s ability to produce large quantities of biomass, the plant exhibits potential to be used for other commercial or economic purposes. The environmental manager stated that, *Casuarina equisetifolia* produces wood which is useful for fuel because of its "high calorific" nature, as well as provides "good straight poles". The academic was able to provide a local example, where the plant's wood is processed to produce charcoal as part of the rehabilitation efforts of Richard's Bay Minerals. These are but a few examples which add to the potential of *Casuarina equisetifolia*, not only with regards to rehabilitation, but in relation to other opportunities.

As a final point, through the rapid appraisal and engagement with the academic and the environmental manager of Haller Park, much was learned about *Casuarina equisetifolia*. However, many of the professionals engaged with throughout this study encouraged further research on *Casuarina equisetifolia*. As per the sentiments of the academic,

> *"Casuarina trees normally fly under the radar and are not studied as much as they should be."*

Furthermore, the academic emphasised that "the uses of Casuarina are overshadowed" by the potential of other trees in South Africa because not enough people are working towards better understanding the plant's potential. With regards to future studies, the environmental manager of Haller Park stated that:

> *"So much has been established here on Casuarina especially in limestone quarries at the coast of Kenya with a lot of success, and unproductive lands but so much still can be learnt about the dynamism around the plant".*

4.6. Conclusion

The overall findings of this study can be summarised in a few main points. Firstly, it was observed that mining companies practice revegetation as their main type of rehabilitation method. Revegetation is a long process, often involving extensive land preparation. Although revegetation is practiced, a lack of research and understanding hinders its overall success. In this regard, it was not evident that the plant species used currently for revegetation are the best available options. *Casuarina equisetifolia* exhibits potential in a number of areas related to revegetation. The plant has been noted as a resilient species able to withstand different conditions. The plant also has the potential to hyperaccumulate a number of heavy metal contaminants. The most important finding in relation to the plant's potential is Casuarina equisetifolia's ability to ameliorate soil conditions.

All of the above will be discussed in the following chapter where the empirical evidence gathered will be used to present the assessed potential of *Casuarina equisetifolia* for phytoremediation and rehabilitation in the mining industry.

CHAPTER FIVE

DISCUSSION

5.1. Introduction

The previous chapter addressed the first four research questions of this study. This chapter, therefore, addresses, in its totality, the final research question. In this regard, this section is dedicated to analysing and discussing the empirical evidence gathered. Through this discussion, an understanding of the information gathered is provided in relation to the current study's aim and objectives. To substantiate this discussion and provide context to the interpretations made, reference will be made to the reviewed literature of Chapter Two. After addressing the objectives and aim of this study, the final research question is therefore addressed, that is, what the wider implications of the findings of this study are, particularly in a mining context.

Firstly, in this chapter, the empirical evidence is discussed and analysed in relation to how the mining industry addresses rehabilitation. Secondly, this chapter delves deeper into better understanding the specific rehabilitation methods mining companies use and what challenges and opportunities companies face related to these methods. Finally, a case is made for the potential use of *Casuarina equisetifolia* for phytoremediation and rehabilitation, considering the first two points.

5.2. Environmental rehabilitation in the mining industry of South Africa

An important element of the current study was identifying how the mining industry of South Africa addresses rehabilitation. In this regard, engagement with the mining industry revealed a range of important information relating to the environmental concerns and different rehabilitation practices in the industry. This had to be better understood before exploring the challenges and opportunities related to specific rehabilitation methods employed by the industry as there are reasons why the mining industry chooses specific methods. How the industry addresses rehabilitation will dictate what methods can be used or what methods can be recommended. It is therefore important to firstly consider the outlook of environmental management and rehabilitation options, and this was achieved by addressing this objective.

The four main environmental concerns of the mining industry are worth placing into the context of mining and of South Africa itself. These concerns of the mining industry were noted as addressing their impact on water, biodiversity, air, and soil. These concerns echo what was addressed in Chapter Two as four of the five noted and researched impacts mining has on the environment. Therefore, it can be inferred that these environmental impacts are addressed by the mining industry through specific rehabilitation and environmental management measures. However, more can be said about rehabilitation in relation to addressing these aspects and why some are viewed as more pressing than others.

As the most reported environmental concern of the mining industry, how individual companies manage water resources will determine the future of operations. Through experience over its century-long history, the mining industry has had an interesting relationship with water (Adler *et al.*, 2007). The mining industry has affected water through their consumption (Gunson *et al.*, 2012) and pollution in the form of acid mine drainage (Naicker *et al.*, 2003; Ochieng *et al.*, 2010; McCarthy, 2011). These factors have been continuously scrutinised as they have had serious implications on the well-being of South Africa’s dwindling resources as an already water-scarce country. As a result, the mining industry in South Africa first and foremost, reports and addresses their impact on water. However, their reporting and addressing of water consumption and pollution is far from perfect, with water concerns persisting for many years to come (Mudd, 2008; Simate and Ndlovu, 2014).

How mining companies address their impact on biodiversity must be discussed considering biodiversity offsetting. As reported by most of the mining companies in the study sample as well as being observed at a visited operation, biodiversity offsetting is a different way mines address their impact on biodiversity indirectly. Although seen as beneficial to the biodiversity of a region, biodiversity offsetting, when done right, should account for biodiversity loss in the affected area and mitigate the impacts of mining activity (Virah-Sawmy *et al.*, 2014; Lukey *et al.*, 2017). The practice of biodiversity offsetting ensures that mining companies address their impact on biodiversity while mining continues at their operation and the actual affected site. It stands to reason, if mining companies address their impact on biodiversity through biodiversity offsetting, not as much effort is required in implementing rehabilitation strategies which consider the ecological well-being of mining sites. This is reflected in the current rehabilitation methods used as well as the reported and observed purposes for rehabilitation.

Following that mining companies address their impact on biodiversity through offsetting, revegetation was observed as the main way mining companies address rehabilitation altogether. Importantly, revegetation has been argued as more of a reclamation, rather than a restoration, rehabilitation, or remediation activity (Vangronsveld *et al.*, 1995; Tordoff *et al.*, 2000; Sheoran *et al.*, 2010). It is suggested that through the revegetation of tailings storage facilities, several environmental issues can be addressed at the same time (Tordoff *et al.*, 2000). This includes addressing soil quality, water regulation, biodiversity as well as aiding any potential for the restoration of the degraded area (Tordoff *et al.*, 2000; Cooke and Johnson, 2002; Sheoran *et al.*, 2010; Sonter *et al.*, 2013). This also supports why several mining companies report and demonstrate focusing on revegetation as well as other aspects at the same time.

Considering that there are so many potential benefits linked to addressing environmental rehabilitation through revegetating a degraded landscape, revegetation is seen as an all-in-one as well as a one-size-fits-all solution. In this regard, the specific methods employed to address environmental management revolve around encouraging the growth of vegetation in a degraded area, allowing for ecological restoration following successful reclamation (Cooke and Johnson, 2002). Once successful revegetation is achieved, natural rehabilitation can take place through the plants, ecosystems and biota which inhabit the landscape and tolerate its conditions (Cooke and Johnson, 2002). As will be discussed in the section to follow, the different plants used for revegetation are the key players leading to reclamation and rehabilitation being successful (Cooke and Johnson, 2002; Wehr *et al.*, 2006). In some case studies, the plants used have been credited as being able to address multiple environmental issues including, erosion, air, and water pollution (Norland and Veith, 1995; Conesa *et al.*, 2007a). However, revegetation is strongly linked to how phytoremediation can be implemented through the species chosen for revegetation (Conesa *et al.*, 2007b; Nirola *et al.*, 2016). The listed advantages are only some of the ways revegetation can address several environmental issues at the same time. An extensive amount of research has been done on the benefits and opportunities of revegetation. These will be discussed in sections to follow.

As a one-size-fits-all solution, revegetation can be considered as an option despite the end-goal of a mining site as it can only lead to the improvement of environmental conditions of the area. The specific revegetation strategy of a site can be planned according to the site itself and therefore involve the employment of different strategies or steps in line with the end goal (Cooke and Johnson, 2002). For example, repurposing a site as an industrial area might be the end goal of environmental management, therefore not requiring the extensive clean-up of pollutants. On the other hand, a site might need to be repurposed as an agricultural area, and therefore needs complete remediation which is possible if employing a well-planned revegetation strategy. In contrast, revegetation can still be beneficial in situations, just as the environmentalist mentioned, where an end-goal is yet to be determined for a mining site. Therefore, revegetation as a singular rehabilitation activity noted in the empirical evidence collected, can be justified as a legitimate and intuitive means of addressing rehabilitation at any mining facility.

As mining companies value the stability of their sites while still active, revegetation is argued to be one of the best rehabilitation practices in this regard (Tordoff *et al.*, 2000). Tordoff *et al.* (2000) argue for the value of revegetation and the use of plants to stabilise conditions at a degraded mining site. This includes addressing soil erosion, preventing contaminated water from entering watercourses and improving the overall health of degraded landscapes. When compared to other options, such as the use of covering or chemical treatment, stabilisation through revegetation is the most effective (Tordoff *et al.*, 2000). Furthermore, the use of revegetation and early stabilisation would lead to facilitating later restoration of the site for uses such as forestry or agriculture as the area would be more prepared to accommodate vegetation.

To re-iterate, an objective of the current study was to identify how mining companies address environmental rehabilitation. By addressing this objective, the above information sets a stage upon which the potential of *Casuarina equisetifolia* for rehabilitation can be established. The observed overwhelming use of revegetation for rehabilitation across the mining industry opens discussion on the possibility of including *Casuarina equisetifolia* as one of the species intentionally planted as part of efforts. This is a critical point in establishing the plant's potential as the use of the plant can be incorporated into the current rehabilitation practices of the industry without arguing for a complete rethinking of how rehabilitation is approached. Furthermore, revegetation as a rehabilitation approach is practiced with the notion that all environmental impacts as mentioned in Chapter Two, will eventually be addressed. Therefore, as with any other plant species, *Casuarina equisetifolia*, has the potential to address primary impacts such as the impact of mining on soil as highlighted by Dudka and Adriano (1997), eventually addressing some of the consequential impacts of mining such as water and air quality. As a specific example, impacts such as acid mine drainage, therefore, can be addressed through revegetation, addressing soil as the source of the impact itself. *Casuarina equisetifolia* also has the potential to address the impact of mining on biodiversity in a unique way. These points will be further discussed later when considering the researched potential of the plant itself. Therefore, the stance that this study upholds is, as Tordoff *et al.* (2000) argue, the revegetation of landscapes is an effective rehabilitation measure. However, as stated by the soil scientist interviewed, the approach to revegetation can be improved to be even more effective.

5.3. Rehabilitation methods used and challenges and opportunities related to environmental rehabilitation in South Africa

As the second objective of the current study, an assessment of the specific rehabilitation methods used by the mining industry of South Africa, and related challenges and opportunities was required. The specific methods associated with the revegetation and stabilisation of mining sites can be discussed in relation to the *Guidelines for the rehabilitation of mined land* compiled by Tanner and Möhr-Swart (2007). As observed at Site B, the rehabilitation of mined land follows a general process which leads to the eventual revegetation of land as the focus of rehabilitation efforts. As discussed above, revegetation would then lead to addressing several impacts mining activity would have had on the environment.

Revegetation is therefore understood as the be-all and end-all of rehabilitation in the mining industry in South Africa. Therefore, this section discusses the different physical, chemical and biological methods in the context of revegetation. Revegetation initiatives observed at the two sites visited can be described as a mix of both direct and non-direct revegetation practices, as per Xie and van Zyl (2020). According to Xie and van Zyl (2020), non-direct revegetation involves the preparation of a substrate through physical methods which then accommodates for natural revegetation to take place. As will be discussed, non-direct revegetation practices were mostly observed at Site B. Direct revegetation is described as the growth of plants directly on raw tailings with the possibility of prior treatment or the minor amelioration of tailings. Different from Site B, direct revegetation was observed at Site A. However, different methods form part of revegetation initiatives. This will be discussed relating to empirical evidence of the current study.

Empirical evidence showed that mining companies make use of biological rehabilitation methods the most. This is justified through mining companies' focus on revegetation. However, it is important to discuss the application of physical and chemical rehabilitation methods in the context of stabilising and reclaiming degraded landscapes. Firstly, more depth must be provided as to why it was observed that many mining companies make use of all three approaches, that is, physical, chemical, and biological, to address rehabilitation. For example, as noted through the comments of the soil scientist, biological and physical methods are employed to address rehabilitation at their site. The biological methods used in this example, involve revegetation. If revegetation can address multiple environmental issues, why then is it important to make use of physical and chemical methods? The answer to this question lies behind specific prerequisites before revegetation can be set in motion.

Cladding, netting, and chemical treatment were observed as the specific rehabilitation measures or methods mining companies implement at their sites. These three methods can be considered preparation for revegetation which is then the main form of implemented rehabilitation. In this regard, for revegetation to be successful, proper preparation is very important (Ruthrof *et al.*, 2013). As Ruthrof *et al.* (2013) suggest, the preparation of land for revegetation can involve several steps. This is supported by Tanner and Möhr-Swart (2007) who highlight that proper conditions are required to facilitate the revegetation of a site. Therefore, cladding, netting and chemical treatment must be discussed in the context of the overall aim to revegetate a degraded mining site.

As noted along the walls and lower slopes of Site B's tailings facility, cladding is a physical method through which topsoil is prepared. It involves a specific process with the result being a layer of topsoil within which a seed bank can be added. According to Tanner and Möhr-Swart (2007), cladding or the placement of a topsoil layer may involve other soil amelioration efforts including the use of chemical treatment. At Site A, chemical treatment was mentioned as a method, where the site supervisor stated that tailings from the plant was pre-treated and impregnated with a seed bank before deposition. Both cladding, chemical treatment or any other soil ameliorating methods are performed to enable the chosen plant species to grow at the site. In this regard, some plants may not be as resilient to the harsh conditions of bare tailings and therefore require aid to flourish.

The use of netting can also be viewed as a form of preparing a site for future revegetation. At Site B, netting was observed at the highest points of the tailings facilities. Slopes at this elevation were steep and would not be able to support any vegetation. However, dust fallout and erosion at the top of the tailings facility has to be addressed. Providing an example of how netting can be used to facilitate future revegetation, Peterson *et al.* (2004) demonstrates that netting is one of the methods used at high elevations to prevent erosion and dust fallout in the

Bryce Canyon National Park in Utah. Therefore, although not currently apparent at Site B, the higher slopes will eventually be levelled off and cladding will be placed, leading to revegetation.

While revegetation may be successful after proper preparation of land using claddings, chemical treatment and netting, a closer look at the different plant species used for rehabilitation merits debate as to what other options are available to the mining industry. As observed, three main points influence what plant species are considered by mining companies for revegetation. These three points are (1) what species were present in the area prior to mining, (2) what species thrive in the surrounding area and (3) what species have been researched as plants with potential to address environmental impacts. This was evident at the two sites visited, as much of the plants identified included indigenous plants found in the surrounding area as well as a few species which have been studied, documented and recommended in the past. An example of this is seen once more in the guidelines provided by Tanner and Möhr-Swart (2007).

Tanner and Möhr-Swart (2007) provide a list of useful plant species which can be considered for use in revegetation projects. The list provided includes indigenous grasses, shrubs, legumes, and trees as well as their potential benefits if used for revegetation. Tanner and Möhr-Swart (2007) also recommend the use of commercially available plants and seeds. It was observed that particular attention was shown to what species were chosen for revegetation at Site B. The identification of grass species including *Cynodon dactylon*, *Eragrostis curvula*, and *Eragrostis tef* at the site and comments of the environmental manager provided evidence to suggest that the guidelines of Tanner and Möhr-Swart (2007) were followed by the managing mining company of Site B to some extent. Each of the mentioned species can be related back to recommendations or guidelines provided by Tanner and Möhr-Swart (2007). However, each of the grass species mentioned above are referred to in different ways by Tanner and Möhr-Swart (2007). While *Cynodon dactylon* and *Eragrostis tef* are considered useful for revegetation purposes, Tanner and Möhr-Swart (2007) argue against the use of *Eragrostis curvula* as the species is difficult to maintain. While *Eragrostis tef* was lightly discussed as an option for re-grassing environments, *Cynodon dactylon*, however, was argued for as a grass species with the potential to survive in the poor mining soil as well as prevent soil erosion.

Grass species are strongly recommended for revegetation as it has several advantages over other plant species (Xia, 2004; Shu *et al.*, 2002). One of these advantages include the ability of grasses to spread and grow faster than other plants (Xia, 2004). Fast growth means that revegetation can occur much faster. Furthermore, some grass species are known to ameliorate soil conditions, preparing the substrate for other plants, especially at sites where a topsoil layer is not initially prepared. However, as observed, a topsoil layer may not be necessary altogether. This suggests that revegetation is possible without extensive land preparation. However, this is dependent on the plant species chosen and used for revegetation.

This initiates a discussion on the other species identified during site visits and their resilience to the conditions at mining sites. It was noted that the tailings deposited at Site A was pre-prepared for natural revegetation to follow deposition. However, a deliberate preparation of a topsoil layer was notably not necessary for vegetation to thrive. Although grass species including *Aristida bipartita* and *Eragrostis curvula* were identified, vegetation at Site A consisted of different *Vachellia* tree species. These trees were noted as able to grow in sandy and rocky environments. Furthermore, *Vachellia nilotica* is able to grow near watercourses which can be compared to the tailings facility itself. As a result, revegetation at Site A is possible with less intervention given that the trees chosen for revegetation are resilient to the conditions imposed on them by raw tailings.

While the plants chosen may or may not facilitate the progress of revegetation, some of the species chosen can contribute to addressing specific environmental impacts. A specific tree species identified at both sites visited, that is *Searsia lancea*, is worth discussing in the context of how the mining industry makes use of species which have been previously researched. The tree species is part of the extensive research program in South Africa known as the Mine Woodlands Project (Dye *et al.*, 2008; Regnier *et al.*, 2009; Dye *et al.*, 2016; Dye *et al.*, 2017). *Searsia lancea* has recently been identified as a species which is able to control water seepage at mining sites (Dye *et al.*, 2017). In this regard, the benefit of including such a plant in revegetation initiatives would be two-fold; firstly, the plant is indigenous to South Africa and therefore would pose no threat to other plants and secondly, the plant could be used for water regulation at sites, which has been noted as a focus of rehabilitation.

Plant species which have phytoremediation potential can also be selected for revegetation purposes and in a similar way as the example above, contribute to the overall rehabilitation of a degraded landscape. *Tamarix usneoides* was a species mentioned by the environmentalist relating to rehabilitation success stories. In the context of the mining industry, Wilson *et al.* (2017) describes *Tamarix usneoides* as a species resilient to saline conditions. Furthermore, it is argued by Wilson *et al.* (2017) that the plant can accumulate salt, making it an option to be used for the phytoremediation of sodic landscapes. This suggests that plants with phytoremediation potential can be integrated into revegetation initiatives as an effective way to address soil or water contamination.

Except for the above case study, empirical evidence suggested that mining companies show little to no interest in the deliberate implementation of phytoremediation. Unless a plant is well-researched and tested, the mining industry seems not to consider the use of plants specifically for phytoremediation purposes. Furthermore, plants are more likely considered if they are part of the natural vegetation in the surrounding area. For mining companies, the use of phytoremediation is seen in a similar way as the above-mentioned methods. Much like cladding, chemical treatment and netting, phytoremediation is understood as a product of revegetation. This was also confirmed by Tanner and Möhr-Swart (2007) who recommend the use of specific plant species for the stabilisation and clean-up of degraded landscapes.

It is important to further discuss the concept of phytoremediation in the context of revegetation and reclamation. Xie and van Zyl's (2020) recent definition aids in understanding the relationship between the three concepts. According to Xie and van Zyl (2020), and as observed, phytoremediation must be understood as a part of revegetation, which is then a part of reclamation. As already discussed, revegetation is a means used to reclaim a degraded landscape. Phytoremediation follows thereafter, as the species used for revegetation may include some which are able to phytostabilise or hyperaccumulate contaminants or heavy metal pollution (Xie and van Zyl, 2020). Xie and van Zyl (2020) makes an important claim that through revegetation, phytoremediation can be indirectly implemented and lead to the specific plant species used for revegetation providing additional benefits inclusive of addressing heavy metal pollution. Following a consideration of the above, rehabilitation in the mining industry and all its related methods can be summarised through a flow diagram (figure 5.1). Figure 5.1 illustrates, in the form of a simplified process, how rehabilitation is conducted in the mining industry as per empirical evidence. As part of this process, phytoremediation is noted as a step following plant species selection and the establishment of the potential benefits of the species selected. This diagram will be revisited when establishing the potential of *Casuarina equisetifolia* in the next section.

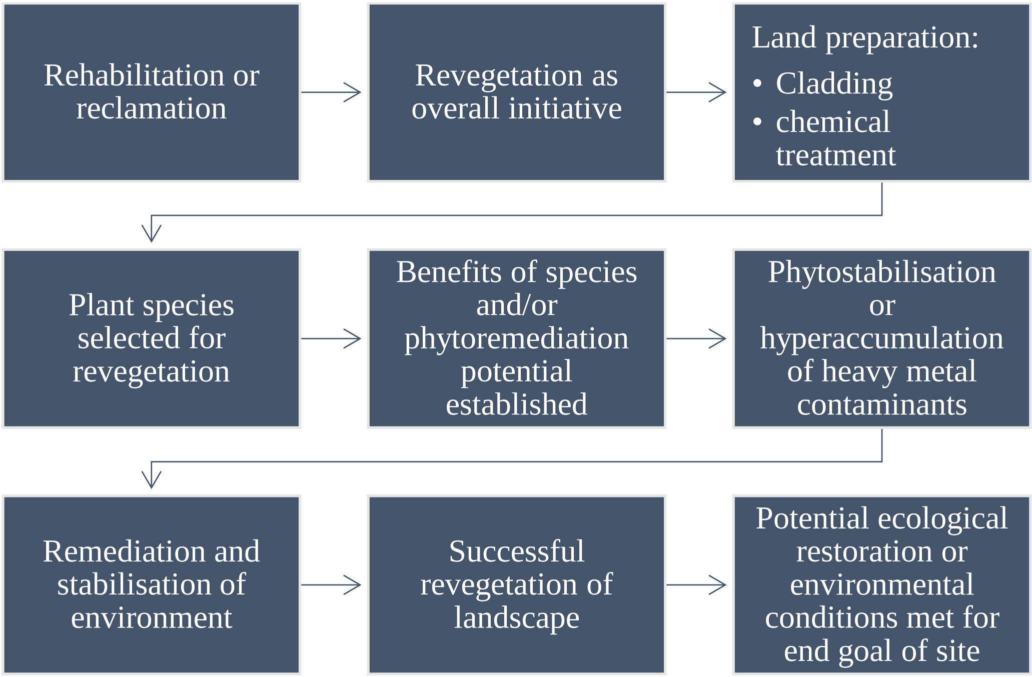

Figure 5.1. Flow diagram illustrating the process of rehabilitation as observed through empirical evidence.

The process illustrated above highlights the rigidity of how rehabilitation is addressed in the mining industry. Emphasised here, is the idea that phytoremediation or the use of plants as a phytotechnology only follows once the species establishes itself and benefits are noticeable. Therefore, this process does not consider phytoremediation as a primary objective of rehabilitation. The potential benefits a plant species can provide is also linked to and limited by the specific end goals of the environmental rehabilitation plans of mining operations. In this regard, an observed challenge for the mining industry would be altering their existing environmental management plans, which in many cases considering the advantages of revegetation, cannot be faulted (Tordoff *et al.*, 2000; Cooke and Johnson, 2002). Overall, by revegetating a degraded landscape using different plant species, whether researched as useful and resilient or not, stabilisation can be achieved through a few steps which may involve preparation of the site and planting species commercially available (Tordoff *et al.*, 2000; Tanner and Möhr-Swart, 2007).

A strong advantage of the current rehabilitation initiatives observed is its cost-effectiveness. Revegetation has been praised as an initiative which does not cost mining companies too much while still addressing the most pressing matter of environmental management at mining sites

(Tordoff *et al.*, 2000; Conesa *et al.*, 2007a). By making use of commercially available, fast spreading plants such as various grass species as suggested through the guidelines of Tanner and Möhr-Swart (2007), costs can be kept in control. While costs may be controlled in the initial steps of revegetation, the benefits of using plants for rehabilitation following the establishment of vegetation, come at little to no cost. However, the use of cheaper or commercially available options as opposed to other options may not be as beneficial for rehabilitation (Bochet *et al.*, 2010)

Although many of the plants used by the mining industry can be argued for their beneficial qualities, such as *Searsia lancea*, the contrary can be said about a plant such as *Vachellia karoo* (Dye *et al.*, 2018). Although used extensively at Site B, Dye *et al.* (2017; 2018) highlight that *Vachellia karoo* may not be as beneficial as *Searsia lancea* for water regulation. In this case, the use of the latter can be better recommended. However, costs may limit the mining operation to move away from using the less-effective option. Therefore, a claim can be made that through further research and with adequate financial resources, revegetation in the mining industry could use plants which may be much more beneficial than current options. Furthermore, this brings into discussion the viewpoint of the environmentalist who emphasised the potential of exotic plant species compared to indigenous options. With further research, exotic species may have more potential and could therefore be recommended in place or alongside the currently used plant species.

It must be noted that mining companies do show interest in exploring new possibilities in relation to rehabilitation. The professionals engaged with showed interest in potentially experimenting with different plant species at their sites. This relates back to the idea that mining companies do make use of previously researched plants such as *Cynodon dactylon*, *Searsia lancea* and *Tamarix usneoides* (Tanner and Möhr-Swart, 2007; Dye *et al.*, 2017; Wilson *et al.*, 2017). This can be viewed as an opportunity associated with rehabilitation in the mining industry and shows that the mining industry is not limited to dated rehabilitation methods. In this regard, other plant species can be recommended in the future, given that sufficient research can suggest their usefulness or potential.

Although the above is an important opportunity observed through the empirical evidence of the current study, it must be noted that the mining industry is not as accommodating to all plant species. As a noted challenge, mining companies show hostility to any plant classified as an invasive species which may be growing among the chosen and plant species part of revegetation initiatives. This is in line with the guidelines of Tanner and Möhr-Swart (2007) who advise for the removal of invasive species as they may be a threat to the well-being and continued success of revegetation. Therefore, it is not certain how mining companies will respond to advice for the use of an exotic or invasive species for revegetation. However, it has been noted that *Eucalyptus* trees were present at Site B and used as part of revegetation initiatives. *Eucalyptus* trees have been studied to have phytoremediation potential and therefore, may benefit revegetation and rehabilitation (El Rasafi *et al.*, 2020). Furthermore, invasive species are used to a great extent by Richard's Bay Minerals, who make use of the tree of interest to the current study, that is *Casuarina equisetifolia* (Potgieter *et al.*, 2014).

To summarise the above, the mining industry of South Africa engages in revegetation for the purpose of reclamation. As part of revegetation initiatives, several methods are used to prepare a landscape for the growing of chosen plant species. It is only after revegetation is established that the grown plants begin clean-up and reclamation of a degraded site through phytostabilisation and phytoextraction or hyperaccumulation. Therefore, phytoremediation is only a potential result of revegetation. The choice of species is crucial and is limited by what is available to mining companies, what has been understood as effective for revegetation, and what would contribute to addressing the degraded area to prepare it for its eventual end-goal. While mining companies are open to exploring new options for revegetation, focus on phytoremediation is not evident and therefore, phytoremediation must be considered, not on its own, but through the plants chosen for revegetation. In other words, if recommendations are to be made for the use of species which have potential as phytoremediation tools, it must be in the context of their already established revegetation projects. This has a bearing on what species can be recommended as some are viewed as a potential danger to current projects. In this regard, researched evidence needs to be presented before making a recommendation.

An argument can therefore be put forward for the potential value of plant species, such as *Casuarina equisetifolia* considering all the methods, challenges and opportunities of environmental rehabilitation as practiced in the mining industry. Firstly, using *Casuarina equisetifolia* for revegetation, entire reclamation projects can be reformed and restructured, removing otherwise costly and tedious steps in the process. This will be further supported in the next section when considering the phytoremediation or phytotechnological potential *Casuarina equisetifolia* has. Several steps involving physical and chemical methods can, instead, be addressed through direct revegetation as argued by Xie and van Zyl (2020). At the same time, with an understanding of the plant's phytoremediation potential, specific remediation results can be foreseen rather than these taking place as a function of established vegetation of reclamation projects. This leads to a discussion of how, if selected for specific use-cases, *Casuarina equisetifolia* has the potential to transform rehabilitation in the mining industry. Therefore, it must be argued that a new stance on how rehabilitation is addressed be taken, with remediation as a primary focus before reclamation can be fully considered. By addressing targeted issues, the larger issue, that is, environmental management or rehabilitation, can be addressed.

5.4. The potential of *Casuarina equisetifolia* for rehabilitation in the mining industry of South Africa

Following from the above information on how the mining industry of South Africa addresses rehabilitation, a case can be made for the potential of *Casuarina equisetifolia*. As will be discussed, this study was initially concerned with the phytoremediation potential of *Casuarina equisetifolia*. However, through investigation and the empirical evidence gathered, it is understood that the plant's potential is much more extensive. This section will discuss the potential of *Casuarina equisetifolia* in the context of how the mining industry addresses rehabilitation, and the specific methods employed as part of rehabilitation efforts. A final proposal will be made for how mining companies could adopt and make use of *Casuarina equisetifolia* in their current rehabilitation programs. This will consider the different benefits *Casuarina equisetifolia* may provide, as well as the potential the plant has, both as a phytoremediation tool and as a phytotechnology altogether.

Firstly, through the empirical evidence gathered, it was concluded that *Casuarina equisetifolia* has potential as a plant which is resilient to harsh environmental conditions. As previously discussed, the success of rehabilitation or reclamation projects is attributed to the resilience of the plant species used for revegetation. Therefore, mining companies tend to rely on plant species observed in the surrounding area, as they are able to adapt better to the harsh conditions of a tailings facility. As argued by Xie and van Zyl (2020), the practice of non-direct revegetation evades concern over the resilience of plant species, as the preparation of a topsoil layer would provide sown seeds with a better environment than being planted in raw tailings. The practice of non-direct revegetation is supported by Tanner and Möhr-Swart (2007) who argue for the application of a topsoil layer to tailings landscapes as part of recommended procedures for the reclamation of mined land. However, *Casuarina equisetifolia* can withstand the harsh conditions of raw tailings, as observed through the experiments of Karthikeyan *et al.* (2009).

In Karthikeyan *et al.'s* (2009) experiment, *Casuarina equisetifolia* seedlings were planted in bauxite mine waste or mine spoil and exhibited healthy growth. As another important piece of evidence gathered, Wehr *et al.* (2006) argues for the use of *Casuarina equisetifolia* for the revegetation of bauxite mining sites in Australia. The plant is among several species able to withstand alkaline and sodic conditions. Although the nature and composition of mine spoil differs among different mining operations and environments, the empirical evidence gathered which suggests *Casuarina equisetifolia* to be resilient to the conditions imposed by raw tailings is a good starting point for further investigation. Therefore, the observed resilience of *Casuarina equisetifolia* merits further experimentation in South African mining contexts.

Being able to grow in raw tailings, it is suggested that *Casuarina equisetifolia* can be used as part of direct revegetation. Many of the methods and steps taken to prepare landscapes for revegetation can subsequently be circumvented or bypassed. This may have a bearing on some of the challenges and opportunities related to rehabilitation as the elimination of the need to prepare a topsoil layer for non-direct revegetation will be more cost-effective. In this regard, *Casuarina equisetifolia* can be employed as a means of direct revegetation in a similar way as was used at Haller Park for ecological restoration (Siachoono, 2010). In the case of Haller Park, and confirmed by the environmental manager of the reserve, *Casuarina equisetifolia* is planted at site without any prior preparation. The plant species grew better than any other species and has therefore been recommended by the environmental manager for potential use in the mining industry of South Africa.

When considering the current phytoremediation and environmental rehabilitation research in South Africa, *Casuarina equisetifolia*'s resilience can also be compared to that of *Tamarix usneoides*. As a plant species of recent interest to phytoremediation and environmental rehabilitation studies, *Tamarix usneoides* has been praised for its ability to withstand saline conditions (Wilson *et al.*, 2017; Newete *et al.*, 2020). However, the empirical evidence gathered through this research shows that *Casuarina equisetifolia*, being resilient to the conditions of raw bauxite mine tailings, is also resilient to saline soil conditions (Ng, 1987; Tomar *et al.*, 2003; Wehr *et al.*, 2006; Hussain and Alshammery, 2008; Djighaly *et al.* 2018; Edrisi *et al.*, 2020). Therefore, it is well established that *Casuarina equisetifolia* can withstand saline conditions and may be comparable to other alternatives being explored by the mining industry of South Africa.

Casuarina equisetifolia's resilience is also not limited to withstanding polluted soil or sodic conditions alone. As seen through empirical evidence, studies indicate that the plant can withstand different environmental conditions. Firstly, *Casuarina equisetifolia* has been observed to be resilient to waterlogged conditions (van der Moezel *et al.*, 1989). As raw tailings take the form of a slurry, the plant should be able to grow well along tailings walls, regardless of the water content of the tailings being stored within. *Casuarina equisetifolia* also can withstand dry conditions (Lee *et al.*, 1997). As suggested by Lee *et al.* (1997), *Casuarina equisetifolia* has the potential to revegetate sandy areas. As a plant found mostly along the coast on well drained coastal sand, the conditions of sandy tailings should pose as no problem to the plant. Finally, as already established, *Casuarina equisetifolia* prefers warmer climates. However, empirical evidence and past research suggest that *Casuarina equisetifolia* can withstand colder conditions if grown and bred appropriately (Li *et al.*, 2017; Li *et al.*, 2018). Most of South Africa's mining industry is concentrated in Johannesburg and the Gauteng province which experiences low temperatures during winter months. Therefore, compared to other plant species, *Casuarina equisetifolia* is resilient to many different conditions, making it an overall resilient option for revegetation.

However, this alone is not enough to justify *Casuarina equisetifolia*'s potential over *Tamarix usneoides*. *Tamarix usneoides* has been argued as the best alternative to remediating sodic landscapes because it is biologically more capable of salt-uptake than any other similar exotic species (Wilson *et al.*, 2017). However, the true potential of *Casuarina equisetifolia* is not limited to resilience nor salt-uptake. The value of *Casuarina equisetifolia* is best observed when considering the extensive research on its capability to ameliorate soil conditions. This is a key point arguing for the potential of *Casuarina equisetifolia* as its ability to ameliorate soil conditions has been part of extensive research in the past.

As seen through empirical evidence, *Casuarina equisetfolia* has been credited with the ability to encourage soil nutrient cycling, but more importantly, fix atmospheric nitrogen. Nitrogen fixation is an important process which not only allows for the support of nitrogen fixing plants, but also entire plant communities (Sheoran *et al.*, 2010). This suggests that by fixing atmospheric nitrogen and ameliorating soil conditions, *Casuarina equisetifolia* has the potential to support and encourage the growth of other plant species. This is a critical point in understanding how *Casuarina equisetifolia* can encourage natural ecological restoration as supported by Parrotta (1999).

As will be further discussed, *Casuarina equisetifolia*'s potential to support and encourage the growth of other plants may be able to reshape the way mining companies address revegetation. Current revegetation strategies require extensive maintenance and the use of grass species, of which some such as *Eragrostis curvula* provides little benefit to mining areas (Tanner and Möhr-Swart, 2007). By addressing soil through nitrogen fixation, *Casuarina equisetifolia* can initiate revegetation by itself, allowing indigenous species to repopulate the area as experienced in Haller Park (Siachoono, 2010). Therefore, not only is *Casuarina equisetifolia* resilient to harsh tailings conditions, but it also has the potential to ameliorate soil conditions for itself and other plants.

An element of research on *Casuarina equisetifolia* which cannot be ignored, however, is the plant's relationship with arbuscular mycorrhizal fungi. As empirical evidence suggested, much of the research done has considered how mycorrhiza can be achieved between different species of arbuscular mycorrhizal fungi and *Casuarina equisetifolia* (Sidhu *et al.*, 1990; Srivastava and Ambasht, 1995; Sayed *et al.*, 2011; Karthikeyan *et al.*, 2013; Karthikeyan, 2016; Diagne *et al.*, 2018). Mycorrhiza has the ability to enhance both, *Casuarina equisetifolia*'s resilience as well as nitrogen fixing capability (Karthikeyan *et al.*, 2009; Djighaly *et al.*, 2018; Zhong *et al.*, 2019). This suggests that *Casuarina equisetifolia* can be even more effective for soil amelioration, or be more resilient to harsh conditions, if inoculated with arbuscular mycorrhizal fungi.

Considering the above experience from Haller Park and the sentiments of the environmental manager of the reserve, if the plant were to be used for revegetation, it is best suited as a pioneer species or a plant used to initiate revegetation. It stands to reason that if *Casuarina equisetifolia* can not only withstand, but can ameliorate the conditions of raw tailings, the plant could help kickstart revegetation projects, supporting other plants grown as part of the same initiatives. Through inoculation with arbuscular mycorrhizal fungi, such as *Frankia*, the success of revegetation projects can be further assured. *Casuarina equisetifolia* can be beneficial for environmental reclamation in one more way, its phytoremediation potential. Therefore, as a plant which can be used as a pioneer species to initiate revegetation, it is able to ameliorate, not only soil conditions, but environmental conditions altogether.

As covered in Chapter Two, phytoremediation is becoming more used around the world, particularly in the mining industry (Festin *et al.*, 2019). Plants with potential in this avenue are valuable for environmental rehabilitation as they are able to ameliorate and restore prior environmental conditions by eliminating harmful heavy metal contaminants in soil and water. However, as mentioned in previous sections, the mining industry of South Africa does not show particular interest in considering the phytoremediation potential of the plant species they use for revegetation. It was observed that mining companies show interest in researched plants and are open to making use of potentially beneficial plant species, however, their focus is revegetation for reclamation of degraded landscapes. In this regard, the phytoremediation potential of *Casuarina equisetifolia* must be understood as an additional advantage and not as the main reason for recommending the use of the plant.

Casuarina equisetifolia has the potential to hyperaccumulate or phytoextract several heavy metals or chemical contaminants. These include As, Pb, Zn, Cu, Cd, Fe, Ni and Cr. Of these heavy metals and contaminants listed, Aucamp and van Schalkwyk (2003) identify As, Cr, Cu and Ni as important trace elements found in a gold mine tailings facility in South Africa. This has also been supported by Maboeta *et al.* (2018) who cite Chen *et al.* (2017) and Pavilonis *et al.* (2017), arguing that As, Pb, Zn, Cu, Cd, Ni and Cr are all noted contaminants in gold mine tailings. This suggests that if *Casuarina equisetifolia* was to be used for the revegetation of tailings with a similar composition, these heavy metal contaminants could be addressed through phytoremediation. Coupled with its resilience to cold conditions and raw mine tailings as well as ability to ameliorate soil, the potential of *Casuarina equisetifolia* is most noticeable fitting all the criteria needed to address gold mines in Johannesburg and Gauteng. As an observed example, *Casuarina equisetifolia* can be used for the rehabilitation of mining sites such as Site B's tailings facility in the Ekurhuleni metropolitan. In this regard, further evaluation of the findings is necessary to qualify the value of *Casuarina equisetifolia* for the mining industry of South Africa.

Through ecotoxicity studies, it has also been observed that some of the contaminants which *Casuarina equisetifolia* is able to address are found in platinum mine tailings. Jubileus *et al.* (2013) support that Cr and Ni are important heavy metal contaminants observed at platinum mines in South Africa. To further support this, Rauwane *et al.* (2018) demonstrate and confirm that Cr, Ni as well as Cu are contaminants found in abundance at platinum mining sites in the Rustenburg area. Therefore, an argument for further research in the potential of *Casuarina equisetifolia* for the rehabilitation of platinum mining areas, such as Site A, can be made.

Together, by having the potential to address phytoremediation at both gold and platinum mining sites, *Casuarina equisetifolia* can be used to address rehabilitation at most mining companies which were part of the current study's sample.

It is, however, important to note that compared to other plants, *Casuarina equisetifolia* may not be the best phytoremediation option available to mining companies depending on the composition of tailings. For example, Ni is a common contaminant observed at both gold and platinum mining sites. However, it has already been established that *Berkheya coddii* is an effective indigenous hyperaccumulator of Ni, thus, making it difficult to recommend *Casuarina equisetifolia* for purposes of addressing Ni contamination alone (Robinson *et al.*, 1997; Robinson *et al.*, 1999; Keeling *et al.*, 2003; Robinson *et al.*, 2003). While further research is needed to determine and confirm the full phytoremediation potential of *Casuarina equisetifolia*, the empirical evidence gathered through the current study suggests that *Casuarina equisetifolia* is a hyperaccumulator of heavy metal contaminants and this can be seen as an additional benefit if the plant is used for revegetation by the mining industry of South Africa.

The potential of *Casuarina equisetifolia* extends to one more avenue, that is, its ability to produce biomass in the form of litter and wood as a large tree. The tree is commonly used as part of forestry projects, as noted in Richard's Bay (Potgieter *et al.*, 2014). As suggested by Haller Park's environmental manager, *Casuarina equisetifolia* is now part of commercial projects in Mombasa, Kenya, where the plant was first introduced for rehabilitation. As an additional advantage or opportunity, the potential use of *Casuarina equisetifolia* could extend into commerce, providing economic benefits to mining companies who use the plant for revegetation. Through empirical evidence and the data collected, *Casuarina equisetifolia*'s biomass is valuable as a source of fuel as well as timber. This can be further explored at sites which have an end-goal of being rehabilitated into forestry land.

In light of all the above, a re-evaluation and proposal for the improvement of current rehabilitation strategies can be put forward considering the potential of *Casuarina equisetifolia*. As illustrated in the previous section, Figure 5.1. demonstrated how mining companies address rehabilitation, while considering the plant species within the full process of revegetation and reclamation. Figure 5.2. updates this process, placing the use and implementation of *Casuarina equisetifolia* as a key step which has the potential to overhaul and improve rehabilitation in the mining industry in South Africa, following observations made.

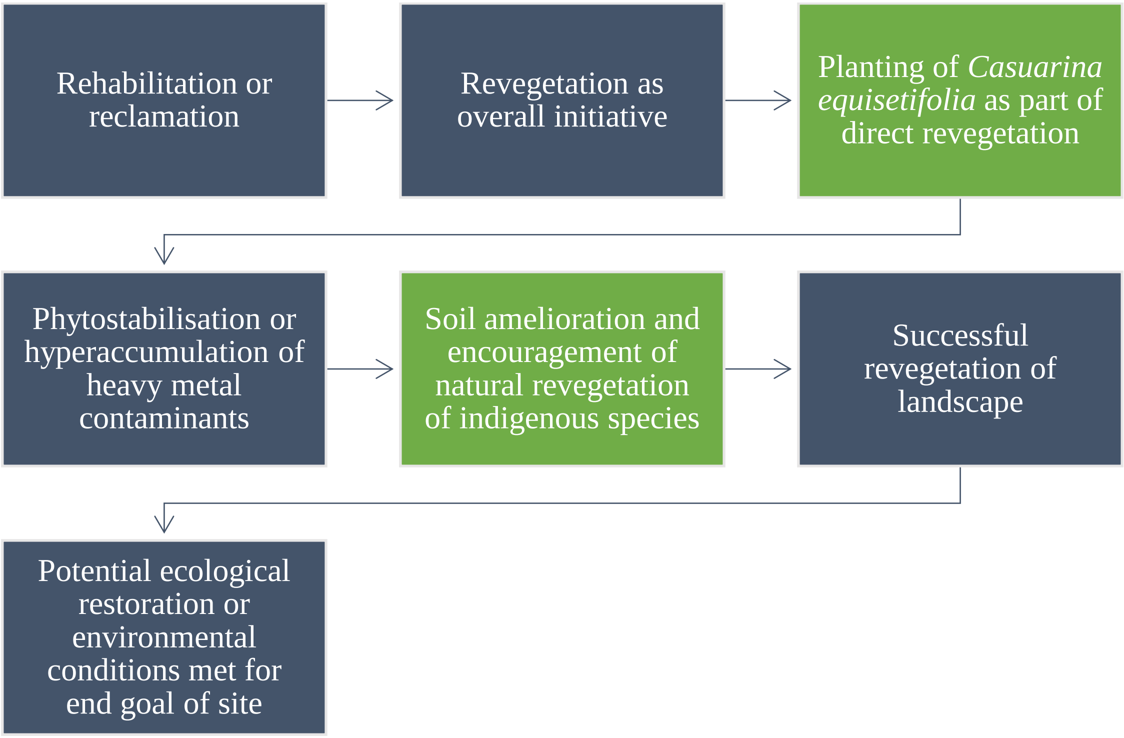

Figure 5.2. A proposed revision of the process of rehabilitation illustrated in Figure 5.1.

In Figure 5.2, land preparation steps can be replaced with the direct revegetation of *Casuarina equisetifolia*. As the phytoremediation benefits of the plant are already known, *Casuarina equisetifolia* will address heavy metal contamination prior to revegetation. Along with hyperaccumulating heavy metal contaminants, *Casuarina equisetifolia* will ameliorate soil conditions and simultaneously encourage the growth of indigenous vegetation at the degraded area. Successful revegetation would follow as natural vegetation returns to the area. The establishment of the benefits of different plant species would no longer be necessary as *Casuarina equisetifolia* would have already ameliorated conditions at this point. In a similar way, remediation and stabilisation would be addressed early in the revegetation process through *Casuarina equisetifolia*. Through successful implementation through revegetation, *Casuarina equisetifolia* would prepare the addressed environment for its end-goal or potential ecological restoration.

The above proposal must be taken as a simple representation of the potential of *Casuarina equisetifolia* in the context of rehabilitation in the mining industry of South Africa. The process itself will highly depend on individual mines and their end-goals. Additionally, experimentation with the plant will establish the plant in different conditions as found across

South Africa, and therefore, the proposal of Figure 5.2. may be altered depending on the dynamics of individual mining companies and their sites. As a justification for proposed use of *Casuarina equisetifolia* as illustrated in Figure 5.2, it is foreseen that rehabilitation costs will be reduced as several steps in the current rehabilitation process will be eliminated, including the need to prepare landscapes before revegetation. It should be noted that netting and erosion measures may still be necessary, depending on how long rehabilitation takes. As for the growth of *Casuarina equisetifolia*, it is expected that these trees will not take longer than two years to reach a height of eight meters as suggested by Siachoono (2010). Therefore, at later stages of the rehabilitation process, the trees may be able to act as windbreaks.

To conclude this section, *Casuarina equisetifolia* has the potential to alter and improve on the entire rehabilitation process followed by the mining industry of South Africa as studied and observed. Not only is it a phytoremediation tool worth considering for use at gold and platinum mines, *Casuarina equisetifolia* also holds potential as a resilient tree which can provide the foundation for natural revegetation. Furthermore, through forestry projects, *Casuarina equisetifolia* can contribute to commercial benefits through its biomass. It is therefore argued that, because of the findings from the current study, *Casuarina equisetifolia* as a potentially beneficial plant species, merits further investigation, exploration, and research, especially in the context of individual mining companies who are willing to engage in experiments with the plant.

5.5. Perspectives on the implications of the findings of this study in a wider context

As an answer to the final research question, the wider implications of the current study must be understood in the light of the current legal status of *Casuarina equisetifolia*. Although the plant shows vast potential, its use is limited by the fact that it is still considered an invasive species. Invasive species have had serious adverse effects on the environmental well-being in South Africa. An example of this is *Eichhornia crassipes* or water hyacinth, which has affected much of South Africa's water ways for years (van Wyk and van Wilgen, 2002). As a species which has been studied as useful for rehabilitation and phytoremediation as suggested by Ebel *et al.* (2007), the plant has become a major problem in South Africa. In polluted and environmentally challenged water systems, water hyacinth has thrived and has become a serious problem for which intervention has been sought and researched without an established solution (Coetzee and Hill, 2012). This, and legislation must be considered before further research and experiments on *Casuarina equisetifolia* can be embarked on.

As per the Alien and Invasive Species Lists of the National Environmental Management: Biodiversity Act (No. 10 of 2004), *Casuarina equisetifolia* is listed as a category 2 invasive species. These species require permission from the government of South Africa to be used for any activity. Therefore, the plant is not considered as a serious threat to the environment as a category 1 invasive which must be eradicated completely. Through permission, projects such as that of Richard's Bay Minerals is thus possible. In a similar way, other mining companies could acquire permits to make use of *Casuarina equisetifolia*. However, a case must be made for the use of the plant as stipulated by legislation.

A case, therefore, must be put forward for the re-evaluation of *Casuarina equisetifolia*, its potential and categorisation as a category 2 invasive species. Considering that the plant was accepted as a species used for dune stabilisation and forestry in the past (Lubke *et al.*, 1996; van Aarde *et al.*, 1996; Lubke and Avis, 1999), more research is necessary to qualify its categorisation. Although an attempt to gather information on this topic was made, neither the academic interviewed, nor any other source was able to justify the categorisation of *Casuarina equisetifolia* as a more dangerous invasive species. Furthermore, the categorisation and listing of *Casuarina equisetifolia* was done prior to research such as the current study which highlights some of the potential for the plant, placing it into context of South Africa's most important economic activities.

It stands thus that the implications of the current study extend beyond the mining industry and *Casuarina equisetifolia*. In this regard, the implications of this study support a motion for openly considering researched plant species for rehabilitation and environmental management in different contexts where they may exhibit potential. Restrictions on invasive plant species must not be taken lightly, however, justification is necessary for their categorisation and for action taken against them. Initial research through rapid appraisals and desktop studies on different plant species may highlight their potential to address environmental issues. Further research can follow suit, to expand on past findings. In the case of *Casuarina equisetifolia*, more can be learned about the potential of the plant through future experiments and trials.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Introduction

As the final element of this dissertation, the chapter provides a conclusion to the completed study. As part of this conclusion, a summary of key findings is presented after addressing all the current study's research questions as well as achieving all objectives, ultimately accomplishing the study's aim. Recommendations and prospects for future studies follow, highlighting some of the avenues that can be addressed through further research drawing from the key findings of this study. Therefore, this chapter will be dedicated to summarising key findings, present recommendations and provide viewpoints on future research following this study.

6.2. Summary of key findings of this study

Considering the severity of the mining industry's impact on the environment and the potential of plants to address these impacts, the aim of the current study was to assess *Casuarina equisetifolia* as a potential phytoremediation or rehabilitation tool for the mining industry of South Africa. Five research questions guided the current study's research process, achieving three objectives to address the study's aim.

The first research question was an inquiry on what ways the mining industry of South Africa addresses rehabilitation. Through desktop research and engagement with the mining industry as well as different professionals, it was learned that the mining industry of South Africa addresses their impact on different environmental aspects. While the mining industry does practice biodiversity offsetting to address their impact on biodiversity, the overarching way mining companies address rehabilitation is through revegetation. In this regard, the environmental management of mining sites is focused on reclamation towards preparing degraded landscapes for their predetermined end goal. Therefore, through introducing plants to mining sites, companies seek to achieve stabilisation in the addressed area. The first objective was thus achieved through addressing the first research question.

The second research question addressed the specific methods used for rehabilitation. Through desktop research, observation, and engagement, it was determined that mining companies make use of different physical, chemical and biological methods as part of singular environmental management strategies. In this regard, different methods are used to secure the well-being of revegetation projects, which are the focus of rehabilitation or reclamation efforts. Guidelines are followed, which aid mining companies in revegetating and reclaiming degraded landscapes. Mining companies make use of indigenous and easily available plant species for revegetation projects. The choice and use of different plant species for revegetation is based on pre-mining environmental observations, observations of what plants grow in the surrounding areas of a mining site and finally, plants which have been researched in the past. However, mining companies show very little interest in making use of plants for the specific purpose of phytoremediation.

Further investigation was done to address the third research question, that is, what opportunities and challenges exist in the implementation of rehabilitation strategies using plants. In this regard, the opportunities and challenges associated with revegetation were studied. Along with addressing the previous research question, the second objective of this study was achieved. One of the noted challenges associated with mining companies' use of plants for rehabilitation was the specific end goals of mining sites as per their environmental management plans. For many companies, there is no apparent need for phytoremediation. Instead, phytoremediation is seen as a potential added benefit which follows revegetation. Reclamation through revegetation is seen as the most cost-effective strategy which has been praised for its versatility in addressing environmental concerns. However, the use of indigenous vegetation may not be the best solution when compared to exotic alternatives as many indigenous plant species would have no additional benefits other than for their ability to revegetate an area. Furthermore, some plants are not as resilient to the harsh conditions of degraded mining sites. Therefore, it was discovered that mining companies are continuously seeking new plant species for revegetation.

By addressing the above research questions and achieving the related objectives, a setting to assess *Casuarina equisetifolia*'s potential for rehabilitation and phytoremediation was therefore established. The fourth research question and final objective addressed *Casuarina equisetifolia* and its potential, drawing information from past studies through a rapid appraisal of literature. In the context of South Africa's mining industry and its approach to rehabilitation, *Casuarina equisetifolia* exhibits potential as a species worth considering for use in revegetation projects. Firstly, *Casuarina equisetifolia* is a resilient plant, able to withstand different extreme conditions, including saline, dry, waterlogged, and cold environments. Secondly, not only is *Casuarina equisetifolia* a resilient species, but it also has the potential to ameliorate soil conditions as a nitrogen fixing plant, encouraging natural revegetation. Through mycorrhiza, *Casuarina equisetifolia*'s potential to fix nitrogen can be enhanced. As a final, and most important consideration of *Casuarina equisetifolia*'s potential, it was learned that the plant is a hyperaccumulator of eight different heavy metal contaminants. These include As, Pb, Zn, Cu, Cd, Fe, Ni and Cr. Therefore, past research indicates that *Casuarina equisetifolia* exhibits potential as a phytoremediation tool. Adding to this, many of these contaminants are known to exist in the tailings of gold and platinum mines, therefore qualifying the phytoremediation potential of *Casuarina equisetifolia*.

Finally, the wider implications of the current study were considered as the point of inquiry of the final research question. This was accomplished after addressing the four other research questions and achieving all the objectives of the study. As an invasive species in South Africa, a case can be made for the potential of *Casuarina equisetifolia* with the possibility of reconsidering how the species is viewed in the country. As this study acts as a testimony for the potential of *Casuarina equisetifolia* for rehabilitation in the mining industry, the potential of the plant may extend into other areas where addressing degradation is necessary.

6.3. Key policy recommendations

Therefore, several recommendations can be made considering the above key findings of this study. Firstly, while mining companies are comfortable with revegetating degraded landscapes, in some cases, the use of phytoremediation may be more beneficial to reach the end goals of a site. This is especially true when the end goal of rehabilitation is ecological restoration or the repurposing of mining landscapes for agriculture and forestry. The use of plant species such as *Casuarina equisetifolia* may be able to initiate or kickstart revegetation projects as well as address rehabilitation more speedily. Therefore, as a recommendation, the mining industry should actively engage with similar studies which essentially aim to help them. Furthermore, by investing or showing interest in similar studies, rehabilitation strategies can be vastly improved while still considering limitations such as cost and risk.

Although this study presents important findings on the rehabilitation and phytoremediation potential of *Casuarina equisetifolia*, the plant's potential would be better understood through practical tests and experiments. These experiments will have to extend over long periods as they will be conducted to test the potential of the plant for revegetation, phytoremediation, and resilience in different mining environments. These experiments would act to expand on the current study's findings in a similar way as the Mine Woodlands Project has on the research of different indigenous plant species. In this regard, this study acts as a precursor or justification for the creation of a larger project. However, as stated above, such projects will need the support of mining companies who would be able to acquire permission to experiment with *Casuarina equisetifolia*.

Therefore, as a final recommendation, the legal status of *Casuarina equisetifolia* as a category 2 invasive must be re-evaluated to properly justify its categorisation considering the plant's potential as presented in this study. Through the various sources consulted, it was not clear why *Casuarina equisetifolia* was categorised as a category 2 invasive species, and as observed, insight on the plant's potential is not apparent in South Africa. It is suggested that the classification of *Casuarina equisetifolia* is related to the classification of *Casuarina cunninghamiana*, which has been noted as responsible for extensive water uptake. If the rehabilitation and phytoremediation potential of *Casuarina equisetifolia* outweighs its risk as an introduced plant, perhaps the plant can be re-categorised as a category 3 invasive, where less restrictions would be placed on using the plant as part of larger projects. In view of this, it is important to note that this study is yet a stepping-stone to some of these larger decisions to be made in the future.

6.4 Recommendations for Future research

Through this study, a setting for future research on similar topics has been provided. In this regard, the current study can be expanded upon through (1) further research on rehabilitation and the mining industry, (2) experimentation with *Casuarina equisetifolia* at mining sites and, (3) consideration of other plant species and their rehabilitation and phytoremediation potential.

While this study has established how the mining industry of South Africa addresses rehabilitation in general, more can be learned by visiting different mining sites. Due to limitations, this study engaged with two companies and only two mining sites were visited. Through further research, more companies can be approached, and their sites visited to better account for what can be learned through observation. Some mining companies may be facing very specific environmental issues which are not reported in ESG reports or may only be identifiable through observation. Through further research in this field, even more can be learned about environmental management and rehabilitation in the mining industry.

The research conducted in the past, being highlighted and considered through the current study has inferred that *Casuarina equisetifolia* exhibits potential to be used for rehabilitation in the mining industry of South Africa. However, to qualify these findings as recommended, experimentation is necessary. Future research could engage with *Casuarina equisetifolia*, assessing the noted areas where the plant exhibits potential. In this regard, future studies can investigate how resilient the plant is to different mining sites, quantify its potential as a hyperaccumulator of certain heavy metal contaminants, or expand over long periods to assess the plant's capability to initiate and aid revegetation. It is only through future research and long-term projects that the different areas where *Casuarina equisetifolia* exhibits potential as highlighted through this study, can be expanded on and individually assessed.

Through the current study, much has been learned about the mining industry, mine rehabilitation and more particularly, the potential of plants such as *Casuarina equisetifolia* to be used for rehabilitation. Available sources such as professionals, field visits and desktop research were adequate means through which the potential of a plant in the context of the mining industry was assessed. In a similar way, other plant species can be evaluated and studied to establish their potential as rehabilitation or phytoremediation tools. Similar studies can be conducted expanding on the current knowledge of how different plant species can be used for rehabilitation, adding to the options available to, not only the mining industry, but also other industries involved with environmental rehabilitation.

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APPENDICES

Appendix A: Ethics Clearance Certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 James

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H19/06/09**
PROJECT TITLE	Phytoremediation: An assessment of the potential of Casuarina equisetifolia in environmental rehabilitation in the mining industry of South Africa
INVESTIGATOR(S)	Mr L James
SCHOOL/DEPARTMENT	Geography, Archaeology and Environmental Studies/
DATE CONSIDERED	21 June 2019
DECISION OF THE COMMITTEE	Approved
EXPIRY DATE	20 August 2022

DATE 21 August 2019 **CHAIRPERSON** J. Knight (Professor J Knight)

cc: Supervisor : Professor M Simatele

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature

21/08/19
Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Appendix B: ESG Report Data tables

Company names censored.

Mining company	Reports	No. of reports	Type of mining	Impacts addressed				Rehabilitation methods			Description of method	View on alien invasives (1=eradication, 2=Use)	Biodiversity Offsetting?
				Soil	Water	Air	Biodiversity	Physical	Chemical	Biological			
A	1	4	Multiple	0	1	0	1	1	0	0	Backfilling	1	1
A	0	0	Copper	0	0	0	0	0	0	0	0	0	0
A	0	0	Iron	0	0	0	0	0	0	0	0	0	0
A Pl	1	7	Platinum	1	1	1	1	1	1	1	All three methods + reveg	1	1
A	1	5	Gold	0	1	1	1	1	0	1	Revegetation	0	1
A	1	1	Iron	1	1	0	0	0	0	0	0	0	0
A	1	3	Platinum	0	0	0	0	0	0	1	Revegetation	1	0
B	0	0	Platinum	0	0	0	0	0	0	0	0	0	0
Bu	0	0	Coal	0	0	0	0	0	0	0	0	0	0
C	1	1	Gold	0	1	1	0	1	0	0	Dust suppression	0	0
Cl	0	0	Chrome	0	0	0	0	0	0	0	0	0	0
D	0	0	Diamond	0	0	0	0	0	0	0	0	0	0
D	0	0	Diamond	0	0	0	0	0	0	0	0	0	0
D	1	7	Gold	1	1	1	1	0	0	1	Revegetation	0	0
E	0	0	Platinum	0	0	0	0	0	0	0	0	0	0
E	1	1	Iron	1	1	0	0	1	0	0	Surface Rehab.	0	0
F	0	0	Multiple	0	0	0	0	0	0	0	0	0	0
G	1	5	Multiple	1	1	1	1	1	0	1	Unspecified	0	1
G	1	6	Gold	1	1	1	1	0	0	1	Revegetation	0	0

Company names censored.

Gr	1	1	Gold	0	1	1	1	0	0	1	Revegetation	0	0
Ha	1	6	Gold	1	1	1	1	0	0	1	Revegetation	0	1
Hu	1	5	Aluminium	0	1	0	0	0	0	0	Unspecified	0	0
Im	1	6	Platinum	0	1	1	1	1	1	1	All three methods + reveg	1	1
Jul	0	0	Platinum	0	0	0	0	0	0	0	0	0	0
Ki	0	0	Coal	0	0	0	0	0	0	0	0	0	0
Ko	0	0	Multiple	0	0	0	0	0	0	0	0	0	0
Ku	1	7	Iron	1	1	1	1	1	0	1	Revegetation/Backfilling	1	1
Lo	1	2	Platinum	0	1	1	0	1	1	1	All three methods + reveg	0	0
Me	1	7	Coal	0	1	0	1	0	0	1	Revegetation	1	1
Me	1	5	Chrome	0	1	0	1	0	0	0	Unspecified	0	0
Mi Di	0	0	Diamond	0	0	0	0	0	0	0	0	0	0
No	1	5	Platinum	1	1	1	1	1	0	1	Revegetation + Physical	0	1
Or	1	1	Multiple	0	1	1	0	1	0	0	Dust suppression	0	0
Pa Re	1	5	Gold	1	1	1	1	0	0	1	Bioremediation (microbes)	0	0
Pe	0	0	Multiple	0	0	0	0	0	0	0	0	0	0
Ra	1	5	Gold	0	1	1	1	0	0	1	Revegetation	0	1
Ro	1	1	Diamond	1	1	0	0	0	0	0	Unspecified	0	0
Ro Pl	1	5	Platinum	0	1	0	1	0	0	1	Revegetation	1	0
Se	1	4	Coal	1	1	0	0	0	1	0	Chemical Rehabilitation	0	0

Company names censored.

	1	7	Platinum	0	1	1	1	1	1	1	All three methods + reveg	1	0
	1	5	Multiple	1	1	1	1	0	0	1	Revegetation	1	1
	0	0	Multiple	0	0	0	0	0	0	0	0	0	0
	1	6	Chrome	1	1	0	1	1	1	1	All three methods + reveg	0	0
	0	0	Coal	0	0	0	0	0	0	0	0	0	0
	1	1	Diamond	1	1	0	0	1	0	0	Backfilling	0	0
	0	0	Multiple	0	0	0	0	0	0	0	0	0	0
	1	7	Platinum	0	1	1	1	0	0	0	Unspecified	0	0
	1	1	Copper	0	0	1	0	1	0	1	Revegetation	0	0

Appendix C: Interview/Questionnaire documentation

Interview guide

Initial introductory comments (Ice-breaking comments): introducing the participant to the research and researcher (4 maximum)

1. Researcher introduces themselves *(at this point, researcher provides the participants with a participant information sheet and consent form)*:
2. Researcher thanks participant for their time.
3. Researcher explains that they wish to learn more and have a general discussion on aspects around environmental rehabilitation.
4. Researcher explains the conditions of the interview or questionnaire and that everything discussed will only be for the completion of a dissertation or only for academic purposes.

Substantial questions: getting to understand the overall information (contextualising the conversation)

1. The institute:
    a. Please provide a background to the company or institute you work for?
    b. (if required for further detail) Who is the institute? What do they do?

2. The interviewee
    a. What is your role?
    b. What do you do as a professional?
    c. Do you have a team? How large is it?
    d. How long have you been doing your current job?
    e. What type of skills are required for your particular job?
    f. What skills are you looking for here?
    g. Is your team or staff qualified?

3. Interviewees opinions (Environmental management and the mining industry)
    a. Why is your job important in the context of environmental management or in the mining industry?
    b. How is your work related to environmental rehabilitation and why is rehabilitation important?
    c. What are the most pressing matters being addressed through rehabilitation?
    d. What is the end goal of environmental management or the rehabilitation of the site you work at?

e. What are some of the rehabilitation methods and strategies you are aware of being used at your site for rehabilitation?
f. How effective are these strategies to address your site's end goal?
g. What other areas of rehabilitation and considerations are also important in the context of your work and the company or site you work at?
h. Any other options and methods you are exploring?

4. Case study of Haller Park and the current study
   a. Case study of Bamburi, Kenya and the use of *Casuarina equisetifolia (at this point, researcher provided a brief overview of the case study of Haller Park)*: what are your views?
   b. Have you heard of the case study?
   c. Ecologists have discredited the use of *Casuarina equisetifolia* in South Africa because of its legal status as an invasive species. What do you think? Could it be that a case has not been made for the potential of the plant?
   d. Could it be that we have made decisions about *Casuarina equisetifolia* under ill-informed premises? Do you think further exploration would justify its usefulness or should we exercise caution in this regard?
   e. Do you think such a study is important for the mining industry? Can such a study help the industry?

Cooling-off comments and questions

1. Researcher thanks participant
2. Based on our discussion, is there anything we've left out?
3. Who else could I speak to who might be of interest for my study?

Consent form

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Phytoremediation: An assessment of the potential of *Casuarina equisetifolia* in environmental rehabilitation in the mining industry in South Africa.

Researcher: Lucien James
Supervisor: Prof. M. Simatele

Consent Form

I, …………………………………………………………………agree to participate in this research project. I have received and read a copy of the participant information sheet. The research has been explained to me and I understand what my participation will involve.

Please circle YES or NO:

I agree that my participation will remain anonymous during the data collection process	YES NO
I understand that my anonymity cannot be guaranteed when results are communicated as the name of my corporation as well as corporate position may be disclosed	YES NO
I agree that my name shall not be used when communicating results	YES NO
I agree that the researcher may use anonymous quotes in this research report	YES NO
I agree that the information I provide may be used by other researchers through reference following this study	YES NO

……………………………………… (signature)
……………………………………… (name of participant)
……………………………………… (date)

Participant information sheet

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Good day,

My name is Lucien James and I am completing my Master of Science in Geography, Archaeology and Environmental Sciences (GAES) degree at the University of the Witwatersrand in Johannesburg. As part of my studies, I have to undertake a research project. I am studying phytoremediation in the context of the mining industry. The aim of my project is to assess the potential use of the tree *Casuarina equisetifolia*, as a phytoremediation strategy or tool for environmental rehabilitation, specifically in the mining industry.

As part of this project, I would like to invite you to take part in an interview or online questionnaire. In the interview or questionnaire, you are invited to answer a few questions and share your views. This will require no more than 45 minutes of your time for the interview, or 15 minutes for the questionnaire.

You will not receive any direct benefits from participating in this research, and there are no disadvantages or penalties for not participating. You may withdraw at any time or not answer any question if you do not want to. The information you give me will be held securely and not disclosed to anyone else during the data collection process. Because your corporation may be named, your anonymity cannot be guaranteed when results are published or compiled. The same will be the case should your corporate position or job title be described when communicating results. If you experience any distress or discomfort at any point in this process, we will stop the interview or resume another time. You may also elect not to submit your questionnaire.

If you have any questions about this research, feel free to contact me or my supervisor on the details listed below. This study will be written up as a dissertation. The final dissertation will be available on the Wits library website or if you wish, will be available in electronic format from me on request. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email Shaun.Schoeman@wits.ac.za.

Yours sincerely,
Lucien James

Contact details:
Researcher: Lucien James, email 949999@students.wits.ac.za , cellphone +27(0) 81 237 6735
Supervisor: Prof. M. Simatele, email: Mulala.Simatele@wits.ac.za , telephone +27(0) 11 717 6516

Appendix D: Online questionnaire draft

Introduction and information for participant

My name is Lucien James and I am completing my Master of Science in Geography, Archaeology and Environmental Sciences (GAES) degree at the University of the Witwatersrand in Johannesburg. As part of my studies, I have to undertake a research project. I am studying phytoremediation in the context of the mining industry. The aim of my project is to assess the potential use of the tree Casuarina equisetifolia, as a phytoremediation strategy or tool for environmental rehabilitation, specifically in the mining industry.

As part of this project, I would like to invite you to participate in this online questionnaire as a substitute to a face to-face interview or discussion given the current circumstances related to the global Covid-19 pandemic. This questionnaire will take no longer than 15 minutes to complete including three questions about yourself and 11 main questions.

You will not receive any direct benefits from participating in this research. You may withdraw at any time or not answer any question if you do not want to. The information you give me will be held securely and not disclosed to anyone else during the data collection process. Because your corporation or professional title may be used, your anonymity cannot be guaranteed when results are published or compiled.

If you have any questions about this research, feel free to contact me or my supervisor on the details listed below. This study will be written up as a dissertation. The final dissertation will be available on the Wits library website or if you wish, will be available in electronic format from me on request. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email Shaun.Schoeman@wits.ac.za.

Other contact details:

Researcher: Lucien James, email: 949999@students.wits.ac.za, cellphone no.: +27(0)81 237 6735 Supervisor: Prof. M. Simatele, email: Mulala.simatele@wits.ac.za

Request for consent

Select Yes or No for each of the following questions (All consent questions compulsory to continue with questionnaire)

1. I agree to participate in this research project. I have read through the introduction and information for participants (section 1). I understand what my participation will involve.
    - Yes
    - No
2. I agree that my participation will remain anonymous during the data collection process.
    - Yes
    - No
3. I understand that my anonymity cannot be guaranteed when results are communicated as the name of my corporation as well as my professional title may be disclosed.
    - Yes
    - No
4. I agree that my name shall not be used when communicating results.
    - Yes
    - No
5. I agree that the researcher may use anonymous quotes in this research report.
    - Yes
    - No
6. I agree that the information I provide may be used by other researchers through reference following this study.
    - Yes
    - No

More about yourself

7. What is your occupation or professional title?

8. You are involved with the:

Select only one option.

- Implementation of mine rehabilitation strategies
- Environmental management of a mining operation or operations
- Ecological restoration of degraded landscapes or mining sites
- Aspects concerning biodiversity at mining sites being rehabilitated
- Other:

9. What stage of mining are you and your work most involved with?

Select only one option.

- Active mining
- Mine closure
- Post-closure
- Other:

Environmental management in the mining industry

10. The operation(s) you work or manage are situated in (can select up to three):

Select all that apply

- The North-West Province
- Gauteng
- Limpopo
- Kwa-Zulu Natal
- The Free State

- Other:

11. The end goal of environmental management strategies implemented at sites you manage or work at is:

Select only one option.

- Yet to be determined (active mining continues on-site)
- Stabilisation and remediation of mined land
- Complete ecological restoration of degraded landscapes
- Reclamation of mined land for other purposes (e.g. creation of industrial areas)
- Remining of waste material (Tailings) or re-instating of old or abandoned mines
- Other:

12. Environmental management or rehabilitation strategies implemented at these mining operations include:

Select only one option.

- No rehabilitation is currently done as active mining continues
- Physical rehabilitation methods (covering, displacement, soil amelioration or amendment, etc.)
- Chemical rehabilitation methods (Chemical washing, thermal treatment, etc)
- Biological rehabilitation methods (Use of micro-organisms, vegetation or phytoremediation, etc)
- All of the above
- Other:

13. If phytoremediation is used at your site, can you name some of the plants used?

14. Can you name any of the plants naturally growing at your site?

15. How effective have implemented rehabilitation methods been in achieving the eventual end goal of the operation(s)?

Select only one option.

- Not applicable (active mining continues)
- Very effective (No challenges. The end goal is clearly in sight)
- Effective (A few challenges faced. Minor compromises are necessary to achieve the end goal)
- Neither effective or challenging (Challenges are face, yet the end goal is not out of reach)
- Challenging (Several challenges have been face. Major compromises are necessary to achieve the end goal)
- Very challenging (No success. The end goal is out of reach)
- Other:

16. What are the most pressing issues needed to be addressed by environmental management at your mining operation(s)? (Select the three most important)

Select all that apply.

- Continued mining
- Management of soil or water heavy metal contamination
- Revegetation of degraded land
- Soil stabilisation
- Re-establishment of ecosystems and indigenous vegetation

- Water quantity/quality management

17. If management of soil and water heavy metal contamination was an answer to the previous question, which heavy metals are most prevalent at your operation(s)?

Case Study of Haller Park: Potential of *Casuarina equisetifolia*.

The case study of Haller Park, Bamburi, Kenya was the inspiration of this study. *Casuarina equisetifolia*, the plant being assessed in this study was used to rehabilitate a degraded cement quarry. The use of the plant led to the complete ecological restoration of the site. Haller Park is now a nature reserve including indigenous plants and animals.

18. Have you heard about the case study of Haller Park before?

Select only one option.

- Yes
- No

19. Besides for its ability to stimulate ecological restoration, *Casuarina equisetifolia* may have other potential uses. In your opinion, which would be most useful to your operation(s) and/or the mining industry as a whole (can select up to three)?

Select all that apply.

- Soil stabilisation (to prevent soil erosion)
- Water quantity regulation (control of excess water or replacing plants which take up too much water)
- Phytostabilisation (plants' ability to restrict the mobility of soil pollutants)
- Phytoextraction (plants' ability to accumulate soil pollutants such as heavy metals or chemicals)
- Rhizofiltration (plants' ability to absorb pollutants from water sources)
- Other:

20. If the plant were useful in some of the ways listed in the previous question, could a case be made for the use of Casuarina equisetifolia in the mining industry?

Select only one option.

- Yes
- No
- Maybe

21. *Casuarina equisetifolia* is classified a category 2 invasive in South Africa. Could it be possible that not enough research has been done to clearly understand the plant's potential?

Select only one option.

- Yes. Classifying the plant as an invasive could have been done under ill-informed premises
- No. the plant's potential danger as an invasive must first be considered
- Maybe. More insight could be gained about the plant's potential. However, its danger as an invasive must be considered

22. As a final question, do you think such a study is important for the mining industry? Can such a study help the industry? Leave any additional comments you may have.

Appendix E: Professionals' responses to interviews and questionnaires.

Interview report 1

Assistant site manager (Site A)

Environmental management and the mining industry

1. *What is the end goal of environmental management or the rehabilitation of the site you work at?*
   Stabilisation and reclamation or eventual re-mining. Stabilisation and remediation of mined land

2. *What are some of the rehabilitation methods and strategies you are aware of and which do you consider most effective?*
   Concurrent rehabilitation using indigenous vegetation. Rehabilitation is for keeping the site stable as the operation is continuously active. Physical and biological methods are therefore used together.

3. *How effective are these strategies to address your site's end goal?*
   Rehabilitation continues without issues.

4. *What are the most pressing matters being addressed through rehabilitation?*
   Soil stabilisation and water quantity/quality management.

Case Study of Haller Park and current study

1. *Have you heard of this case study?*
   No.

2. *Ecologists have discredited the use of Casuarina equisetifolia in South Africa because of its legal status as an invasive species. What do you think? Could it be that a case has not been made for the potential of the plant?*
   Yes. If the potential of the plant can be demonstrated or shown through research, it could be worth considering.

3. *Could it be that we have made decisions about Casuarina equisetifolia under ill-informed premises? Do you think further exploration would justify its usefulness or should we exercise caution in this regard?*

Yes. As stated above, further research is necessary before making any decisions.

4. *As a final question, do you think such a study is important for the mining industry? Can such a study help the industry?*
   Yes. More could be learnt about the plant and its potential uses.

Interview report 2

Site supervisor (Site A)

Environmental management and the mining industry

1. *What is the end goal of environmental management or the rehabilitation of the site you work at?*

   Stabilization and re-mining

2. *What are some of the rehabilitation methods and strategies you are aware of and which do you consider most effective?*

   The tailings that come from the plant are mixed with chemicals. Seeds are also added before deposition. As you may observe, revegetation continues naturally. Plants on the site are no different than those growing around it.

3. *How effective are these strategies to address your site's end goal?*
   Effective while minor compromises are necessary to achieve the end goal.

4. *What are the most pressing matters being addressed through rehabilitation?*
   Wind and dust control, soil stabilisation and water regulation

Case Study of Haller Park and current study

1. *Have you heard of this case study?*

   No.

2. *Ecologists have discredited the use of Casuarina equisetifolia in South Africa because of its legal status as an invasive species. What do you think? Could it be that a case has not been made for the potential of the plant?*

Maybe. (Participant expressed scepticism regarding the use of invasive species)

3. *Could it be that we have made decisions about Casuarina equisetifolia under ill-informed premises? Do you think further exploration would justify its usefulness or should we exercise caution in this regard?*

Maybe.

4. *As a final question, do you think such a study is important for the mining industry? Can such a study help the industry?*

Studies like these are important. However, caution should be exercised before implementing any strategies.

Interview report 3

Environmentalist

Environmental management and the mining industry

1. *How is your work related to environmental rehabilitation and why is rehabilitation important?*

   I work with mining companies, ensuring sustainable environmental management continues smoothly.

   Please see Sutton and Weiersbye (2007). Rehabilitation is a necessary practice mining companies must perform in order to comply with legal requirements and make sure the area is sustainable for its future use after the closure of the mine.

2. *What are some of the rehabilitation methods and strategies you are aware of being used at mining sites for rehabilitation?*

There are many options available to mining companies. The type of rehabilitation performed is dependent on the end goal of the site. The end goal is determined very early before mining commences. Therefore, all rehabilitation efforts work towards preparing the site for its end goal use.

Please see Tanner and Möhr-Swart (2007). They have compiled a document which most mines use for rehabilitating their operations. The guidelines contain a number of approaches and steps mining companies make use of.

Most mining companies revegetate their landscapes, first preparing the ground. For example, mining companies like *censored* re-grass their land. To do this, they level the land to prepare it for grassing.

Plants have been used for rehabilitation in many cases in the past. One example is at a mining company which actively uses Tamarix plants for salt uptake. The plant is highly effective and lots of research been carried out on Tamarix. Particularly at the University of the Witwatersrand (the researcher's University). Another plant that has been considered useful is Pampas grass to address contamination and mine residue. There has even been a study on the potential of bamboo and exotic reeds. However, these studies were not very successful in practice as reeds had no effect on mine pollution.

There have been many studies done on *Searsia lancea* and this was done through a project of the University of the Witwatersrand as well. *Berkheya coddii* has also been another plant of interest as it has the ability to accumulate nickel.

I must express that uptake is very slow on the use of plants for rehabilitation.

3. *How effective are these strategies to address mining site's end goal?*

   Challenging. Many of the methods used are not effective enough to address environmental issues.

4. *What are the most pressing matters being addressed through rehabilitation?*

   Most mining companies only wish to make use of rehabilitation to stabilise environmental conditions and secure its future sustainability. Stabilisation includes addressing soil erosion, heavy metal contamination as well as for water quality and quantity control.

Case Study of Haller Park and current study

1. *Have you heard of this case study?*

   I may have heard about it a long time ago.

2. *Ecologists have discredited the use of Casuarina equisetifolia in South Africa because of its legal status as an invasive species. What do you think? Could it be that a case has not been made for the potential of the plant?*

3. *Could it be that we have made decisions about Casuarina equisetifolia under ill-informed premises? Do you think further exploration would justify its usefulness or should we exercise caution in this regard?*

   Most probably. It is important that I express how effective exotic plants are for rehabilitation compared to indigenous plants. Many experiments have been done on indigenous plants, with the plants being totally ineffective in addressing environmental issues. In fact, many species are not able to withstand mining conditions. There was a study done by international professionals a long time ago. Three specimens of Buffalo thorn trees (*Ziziphus mucronate*) were planted in tailings. The plants could not withstand conditions and therefore died very quickly.

4. *As a final question, do you think such a study is important for the mining industry? Can such a study help the industry?*

   It is worth exploring and investing in studies such as yours. Such a study is very important to establish more information on new ways to rehabilitate the impacts of mining.

Interview report 4

Academic

(Interview took on an altered format of the interview guide as the professional did not work in the mining industry and to acquire the appropriate information)

Casuarina equisetifolia and environmental management

1. *What are you currently working on or studying?*

   I am studying invasive plants in urban areas.

2. *Tell me more about what inspired or led you to study Casuarina trees?*

   I was inspired to study invasive plants as they adversely affected farming where I lived as a child. Casuarina trees (*Casuarina cumminghamiana* specifically) were known to take up a lot of water.

3. *Do you know of any ways Casuarina equisetifolia has been and can be used for rehabilitation, that is, how can Casuarina be used to improve water, soil and air quality?*

   There are projects making use of Casuarina trees all over the world. A local example is Richard's Bay Minerals, where the tree is used for dune stabilisation. A whole industry has been formed through the forestry of *Casuarina equisetifolia* including the manufacturing of wood and coal. Richard's Bay Minerals has a coal factory and a nursery where they grow Casuarinas for forestry purposes.

   I know lots of research has been done on the nodules of Casuarina and how that can contribute to better rehabilitation. Also, the trees make good windbreaks and that is one of their biggest uses.

4. *Do you think Casuarina equisetifolia could be used for more than helping the environment?*

   Yes. In fact the potential of the plant and its uses are normally overshadowed by that of indigenous trees. But not enough research is being done in South Africa in this regard.

5. *If Casuarina equisetifolia was used in a mining environment, what are some of the challenges that might develop?*

The biggest challenge I can see is maintenance. Casuarinas spread fast and require constant attention to ensure they do not grow and spread out of hand. This is true for certain Casuarina species such as *Casuarina equisetifolia* which is able to seed itself.

Remember that because there is a lot of potential maintenance, this could cost mining companies more and so, I don't think they will be too happy to explore this option.

6. *What is your opinion on the use of Casuarina equisetifolia for phytoremediation in South Africa?*

   It is assumed that Casuarina trees are good windbreaks, but as the tree might be difficult to maintain, some precautions need to be made before planting them. For example, mines can plant only male trees and not female trees as this will limit their ability to spread. But *Casuarina equisetifolia* is definitely a good plant to consider for rehabilitation.

Case study of Haller Park and current study

1. *What are your thoughts on this case study?*

   I haven't heard of the case study before, but I have heard about Casuarina. I've heard it is a good option for rehabilitation. Like previously said, more research is definitely needed to learn more from similar case studies.

2. *Do you think the same could be possible in South Africa?*

   Compared to indigenous alternatives, Casuarina outperforms all options. It grows fast and so, can spread fast to rehabilitate an area. It does have potential benefits, but the true benefit will have to be assessed through experiments.

3. *Casuarina is classified as a category 2 invasive species. Is there any evidence to support why the plant is a category 2?*

   There is a lack of evidence relating to *Casuarina equisetifolia*. But I have recently been contacted to advise on the recategorization of *Casuarina cunninghamiana* as a Category 1.

4. *Do you think it is worth further research and experiments to test how Casuarina can be used?*

I believe not enough is being done on the plant. Casuarina trees normally fly under the radar and are not studied as much as they should be. It is really an interesting plant with a lot of potential. Not enough people are engaging with it through research.

Interview report 5

Environmental manager (Site B)

Environmental management and the mining industry

1. *How is your work related to environmental rehabilitation and why is rehabilitation important?*

   Rehabilitation is important to keep the site stabilised. I contribute to support of a large rehabilitation plan for the site and includes many people as well as many different methods.

2. *What are the most pressing matters being addressed through rehabilitation?*

   Stabilisation, wind and dust control but above all else, revegetation of the dam itself.

3. *What are some of the rehabilitation methods and strategies you are aware of being used at your site for rehabilitation?*

   As observed, some of the methods used includes cladding or preparing a topsoil layer of 60% soil, and 40% dolerite. Cladding is done to prepare the ground for revegetation. All the plants used for revegetation are either grown on site at our nursery or purchased from local nurseries. Seeds of indigenous plants are used with cladding material to initiate revegetation.

   Plants are very important for rehabilitation as they eventually revegetate the tailings area. We use mostly grass species including *Eragrostis curvula*, *Eragrostis tef* and *Cynodon dactylon*. We make use of a number of tree species too. We use Acacia karoo (*Vachellia Karoo*), Karree trees (*Searsia lancea*), some Eucalyptus as well as indigenous olive trees (*Olea Africana*). Most of these trees are grown at our nursery and are found in the surrounding area so they grow well on the tailings. The main purpose of planting these trees is to revegetate the levelled slopes of the tailings facility and stabilise the area.

At the higher elevations, revegetation is not yet possible, so netting is used to prevent soil erosion and dust fallout. An entire team is dedicated to managing and placing the netting. Netting is placed according to the direction of the wind at the time. Therefore, nets need to be maintained and managed.

As you can also see, we eradicate invasives (pointing out a dry *Solanum mauritianum*)

(After being prompted about observed Chrysopogon zizanioides on site)

The remaining vetivers (*Chrysopogon* zizanioides) you see will eventually be removed. There has been a whole case of confusion related to the plant. At first, the plant was recommended for revegetation and stabilisation. Not too long after, the site was told by governing bodies to remove the plant. In any case, *Cynodon dactylon* is still a better choice having more potential than vetiver. *Cynodon dactylon* is known to have a better root system which prevents soil erosion.

(After being prompted about Casuarina cunninghamiana trees on site)

I think those trees were planted before we took over. They have been here as long as I can remember. They might have been planted as windbreaks around the nursery.

4. *How effective are these strategies to address your site's end goal?*

As for the end goal, it is one day hoped that the site can be re-integrated into the rest of the surrounding environment. The methods used are certainly effective and have been in use for years. But our company is always looking for ways to improve their approach.

Case study of Haller Park and the current study

1. *Have you heard of the case study?*

No. I haven't. But I do know about Casuarina. Another name for the tree is beefwood.

2. *Ecologists have discredited the use of Casuarina equisetifolia in South Africa because of its legal status as an invasive species. What do you think? Could it be that a case has not been made for the potential of the plant?*

I don’t know too much about Casuarina and why they consider it an invasive species. But it would be interesting to see how it could benefit the mining industry for addressing pollution.

3. *Could it be that we have made decisions about Casuarina equisetifolia under ill-informed premises? Do you think further exploration would justify its usefulness or should we exercise caution in this regard?*

   There must be a reason why the plant is considered dangerous. But like previously stated, it would be interesting to know more about the potential of the plant.

4. *Do you think such a study is important for the mining industry? Can such a study help the industry?*

   Yes. But what is learned through research has to be turned into solutions. Maybe experiments could be done in the future, provided the plant is not too dangerous or difficult to maintain.

Questionnaire report 1

Environmental manager (Site A)

Environmental management in the mining industry

1. *The end goal of environmental management strategies implemented at sites you manage or work at is:*

   Stabilisation and remediation of mined land

2. *Environmental management or rehabilitation strategies implemented at these mining operations include:*

   Physical rehabilitation methods (covering, displacement, soil amelioration or amendment, etc.)

3. *How effective have implemented rehabilitation methods been in achieving the eventual end goal of the operation(s)?*

Effective (A few challenges faced. Minor compromises are necessary to achieve the end goal)

4. *What are the most pressing issues needed to be addressed by environmental management at your mining operation(s)?*

   Revegetation of degraded land

   Soil stabilisation

   Water quantity/quality management

Case Study of Haller Park: Potential of *Casuarina equisetifolia*

1. *Have you heard about the case study of Haller Park before?*

   No

2. *Besides for its ability to stimulate ecological restoration, Casuarina equisetifolia may have other potential uses. In your opinion, which would be most useful to your operation(s) and/or the mining industry as a whole?*

   Soil stabilisation (to prevent soil erosion)

   Rhizofiltration (plants' ability to absorb pollutants from water sources)

3. *If the plant were useful in some of the ways listed in the previous question, could a case be made for the use of Casuarina equisetifolia in the mining industry?*

   Yes

4. *Casuarina equisetifolia is classified a category 2 invasive in South Africa. Could it be possible that not enough research has been done to clearly understand the plant's potential?*

   Yes. Classifying the plant as an invasive could have been done under ill-informed premises

5. *As a final question, do you think such a study is important for the mining industry? Can such a study help the industry? Leave any additional comments you may have.*

In my opinion, I think the study will help the industry and trials of more than 24 - 48 months should be done in order to see the success of restoration.

Questionnaire report 2

Soil scientist

Environmental management in the mining industry

1. *The end goal of environmental management strategies implemented at sites you manage or work at is:*

   Other:

   Proper planning to ensure that final rehabilitated mine is sustainable.

2. *Environmental management or rehabilitation strategies implemented at these mining operations include:*

   Other:

   Physical plus biological rehab: use of mine water for irrigation you may consider to be “chemical”

3. *How effective have implemented rehabilitation methods been in achieving the eventual end goal of the operation(s)?*

   Other:

   The end goal will ultimately be partially reached. The work done has ameliorated some of the negative conditions but things could be done much better!!!

4. *What are the most pressing issues needed to be addressed by environmental management at your mining operation(s)?*

   Soil stabilisation

   Re-establishment of ecosystems and indigenous vegetation

   Water quantity/quality management

Case Study of Haller Park: Potential of *Casuarina equisetifolia*

1. *Have you heard about the case study of Haller Park before?*

   No

2. *Besides for its ability to stimulate ecological restoration, Casuarina equisetifolia may have other potential uses. In your opinion, which would be most useful to your operation(s) and/or the mining industry as a whole?*

   Soil stabilisation (to prevent soil erosion)

   Phytostabilisation (plants' ability to restrict the mobility of soil pollutants)

3. *If the plant were useful in some of the ways listed in the previous question, could a case be made for the use of Casuarina equisetifolia in the mining industry?*

   Maybe

4. *Casuarina equisetifolia is classified a category 2 invasive in South Africa. Could it be possible that not enough research has been done to clearly understand the plant's potential?*

   Maybe. More insight could be gained about the plant's potential. However, its danger as an invasive must be considered.

5. *As a final question, do you think such a study is important for the mining industry? Can such a study help the industry? Leave any additional comments you may have.*

   Apart from *Casuarina equisetifolia*, the potential for use of black wattle for seriously degraded mine sites could be considered.

Questionnaire report 3

Environmental manager of Haller Park, Bamburi, Kenya

Personal information

1. *Please provide a background on the work you do and Haller Park in general?*

- I work for Lafarge Eco Systems, a subsidiary company of Bamburi Cement Company. Bamburi Cement is a member of Lafargeholcim (global producer of building materials and aggregates- also with presence in South Africa).
- Bamburi Cement mines limestone (CaCo3), pozolana and shale quarries in Kenya for Cement production. At the coast of Kenya, Bamburi produces between 0.8-1million tonnes of cement in a year, leaving behind large tracks of quarry wasteland. Bamburi has a commitment and policy to rehabilitate all the quarries and leave behind a net positive impact to the environment and society.
- This is the basis and background transforming the quarry wastelands into ecosystems for biodiversity conservation and environmental sustainability. Bamburi Haller Park is Bamburi's environmental rehabilitation showcase which was transformed to provide ecosystems services. The Cement Company started production in 1954 and rehabilitation of the quarries begun in 1971 and continues to date.

2. *What is your professional title and what does your job entail?*

- My new tittle is Restoration, Education & Ecosystems Manager.
- I develop Quarry Rehabilitation Plans; Biodiversity Management Plans and other land use plans, then lead the implementation.
- I rehabilitate the quarries, restore ecosystems, and manage the ecosystems through biodiversity conservation and sustainable land utilization of ecosystems resources – through ecotourism, conservation education and awareness, recreation, etc.

3. *How long have you been working in this field?*

- Over 23 years- in different roles within the organization under Environmental Sustainability activities.

4. *Do you work with a team?*

- Yes: As Head of Department, I work with a team of Section heads and their subordinates. 3 section Heads. Total of 15 employees in my department.

5. *What skills are required as part of your work or as a member of your team?*

- Leadership skills. And specialized skills mainly in Environmental and Conservation Sciences, as well as sustainable Development.
- Personally I have a mixed background. Am an Environmental scientist with background in Education – Geography major., Biodiversity monitoring and Assessment., Tourism Management., Environmental Science., and sustainable Development.

1. *Why is Casuarina equisetifolia so valuable in the context of Haller Park?*

- Its ability to survive in the saline waters.
- Ability to fix free nitrogen from the air in the wasteland.
- Tolerance of the harsh conditions.
- Fast growth – about 4 metres/year - here in our wastelands.
- Symbiotic relationship with *Frankia* and *Mychorrhiza* with the casuarina which help it to survive.

2. *What are some of the challenges, if any, associated with the maintenance of Casuarina equisetifolia in the context of Haller Park?*

- Leaf litter is rich in tannin and therefore takes too long to breakdown for decomposition.
- There are not many organisms that feed on it to quickly break the leaves down.
- Without thinning, they will not easily give room for other species to grow among them.

3. *Besides for Casuarina equisetifolia, which other plants and animals are important for the continued support of Haller Park's ecosystems and ecological well-being?*

- *Conocarpus lancifolia*- also tolerant of the harsh conditions at the quarry.
- Aquatic plants- *Acrosticheum aereum, Rhizophora mucronata Heritiera Xylocarpus granatum littoralis, Ceratophylum spp, Spyrogyra spp.*

4. *What are some of the opportunities related to Casuarina equisetifolia's presence at Haller Park? (for example, how does it benefit soil, water, air quality, or ecosystems in general?)*

- Useful in jump-starting soil formation due to its ability to fix nutrients in the soil.
- Attracts *Epibolus pulscripes* (red legged millipede) which feeds on the leaf litter and gives humus ready for soil formation.
- Fodders for wildlife and so contributing in nutrient cycling.
- Provides high calorific value trees for fuelwood.
- Provides good straight poles thus contributes to revenue generation for the quarry rehabilitation works.

5. *In South Africa, Casuarina equisetifolia is considered an exotic invasive. What is the legal status of Casuarina equisetifolia in Kenya?*

- It is locally acceptable to grow and utilize *casuarina equisetifolia* – with popularity in disturbed wastelands.
- It is actually easy to manage.

Potential of *Casuarina equisetifolia* in South Africa's mining industry

1. *Do you know of any examples of the use of Casuarina equisetifolia in the mining industry within or outside of Kenya?*

- In Kenya, institutions as well as individuals are beginning to borrow principles from the rehabilitation projects. This is encouraged and supported by the Government of Kenya through legislations. However most of the Cement Companies are yet to embrace this.

2. *In what ways could Casuarina equisetifolia be useful for environmental rehabilitation of degraded mining environments?*

- It can be used to jumpstart the initial rehabilitation degraded lands and utilization of unproductive / barren lands.
- It grows very fast and is quickly dispersed by wind making it easy to self-seed aiding colonization and succession.
- Used as construction poles and fuelwood thus reducing pressure on the destruction of indigenous forests and ecosystems for domestic and industrial use.
- Can be used for integration of wildlife as fodder for wildlife in ecosystems development after initial rehabilitation.

3. *What are some of the challenges and opportunities you can foresee if Casuarina equisetifolia was used in the mining industry of South Africa (Besides for legal implications)?*

- You need good plan for Land preparation, planting, gapping, weeding, thinning, pruning, and harvesting and integration plan.
- Casuarina needs steady water supply in the first 3 weeks of planting and good care after.
- **There are more benefits to casuarina than challenges.**

4. *Would it be worth performing tests and experiments to assess Casuarina equisetifolia's potential for environmental rehabilitation?*

- So much has been established here on Casuarina especially in limestone quarries at the coast of Kenya with a lot of success, and unproductive lands but so much still can be learnt about the dynamism around the plant.
- I am considering testing the Casuarina in a pozzolana quarry near Nairobi.

5. *Please provide any additional comments you may have on my study.*

- Casuarina is only used as a pioneer species for initial planting, later interplanted with other species to speed up restoration exercise.