Food diamonds? An evaluation of the impact of alluvial diamond mining activities on the agricultural potential of land

Submitted by

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February, 2018

A research report submitted to the Faculty of Science, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Environmental Science

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DECLARATION

I, Mariné Pienaar, (Student number: 542234) am a student registered for MSc. in Environmental Science at the University of the Witwatersrand, submitting my final research report in February 2018. I hereby declare the following:

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- I confirm that the work submitted for assessment for the above course is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
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ABSTRACT

South Africa depends on rainfed agriculture for a large volume of food produced and producers have to cope with erratic rainfall conditions that often result in crippling droughts. The situation is aggravated by the limited availability of soil with high crop yield potential that is further decreased by competing land uses such as urban development and mining. The study aimed to evaluate the impact that alluvial diamond mining activities have on rainfed maize production in North-West Province.

Case study methodology was used to investigate the phenomenon of alluvial diamond mining and prospecting as a temporary land use on productive farmland. Soil classification data of four crop fields were analysed to determine the key soil properties that are important for sustainable crop yield in the study area. Environmental management plans submitted to the Department of Mineral Resources (DMR) as part of the alluvial diamond mining authorisation process were evaluated to determine whether these pre-mining soil properties are reflected in the process. A comparative analysis was then conducted between the soil assessment and approaches of crop producers and alluvial diamond miners on the same land. The success or failure of current rehabilitation processes to restore the agricultural potential of the land was evaluated through comparative analysis of maize yields on undisturbed and mined land over a period of six years and under fluctuating rainfall conditions.

Results showed that the presence of slowly permeating subsurface soil horizons contribute significantly to high crop yield in the study area, especially during lower rainfall years. The depth and thickness of such horizons are crucial to the functionality of the higher yielding soils. In contrast to this, documents submitted as part of the environmental authorisation process, provide very limited information about the soil properties of the areas to be mined. Soil information was found to be replicated for applications over large areas without any specific soil management measures to address the heterogeneity. These documents also fail to communicate the crop yield potential of the pre-mined areas to the DMR.

The comparison of yields on rehabilitated mine soil with that of undisturbed land, showed that yield losses are still suffered, even in the case of best practice soil

rehabilitation. These differences are particularly evident in low rainfall years following high rainfall years, where stored soil-water in undisturbed soil profiles contribute significantly to the yield potential of soil. Comparative analysis between undisturbed and rehabilitated soil profiles showed that the organisation of soil horizons cannot be recreated with the rehabilitation process even when the topsoil is removed and stored separately from the overburden. Loss of the horizon organisation negatively affects the water-holding capacity of soil in the study area, thereby impacting negatively on the long-term sustainability of rainfed agriculture in this area.

DEDICATION

"Agriculture for an honourable and high-minded man, is the best of all occupations or arts by which men procure the means of living." - Xenophon

This research is dedicated to my beloved uncle, Daniël Pienaar. You were both farmer and artist and your maize fields all masterpieces. Even though you may no longer be able to spend your days on a John Deere under the Western Transvaal sun, you will always be a part of my best memories.

ACKNOWLEDGEMENTS

A warm thank you to my supervisor, Ingrid Watson, for her patience and encouragement during this process. Throughout my attempts towards completing this project, she remained positive and provided me with insightful comments.

Adriaan Dreyer and Cobus Burger of SGS-Nvirocrop (Pty) Ltd for allowing me to use the precision farming data generated by them and for an explanation of the more technical aspects related to this data. The following farmers have allowed me access to their land and valuable soil data and trusted me to use it objectively:

- Willie Marx
- Pieter Scholtz
- Ben Rheeder
- Jaco Beyers
- Gideon Koegelenberg

Anneliza Collett at the Department of Agriculture, Forestry and Fisheries for assisting in obtaining the newest land capability classification data from the Department as well as for guidance on the depiction of the data in ArcGIS. Thanks so much for all your friendly communication and encouragement.

Johann Friedrich and Susan Foster-Smith for the insightful discussions on the legislative aspects of the study. Besides that I had many informal discussions with diamond miners who provided invaluable insight on the practicalities around alluvial diamond mining. Thanks so much to Dr Tania Marshall for discussing her doctoral research on the diamondiferous gravels in my study area with me in person.

My GIS mentor and friend, Philip Beukes, for all your guidance in understanding the intricacies of ArcGIS and keeping a watchful eye over my interpretations of the data.

To my amazing family and friends for the constant encouragement and support that kept me going. A special thank you to my wonderful father for carrying the full weight

of our business on your shoulders to enable me to do this study and for cheering me on in this race all the way to the finish line.

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NOMENCLATURE

ARC	Agricultural Research Council
BAR	Basic Assessment Report
BFAP	The Bureau for Food and Agricultural Policy
CARA	Conservation of Agricultural Resources Act
CGS	Council of Geoscience
DAFF	Department of Agriculture, Forestry and Fisheries
DMR	Department of Mineral Resources
DRC	Democratic Republic of Congo
EAP	Environmental Assessment Practitioner
EIA	Environmental Impact Assessment
EIR	Environmental Impact Report
EMPs	Environmental Management Programmes
ENPAT	Environmental Potential Atlas of South Africa
Et al.	(Latin) And others
FAO	Food and Agricultural Organisation
FAO	Food and Agriculture Organisation of the United Nations
GDACE	Gauteng Department of Agriculture, Conservation, and Environment
GDP	Gross Domestic Product
IFAD	International Fund for Agricultural Development
MPRDA	Mineral and Petroleum Resources Development Act
NEMA	National Environmental Management Act

PGMs	platinum group metals
SA	South Africa
SDGs	Sustainable Development Goals
UN	United Nations
USA	The United States of America
WFP	World Food Programme

CHAPTER ONE: INTRODUCTION

1.1 Study context

The global community is realising the limitations of a finite planet in supporting a rising population. An important realisation is that soil management is the cornerstone of sustainable agriculture (Parr et al., 1992; Lal, 2008; Powlson et al., 2011; White et al., 2012). According to the Food and Agricultural Organisation (FAO) of the UN (FAO, 2011), 25% of global agricultural lands are already degraded. This degradation is caused by soil erosion through water or wind, nutrient depletion and loss of biological soil functions (Bindraban et al., 2012; Scholes & Scholes, 2013; Lal, 2015), soil compaction (Bindraban et al., 2012), pollution and conversion of productive land to other land uses (Bindraban et al., 2012; De Long, Cruse & Wiener, 2015). These include using land for human settlements (urban or peri-urban tenure) and extracting raw materials and energy resources such as fossil fuels.

Soil is a complex medium consisting of a mixture of abiotic and biotic components and the important interphase between the geological base and the living environment it sustains. It is not just a storage facility of plant nutrients and water but harbours a living environment with greater genetic variety than any living organism on earth (Lal, 2015; Scholes & Scholes, 2013). Besides its importance for sustainable food production, it is also a key component of other existential environmental challenges such as water and energy security, and is a critical tool in the fight against climate change (McBratney, Field & Koch, 2014). The United Nations (UN) declared 2015 as the international year of soils to create global awareness about the soil (DeLong, Cruse & Wiener, 2015).

South Africa is not exempt from soil degradation issues and provides a striking example of the impacts of land use changes on agriculturally productive land. According to the report of the UN special rapporteur on the right to food in 2011 (UN General Assembly, 2012) and the South African national policy on food and nutrition security (Department of Agriculture, Forestry and Fisheries [DAFF], 2013:12), mining and urbanisation deleteriously influenced agricultural land, reducing the area under production by 30% between 1994 and 2009. This poses a significant threat to the food basket of the country since it has limited production resources. The FAO (2005) reports that only 14 million hectares receive enough rainfall for rain-fed agriculture, while still susceptible to production risks because of drought. Only 12% of South Africa's land surface is considered arable (GCIS, 2012), while Collett (2008) states only 4% has high production potential.

In contrast to the country's limited productive soil, South Africa is extremely rich in mineral resources and has a well-organised mining industry. The mining sector contributed 7.1% to the country's total Gross Domestic Product (GDP) in 2015, while directly employing 457,698 people (Chamber of Mines, 2016).

The development of this industry caused significant environmental degradation such as acid mine drainage in coal and gold mining (McCarthy, 2011), not only polluting ground- and surface water, but also contaminating soil (Naicker, Cukrowska & McCarthy, 2003; Eijsackers et al., 2014). While underground mining has significant impacts on groundwater, surface mining is especially destructive to soil. The mining action necessarily depends on the removal of the surface layer to access the ore body (Bradshaw, 1997).

South African mining legislation followed suit with the global trend to enforce land rehabilitation through financial means to minimise and manage these impacts, and improve the sustainability of mining as a land use. The Minerals Act of 1991 was the first legislation that held mining right holders responsible for the rehabilitation of mined surfaces until the final closure of the mine (Carrick & Krüger, 2007). However, the rehabilitation of collieries back to agriculturally productive land proved to be more of a theoretic possibility than a reality in South Africa.

Even though the Chamber of Mines developed rehabilitation guidelines for collieries (Chamber of Mines, 1981), post-rehabilitation soil properties were altered drastically causing maize production trials on rehabilitated soils financially non-viable (Prinsloo & Erasmus, 2000). The high bulk densities measured (Nell & Steenekamp, 1998) and the altered water-holding capacity of these soils, restricted the root development of both crops (Prinsloo and Erasmus, 2000; Schoeman, Matlawa & Booyens, 2000) and pastures (Tanner, Roper & De Villiers, 1986).

In 2002, the Mineral and Petroleum Resources Development Act No. 28 of 2002 (MPRDA) succeeded the Minerals Act of 1991 with more rigorous stipulations on the rehabilitation of mined land. The MPRDA explicitly states that any mined area or area affected by prospecting have to be rehabilitated to “its natural or predetermined state”. While the MPRDA made mine rehabilitation a legal obligation for the holder of the mining right, it does not provide practical guidelines to the mining industry on rehabilitation practices. The mining industry’s response was the development of a set of guidelines for mine rehabilitation not only for coal mining but “all forms of mining, both surface and underground, and all mineral extraction industries” (Chamber of Mines, 2007).

The Guidelines for the Rehabilitation of Mined Land rightly understood the destructive nature of mining on soil properties and that rehabilitation should aim to return as large a volume of the topsoil as possible to the areas from where it was initially removed (Chamber of Mines, 2007). It also realised that the in situ soil properties are directly linked to the pre-mining productivity of the land through the concept of land capability and that extreme variation can occur in land capabilities over short distances as a result of the variety in the land capability parameters (Chamber of Mines, 2007). In order to address this variety and meet the rehabilitation objectives stated in the MPRDA, the guidelines stated that the only objective land capability rehabilitation targets can be determined by a “detailed evaluation of agricultural capability” before any mining or prospecting commences (Chamber of Mines, 2007).

Even with all the current environmental legislation, regulations and guidelines in place to promote and regulate mining as a short-term but sustainable land use through mine rehabilitation practices, it has not been proven yet that the rain-fed crop production potential of surface mined land can be restored successfully in South Africa (Bureau for Food and Agricultural Policy [BFAP], 2015). Still, surface mining and prospecting rights have been, and are still, authorised on productive land to the extent that approximately 12 million hectares of agricultural land is now registered by the Department of Mineral Resources (DMR) as mining land (BFAP, 2015).

1.2 Motivation for the study

In 2015, the Council of Geoscience (CGS) commissioned an investigation into the alluvial diamond resources of the North-West province as part of a national campaign by the DMR for the proliferation of mining in the country (CGS, 2016). The CGS team identified three main areas bearing subsurface diamondiferous gravels. One of these areas stretches between the towns of Lichtenburg, Delareyville, Bloemhof and Klerksdorp (CGS, 2016), overlapping an area previously identified by Marshall (1990) as the southern diamondiferous gravel fields.

Grain and cattle farmers in this area have been objecting strongly to mining and prospecting for alluvial diamonds on their land in the past years. An article on their concerns and the reason for their objections was published on 17 March 2017 in the Landbouweekblad (Smith, 2017). The main objection offered was the deleterious effects of these activities on the productivity of their land. It was claimed damages would be significant enough to result in financial losses, thereby making future production activities unsustainable.

The objections of several farmers took the form of legal objections lodged with the DMR, especially where mining and prospecting permits were granted with no prior consultation with the landowner. In cases of strong legal objection involving groups of farmers represented by a team of lawyers, DMR arranged arbitration meetings that included a representative from the DAFF. As a participant observer to these meetings, the researcher witnessed that the farmers' claims and objections were mainly dismissed by DMR on two grounds:

- The agricultural potential of soil in the areas applied for are considered of marginal land capability, as described in the documentation submitted to DMR as part of the environmental authorisation process.
- DMR claims alluvial diamond mining is only disruptive to the existing land user for a short period and the negative impacts of the soil disturbance activities are counteracted by the land rehabilitation procedures. Since alluvial diamond mining do not involve complex processing such as gold or platinum extraction, resulting in

large waste dumps, its impact is considered almost negligible as long as the land surface has been levelled and revegetated.

While the land capability classification system by Schoeman et al. (2002) grouped large areas of land in the province as marginal for crop production, Mbatani (2000) found that soil in many areas in North-West Province has water retention properties that make it suitable for crop production, even under drought conditions. Even though soil in this area may not have been classified as having high land capability (Schoeman et al., 2002), it can be considered unique agricultural land. Unique agricultural land has a “special combination of location, terrain features, climate and soil properties” that makes sustainable agriculture and financially viable crop yields possible even in areas traditionally considered marginal (Schoeman, 2004).

As a participant observer to the area and a consulting soil scientist, the researcher is familiar with the extensive dryland crop production activities, even under limiting climatic conditions and the soil management measures implemented by farmers in this area to maximise the plant available water capacity of their crop fields. The researcher is also familiar with the extensive scars in the landscape as a result of alluvial diamond mining and the extent to which it still continues in both crop and grazing fields.

The main problem identified was that current administrative processes followed to authorise alluvial diamond mining and prospecting permits and rights fail to recognise and protect the inherent agricultural potential of soil, even though it is already a scarce resource and crucial for sustainable food production. Since no evidence currently exists that the rain-fed yield potential of soil can successfully be restored once the alluvial diamond operations have ceased, renewed interest in the study area’s diamond deposits may cause significant cumulative loss of agricultural capability. This will not only affect the sustainability of agriculture of the North-West province, but the entire country since the province is a main maize production region together with Mpumalanga and the Free State provinces (BFAP, 2015).

1.3 Aims and scope of the study

The aim of the study is to assess the impact of alluvial diamond prospecting and mining on the agricultural potential of soil, particularly physical soil properties and their relation to soil capabilities, and whether these are adequately considered in the mining authorisation process. While soil in its entirety is a complex system, the agricultural potential of soil in South Africa is largely determined by the capability of soil to store plant available water with soil fertility only accounting for 3% of total soil capability (DAFF, 2017).

The scope of the study was focused on the alluvial diamond mining and prospecting activities in the diamond fields of North-West province. While both surface and underground mining for a variety of minerals have impacts on the soil properties to a more or lesser extent, the impacts caused by alluvial diamond mining largely affects the physical soil properties. Alluvial diamond mining is a mechanical process, which involves excavation of soil and overburden to access the diamond-bearing gravel. The diamonds are recovered by subjecting the gravel to a separation process that include mechanised washing plants. The tailings generated is chemically inert as it consists of a mixture of the original soil particles and the water used for the washing process.

The study focussed on the prospecting and mining authorisation process, the evaluation of the pre-mining administrative processes and the documents submitted for environmental authorisation. While mine closure plans usually form part of these documents for mining rights of larger mines, the alluvial diamond mining permit and/or prospecting right closure planning is limited to what the templates provided by DMR requires. However, it was not possible to obtain examples of such closure certificate applications or the risk assessments that are submitted as part of the closure applications from DMR. Post-closure land use in the study area will however be discussed in Chapter 5.

1.4 Research questions

In order to achieve the aim of the study within the scope delimited for it, the following research questions were developed:

- How are the pre-mining land capabilities and associated soil properties reflected in the legislation and application of the required administrative process for alluvial diamond mining permits and prospecting rights?
- What are the soil capabilities and agricultural potential of soil in the study area?
- What is the post-mining land capability of rehabilitated land once alluvial diamond mining and prospecting operations have been decommissioned?

1.5 Approach and outcomes

The impact that alluvial diamond mining activities have on the agricultural potential of soil in North-West province was investigated as a case study of a contentious national phenomenon where mining irreversibly affects productive land. The methodology was designed within the scope limitation to illustrate that although several soil properties contribute to soil quality, it is a few physical soil properties that affect the plant water holding capacity of a soil profile and thereby it's potential for rain-fed crop production in an important maize production region susceptible to cyclical droughts.

The documents submitted for the environmental authorisation of the mining and prospecting permits were qualitatively analysed to determine whether it follows the pre-mining assessment requirements outlined in the Guidelines for the Rehabilitation of Mined Land (Chamber of Mines, 2007) and adequately considers soil capability. The quantitative results of soil classification surveys of three crop fields were analysed and interpreted to determine the critical physical soil properties that qualifies a specific soil form as having high water holding capacity and thereby good arable land capability. A sub-case was used to illustrate what the current land capabilities of both rehabilitated crop and grazing fields are after mining and prospecting operations have been decommissioned.

1.6 Overview

Chapter 2 explains the importance of certain soil properties for rain-fed agriculture as well as the importance of soil classification in the identification of these properties. It evaluates the legislative requirements for alluvial diamond mining authorisation and discusses previous research on the success of reclamation efforts where surface mining influenced croplands. Chapter 3 describes the methodology adopted. Chapter 4 presents the results. Chapter 5 puts the results into perspective, including its implications for current policy processes. Chapter 6 summarises the key points of the study and makes recommendations for future studies.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The literature introduces the importance of rain-fed agriculture as the main production system of staple food in South Africa and the risks it faces as a result of natural resource limitations. It elaborates on the physical soil properties that contributes to soil capability under water-restrained dryland production systems in the country and how these properties are identified through soil classification. The impacts of mining on agriculture is evaluated through interrogation of existing studies to evaluate the impacts that mining as a temporary land use has on soil properties and the production potential of land. It then touches on the administrative processes required for the authorisation of mining and prospecting activities on land as an instrument to manage the anticipated impacts of mining. This section closes with a discussion on existing soil policies and legislation that aims to protect this natural resource against degradation and unsustainable use.

2.2 Soil physical properties important for rain-fed agriculture

Globally the demand for food increase while society faces numerous environmental challenges such as water scarcity and land degradation (FAO, 2011). This demand necessitates a shift in focus towards sustainable agriculture on the remaining productive land with limited water resources (Singh, Pandey & Singh; 2011; White et al., 2012). Rain-fed agriculture is the main global food production system with disproportionate future production risks associated with climate change between the northern and southern hemispheres (FAO, 2011). Climate change impacts predict continuous grain supply and expanded production areas for the northern hemisphere while southern hemisphere countries will have to cope with more intensive floods and droughts.

Such changes in rainfall patterns are particularly concerning since currently only five per cent of rainfall is captured and used efficiently by crops with rain-fed agriculture (Wallace, 2000; Röckstrom et al., 2010). While inherent low soil fertility and poor soil structure are also pointed out as potential risks to sustainable rain-fed agriculture, soil fertility can be corrected through soil amendments and management practices (FAO, 2011). However, improved yields may still be hindered by the inconsistent availability of soil moisture (FAO, 2011).

The ability of soil to store water and provide soil moisture to both natural vegetation and crops was captured in the concept of ecosystem services. The capacity of soil to perform these functions is determined by the different soil properties and the impact of land uses (Schulte et al., 2014). Hallett and Bengough (2013) explain that physical soil properties impact significantly on soil quality and defined soil of high quality as having "a porous structure that drains well but stores water to support plants", allowing root penetration into the profile for soil and water uptake. These essential functions are possible because of soil structure, soil strength and the water held in the soil pores as affected by soil texture (Hallett & Bengough, 2013).

Following Brady and Weill, soil structure is descriptive of how primary soil particles are arranged into secondary soil units. Soil structure can be classified as prismatic, columnar, and blocky. The absence of structure is referred to as apedal (MacVicar, 1991; Brady & Weil, 2008). This soil property describes how soil pores and channels are distributed in the soil profile (Brady & Weil, 2008).

Soil structure also affects the soil-water movement in a profile. When soil is compacted, the soil pores change to a higher proportion of small- and medium-sized pores holding on to water with greater tenacity rather than larger soil pores. Texture refers to the relative fractions of sand, silt and clay particles in soil. The combination of these fractions is used to divide soils into texture classes (MacVicar, 1991).

2.3 Rain-fed agriculture in South Africa

The consistent availability of water to crop roots during the growth cycle was found to be the main constraint to crop production in South Africa (Prinsloo & Erasmus, 2000; Bennie & Hensley, 2004). In addition to the volume of plant-available water, the seasonal distribution of water availability should coincide with water requirements of the crop growth stages that peak during the flowering phase (Prinsloo & Erasmus, 2000).

The correlation between soil properties affecting soil-water content and crop yield was found highly beneficial for use in precision farming applications (Zhu, 2009) and in climate-impaired dryland production areas of North-West province, South Africa (Mbatani, 2000). Using soil conservation practices reducing water losses have the potential to increase crop yields in these dried production areas (Van Rensburg, 2010).

According to Brady and Weil (2008), “impervious layers drastically slow down the rate of water movement” and correct management of such properties can improve crop yields. This is especially relevant for rain-fed production in the drier production areas of South Africa such as North-West province and the Free State. Henning (1991) states the yield potential of soils in the north-eastern parts of the Free State is significantly higher when underlain by a subsurface perched water table.

Soil forms such as Hutton and Clovelly lacking these water-impeding subsurface horizons have a higher risk for crop failure during low rainfall years (Henning, 1991). This was confirmed by Van Rensburg (2010) indicating statistically the rainfall storage efficiency translating into crop yield is 30% higher for soils with slowly permeable subsoil layers compared to soils without these layers.

Mbatani (2000) also points out that soil forms consisting of soft carbonate or soft plinthic sub-surface horizons, have higher dryland production potential because of impeding water infiltration to depths where it is unavailable for uptake by crop roots. She recommends that the phenomenon be quantified.

While the study by Henning (1991) was not aimed at the quantification of the water held in such soil profiles, it contributes understanding of the mechanisms and significance of the presence of certain soil forms for rain-fed maize production. The study explains that a perched water table accumulates between sandy soil horizons and clayey weathering products such as soft plinthite and calcrete, contributing to the volume of plant available water (Figure 1).

Perched water tables between hard plinthite and sandy topsoil horizons were also found (Henning, 1991). Identification of soil forms with slowly permeable subsoil layers are indicators of water tables in close proximity to the crop root zone (Van Rensburg, 2010).

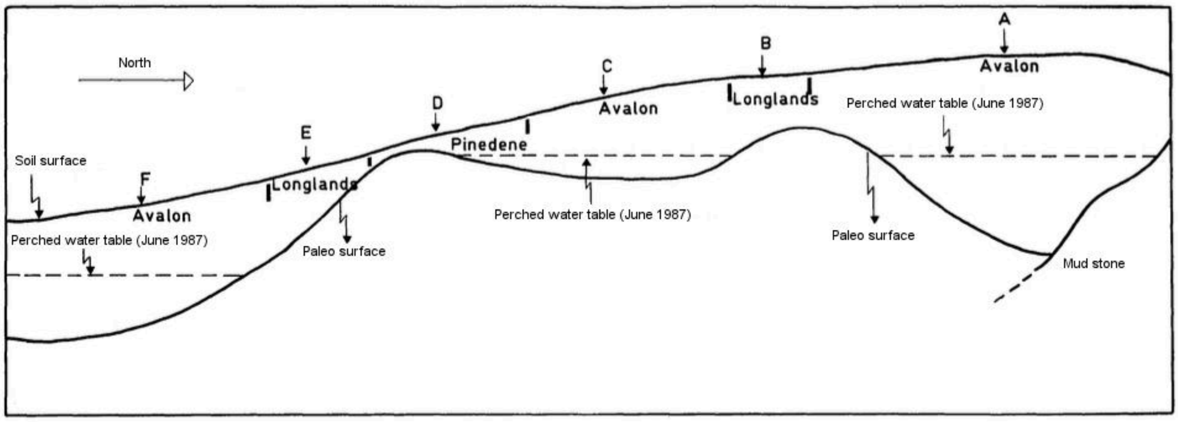

Figure 1: Diagrammatic representation of the perched water table accumulating in a landscape (adapted from Henning, 1991)

The position of these horizons in the profile is important since crops can only benefit from the perched water table if it can move into the root zone with capillary forces (Henning, 1991). It will result in water-saturated conditions inhibiting germination and strain root development, should it be located too close to the soil surface (Henning, 1991; Le Roux et al., 1999; Fey 2010). The depth and thickness of the soft plinthite and calcrete horizons also determine agricultural management practices such as nitrogen fertilisation and tillage depth, ensuring maximum yield (Henning, 1991).

2.4 Soil capability

The position and properties of soil horizons influence the plant available water and water movement in the soil profile significantly (Brady & Weil, 2008). Francis et al. (2007) show that abrupt textural differentiation is not a requirement. Increases in the clay content of subsoil as low as 0.1 to 0.4 per cent, result in increased soil-water storage of soil in Namaqualand.

In contrast with the World Reference Base for Soil Resources, the South African Soil Classification System follows a morphogenetic approach with few physical and chemical analyses requirements (Van Huyssteen et al., 2014). The South African Taxonomy is a binomial system (MacVicar, 1991) distinguishing between five topsoil and 25 subsoil diagnostic horizons, which in combination, allow for 73 different soil forms (Van Huyssteen et al., 2014). This is considered a suitable system for use in Africa where access to complicated field measuring equipment and detailed laboratory analyses are costly and limited. This system recognises a soil horizon as an entity with specific characteristics such as texture and structure but emphasises the importance of the combinations of horizons of a soil profile to understand its pedogenesis and usability (MacVicar, 1991).

Soft plinthite refers to the soft plinthic B horizon as defined by the South African Soil Classification System. Van Huyssteen et al. (2014) explain the soft plinthic horizon as defined for South African soils does not harden irreversibly. It differs in this regard from the international concept of plinthic soils. The main characteristic of this horizon is the presence of iron and/or manganese oxides and hydroxides developing because of the intermittent water movement horizon (MacVicar, 1991). This water originates from water impediments lower down the profile rather than being stored in the horizon itself (Le Roux et al., 1991, quoting Washer & Collins, 1984).

Van Huyssteen, le Roux and Hensley (2004) correlated the duration and intensity of the water movement in the soft plinthic horizon with the colour intensity of the overlying horizons and the iron and manganese mottles. The calcrete horizon mentioned by Henning (1991) refers to the hardpan carbonate horizon as per the South African Soil Classification System (MacVicar, 1991).

2.5 Soil and legislation

Globally, soil as a natural resource worthy of protection remained in the shadows while environmental legislative tools were developed for the protection of other natural resources such as water and unpolluted air (Boer and Hannam, 2015). Growing international awareness of land degradation led to the revision of the World Soil Charter in 2015 and the endorsement of the Voluntary Guidelines for Sustainable Soil Management in 2016 (FAO, 2017). These voluntary guidelines outline principles for the incorporation of soil management into national legislation and policies of countries (Boer, Ginzky and Heuer, 2017).

In South Africa, the Conservation of Agricultural Resources Act No. 43 of 1983 (CARA) for “the conservation of the natural agricultural resources of the Republic”. The conservation objectives of CARA were centered around prevention and rectification of erosion, plant protection through control of weeds and other invasive species and maintaining the productivity of the land (CARA, 1983). Section 14 of this Act makes provision for the expropriation of degraded agricultural land by the Minister of DAFF for the purpose of the reclamation or restoration (CARA, 1983).

The Preservation and Development of Agricultural Land Bill was drafted and made available for public comment in 2016 by DAFF as an improved legislative tool to combat the rapid conversion of agricultural land to other uses in South Africa through a number of requirements (DAFF, 2016). The general objectives of this Bill are the protection of agricultural land and productivity and states that an application must be lodged to DAFF for any planned non-agricultural land use on agricultural land (DAFF, 2016). It does however not address any specific soil properties or its relation to the productivity of the land.

2.6 Impact of mining on agriculture

An example of the complex interactions between mining and agriculture is found around the gold mining areas of the Geita District in Tanzania and the Wassa West District of Ghana. While it was found that mining communities benefited from the provision of services by the mine and created markets for the produce of local farmers (Kitula, 2006), the financial benefits of mining did not filter through to the regional level in Ghana (Schueler, Kuemmerle & Schröder, 2011). In the Wassa West district, 4935.3 ha of farmland was converted to open pits, forcing displaced farmers to clear forests in search of new farmland (Schueler, Kuemmerle & Schröder, 2011).

Land degradation caused by the excavations in the Geita district is so severe that society abandoned their traditional agro-pastoral systems and land reclamation is considered non-feasible (Kitula, 2006). Aragón and Rud (2015) calculate that the pollution caused by gold mines in Ghana reduced the agricultural productivity of maize and cocoa by 40 per cent between 1998 and 2005.

Bangladeshi have similarly been protesting against open pit coal mining on productive land since 2006 and protests became violent through police intervention (Bedi, 2015). Following Bedi (2015), the government of Bangladesh was warned by a group of UN Special Rapporteurs in 2012 that the destruction of fertile agricultural land and resulting displacement of people, is a violation of human rights.

South Africa is not exempt from these impacts. The Bureau for Food and Agricultural Policy [BFAP], (2015) found a void in the public awareness on the long-term negative consequences of productive agricultural land to mining. Accordingly, this results in a lack of policies or planning initiatives to address potential future food insecurity. The situation resulted in large areas of crop fields being intersected by mines, especially in Mpumalanga and North-West province (BFAP, 2015).

2.7 Mining and productive land

South Africa is rich in a variety of mineral resources ranging from gold, coal and iron ore to the largest deposits of high-grade vermiculite (Gauteng Department of Agriculture, Conservation, and Environment [GDACE], 2008). This wealth resulted in an economic shift from agriculture to mining and industrial developments.

Coal, gold, platinum group metals (PGMs) and iron ore are the four main contributors to mineral sales and diamonds, manganese and copper also contribute to export sales (Chamber of Mines, 2016). Following GDACE (2008), South Africa has the widest range of diamond deposits and ranks fifth in total global production, contributing nine per cent to the international market (Read & Jansen, 2009). These deposits include underground and open pit kimberlite and alluvial and offshore marine mining (GDACE, 2008).

2.7.1 Alluvial diamond mining

The World Diamond Council differentiates between formal or industrial alluvial diamond mining and small-scale informal digging (Diamondfacts.org, n.d.). Large companies such as De Beers and Rio Tinto (Read & Janse, 2009) dominate the formal alluvial diamond industry. Small-scale mining is practiced by individuals or groups and provide jobs to approximately 1.3 million people in African countries such as Angola and the Democratic Republic of Congo (DRC) (Diamondfacts.org, n.d.).

Historically, mining of alluvial diamonds was executed with manual methods but have since progressed to a mechanised process. Manual methods are still used in South Africa and elsewhere since it requires minimal capital investment (Priester et al., 2010). The trenches and pits are dug with picks and spades and the gravel separated with sieves.

Mining for alluvial diamonds is mainly a three-phased process. The overburden is first removed, the gravel is then extracted and transported and the diamonds then concentrated. Even though the operations can be highly productive, there are safety risks (Priester et al., 2010) and rehabilitation is haphazard. The higher capital investment associated with mechanised operations enables better recovery of diamond deposits and enabling systematic mining and rehabilitation (Priester et al., 2010). It requires larger mining areas to be financially viable.

The first diamond in South Africa was found in the Northern Cape (formerly known as Griqualand West). Alluvial diamond diggings progressed in a north-eastern direction along the Vaal river to Klerksdorp in 1917, including areas where the towns of Christiana and Bloemhof are now situated (Marshall, 1990). Another diamond rush followed in 1920 when diamonds were found the northern part of the Mooi River Valley near Potchefstroom (Marshall, 1990).

The most significant development was the rich Lichtenburg alluvial diamond field discovered in 1926 that catapulted the world's diamond production to previously unknown volumes (De Wit, 1996). The Great Depression of the early 1930s, resulted in the closure of many alluvial diamond diggings because of the decline in global demand for diamonds (Wilson, Henry & Marshall, 2006). Since 2008, South Africa reclaimed its position as one of the five biggest producers of quality diamonds globally (Read & Janse, 2009).

Even though some of these operations commenced with mining activities again, it was ended when the underlying water table was reached. This, together with the difficulty of accessing deeper-lying deposits, resulted in these resources being under-explored (Wilson, Henry & Marshall, 2006). Exploring diamonds includes remote sensing, geophysical methods, reverse circulation drilling and pitting and bulk sampling. To achieve statistically significant results from bulk sampling, large volumes of ore have to be processed. This is because of the uneven distribution of diamonds in the gravel and entrapment of these deposits in gullies and potholes (Wilson, Henry & Marshall, 2006).

2.7.2 Legislative framework for mining

The first commercial mining operations started in the 1850s and were followed by almost 150 years of large-scale mining developments without strict regulation on the environmental impacts caused by the mining activities (Davenport, 2010). According to Carrick and Kruger (2007), the Minerals Act of 1991 was the first holding mining right holders responsible for rehabilitation of mined surfaces until the final closure of the mine. The MPRDA that succeeded the Minerals Act of 1991, explicitly states that any mined area or area affected by prospecting has to be rehabilitated to "its natural or predetermined state". Section 38 (1) (d) further states that the post-mining land use may alter from the pre-mining use, permitted it follows sustainable development principles (MPRDA, 2002).

Although the South African mining industry is dominated by medium-sized to large mines, there has been an increase in the small-scale alluvial diamond mining industry since 1991 (Dreschler, 2001). According to Mutemeri and Petersen (2002), small-scale mining in South Africa can be defined as a mining operation employing "less than 50 people and with an annual turnover of less than R7.5 million". This definition also includes artisanal mining usually considered to be non-mechanised mining techniques used by poor people for subsistence livelihoods (Hoadley & Limpitlaw, 2004).

2.7.3 Properties of mine soils

Both mining and mine rehabilitation influenced the physical and chemical properties of soil significantly (Shrestha & Lal, 2011). Bradshaw (1997) argues against using topsoil as the only option for restoration and states that soil-related issues are rather few and treatment options are developed and widely published. Post-rehabilitation research indicated otherwise. Even though rehabilitation techniques may be uniform in an area, it results in high heterogeneity of the chemical properties (Prinsloo & Erasmus, 2000) and physical properties of mine soils (Krümmelbein et al., 2010).

The chemical characteristics of rehabilitated coalmine soil have high variability over short distances and between the topsoil and subsoil. Prinsloo and Erasmus (2000) report that the uneven soil conditions on rehabilitated sites lead to over-fertilisation that result in high expenditure on fertilizer. They suggest precision farming style sampling densities.

The carbon content between topsoil and subsoil also differs significantly with subsoil having high carbon content because of the large quantities of carbonates and not because of high organic matter content (Nell & Steenekamp, 1998). A study of 54 sites in Ohio in the USA has shown that mine soil profiles reduced nitrogen and organic carbon concentrations and increased soil pH, bulk density and electrical conductivity, compared with undisturbed soil profiles (Shrestha & Lal, 2011). Besides the absence of horizon differentiation, similar low organic carbon and nitrogen levels were measured at a rehabilitated lignite mine in Lusatia, Germany (Rodionov et al., 2012).

Nell and Steenekamp (1998) report high bulk densities were measured in most of the rehabilitated soils of the coal mines part of their study. They conclude that this was because of soil compaction and has a negative effect on plant growth and root development. Although cover-soil was as deep as 1500mm in areas, the average root depth of vegetation that established was never deeper than 300mm (Nell and Steenekamp, 1998).

2.7.4 Rehabilitation of productive potential of soil

The MPRDA gives outlines for rehabilitation objectives, stating mined land must be "rehabilitated, as far as is practicable, to its natural state, or to a predetermined and agreed standard or land use which conforms to the principles of sustainable development" (MPRDA, 2002).

Monitoring rehabilitation success is important. One way of measuring rehabilitation success is with landscape function analysis (Tongway & Hindley, 2004). This system recognises the importance of soil in the reclaimed landscape and makes use of a soil surface assessment simple field indicators of soil stability, nutrient cycling and water infiltration may assess restored ecosystem functions of rangelands and mine sites but fail to measure the yield potential for dryland agriculture (Pauw, 2011).

In the USA, the success of reclamation projects on cropland is determined by post-reclamation production levels. Crop yields on the reclaimed land area are either compared to reference areas or approved statistical procedures. The productivity standards set must be met for at least three production years in the allocated research period.

This approach was opposed by research and regulating authorities. They felt that the development of measurable soil physical and chemical indices can be measured directly after reclamation, opposed to actual measured crop yields (Nieman & Merkin, 2000).

Dunker and Barnhisel (2000) quote Hammer (1992), suggesting a soil productivity index where aeration, pH, bulk density, potentially available water-holding capacity, and salinity are determined. These five parameters were chosen on the view that the soil environment affects root growth and that root growth equals crop yield. A four-year study by Barnhisel and Hower (1994) indicates that such an evaluation system is flawed and that correlation with yields is weak.

A few significant studies were conducted on crop production on rehabilitated mine soils in Mpumalanga. Prinsloo and Erasmus (2000) conducted trials on rain-fed maize and sunflower production for a period of six years at three different collieries in Mpumalanga, using a variety of tillage practices to alleviate the soil compaction.

Even though rainfall was sufficient for rain-fed production, yields obtained were so low that the practice of crop farming on rehabilitated collieries was discouraged because of the high economic risk (Prinsloo & Erasmus, 2000). Even though the chemical soil properties of these mine soils were heterogeneous, crop failures were attributed to poor water holding capacity, high bulk density because of compaction and limited soil depth.

It was proposed that unless new rehabilitation techniques be developed that will aim at improving all the properties influencing the soil water holding capacity while reducing bulk density, rehabilitated collieries are only suitable for the establishment of pastures and lucerne (Prinsloo & Erasmus, 2000).

Annandale et al. (2001) focused on the potential of irrigated production of sugar beans (*Phaseolus vulgaris*) and wheat (*Triticum aestivum*) with gypsiferous mine water on both undisturbed and mined soils. While sugar beans on rehabilitated soil delivered low yields compared to that on undisturbed soil, wheat performed well on both soils.

It was suggested that agricultural management issues, soil compaction, and chemical imbalances might have caused the low yield of sugar beans on the mine soils (Annandale et al., 2001). Even though the yields of the irrigated crops were reported to be considerably higher than that of rain-fed production (Annandale et al., 2001), the economic viability of this practice and long-term sustainability, was not determined by this trial.

Similarly, the establishment of pastures had management issues. While it was possible for grass species such as *Eragrostis curvula, Eragrostis plana, Cynodon dactylon, Pennisetum clandestinum* and *Panicum coloratum* to establish itself again, the practice of continued fertilisation, suppressed the establishment of *Themeda trianda*, an important highveld grass species (Schoeman, 2001).

This literature review focused on illuminating the importance of rain-fed crop production to the food basket of South Africa and the important role that soil plays in the sustainability of this system. It provided detail on the specific physical properties that determine the capability of soil to be a suitable crop growth medium in under erratic rainfall conditions. The various key physical soil properties determined included the presence, depth and thickness of a slowly-permeating subsurface horizon together with textural gradients between the different soil horizons. The literature then shows that although mining is a temporary land use, it may impact irreversibly on the production potential of land and therefore the sustainability of agriculture. While the impacts of mining is currently considered and managed as part of both environmental and mining legal framework of the country, no proof was found in the literature that the crop yield potential of rehabilitated collieries can be successfully restored to its pre-mining potential. The literature highlighted that although the impacts of coal-mining on soil and productive land has been documented, there is currently a gap in the understanding of how alluvial diamond mining impacts on the soil capability of productive land through its impact on the soil physical properties. This research aims to contribute to the limited knowledge available through investigation of a case study of alluvial diamond mining in the North West province.

CHAPTER 3: METHODS AND DATA

3.1 Introduction

This chapter explains how case study methodology with an interdisciplinary approach was used to illuminate the phenomenon that mining has an irreversibly negative impact on the soil properties that allows for sustainable rain-fed crop production. The case study was designed with imbedded subcases to investigate the impact of alluvial diamond mining activities on the production potential of soil in North-West province. It provides background information on case study methodology and the interdisciplinary approach followed to answer the research questions sufficiently. The delineation of the study boundaries and the gathering and analysis of data for each of the subcases is described while the locality of each of the subcases is indicated in Figure 2. The limitations to data collection are explained and the precautions that were taken to ensure that results obtained can lead to scientifically defendable discussion and conclusions.

3.2 Research design and approach

Yin (2014) defines case study methodology as “an empirical enquiry that investigates a contemporary phenomenon in depth and in its real world context especially when phenomenon and context may not be clearly evident”. It is important that several data sources are collected for a better grasp of the case (Yin, 2014). In case study research, differentiation is made between single and multiple case studies and between the units of analysis used in a single case study (Yin, 2014). While subunits in a single case study provide opportunities for more thorough analysis, it is important to maintain a holistic approach towards meeting research objectives (Yin, 2014).

The case study was exploratory and comprised a single overall holistic case with embedded subcases. According to Scholz and Tietje (2002), exploratory studies can be considered pilot studies where the understanding gained from studying phenomena, leads to the developing models, theories and hypotheses.

The rationale for a single case study with embedded sub-units, was to provide an in-depth analysis of a situation poorly documented with possible significant future implications (Yin, 2014). Embedded sub-units make the integration of both qualitative and quantitative data possible (Scholz & Tietje, 2002). Both qualitative and quantitative data can be collected and used for a case study if there are sub-units, embedding a mixed methods methodology in the case study methodology (Yin, 2014).

In environmental science where complex issues arise, it is not always possible to follow a traditional disciplinary approach where methodologies of only one discipline are used. While developing the research statement, an interdisciplinary case study is required to address the complexity of the thesis.

Repko and Szostak (2017) define Interdisciplinary studies as an approach to questions or problems “too broad or complex” for the scope and methods of one academic discipline“ with the goal of integrating their insights to construct a more comprehensive understanding”. Both multidisciplinary and interdisciplinary studies can be conducted either by an individual researcher or by a research team. Multidisciplinary studies consider only other disciplines besides the main study discipline without integrating the results (Repko & Szostak, 2017).

As indicated by Scholz et al. (2006) and Repko and Szostak (2017), maintaining the research methodologies of the disciplines involved in an integrated disciplinary approach, will improve the concreteness of the results by reducing the complexity. Repko and Szostak (2017) further advocate the research problem is mapped to identify the various disciplines involved, that will then aid in choosing suitable methodologies. Table 1 illustrates how the disciplines of history, law, soil science, agricultural science and political science are interlinked in the study aim and underlying research questions .

Table 1: Disciplinary analysis of the research problem

Discipline	**How it relates to the study aim and research questions**

History	Have soil and land capabilities of the study area already been affected by historical alluvial mining activities?
Law	Do mining and other legislation consider unique soil properties and how it will be impacted by alluvial diamond mining and prospecting?
Soil science	Which soil properties are crucial for sustainable crop production in the study area?
Agricultural science	Are the negative impacts on food production reversible through land rehabilitation practices?
Political science	What is the responsibility of DMR towards monitoring soil management measures and rehabilitation efforts?

3.3 Researcher as participant observer

The initial observations and identification of the research problem were possible because of the researcher being a participant observer in the study. The researcher is a landowner and a soil scientist who resides in the study area. However, all the data gathered and presented in this research report was for the purpose of addressing the research questions and have not previously been collected as part of any consultation project or for commercial gain.

3.4 Data sources and limitations

3.4.1 Documents submitted for environmental authorisation processes of alluvial diamond mining and prospecting

The environmental documents analysed were obtained from both the landowners whose properties are subject to the applications as well as the lawyers who have requested these documents as part of the public participation process in order to obtain these documents on behalf of their clients. The documents analysed have been compiled by four different Environmental Assessment Practitioners (EAPs) and includes documents that were submitted before and after the NEMA regulation changes of November 2014.

The scope of the study was limited to assess to the assessment of baseline soil properties and soil management measures during the mining project cycle and to compare it with the soil management guidelines outlined by the Chamber of Mines (Chamber of Mines, 2007). It was outside the scope of the study to provide critique on the competency and experience of the EAPs who compile the documents.

3.4.2 Land capability classification data

The spatial data of the new land capability classification system was formally requested from DAFF. The new classification system was developed through a spatial evaluation modelling approach that used mathematical calculations underlain by the latest published scientific principles to provide a more accurate indication of the rain-fed agricultural potential of South African land (DAFF, 2017). The data is currently only made available as a raster layer as vector data will reduce the level of detail (Collett, personal communication, 2017). The level of detail available is also more suitable for a regional overview than use on the farm-scale level and the areas of different land capability classes should not be measured on the farm-scale level as absolute values (Collett, personal communication, 2017).

3.4.3 Soil classification data for the farms Hartebeestpan, Doorndam 1 and Doorndam 2

The soil classification data that was used is secondary data obtained from a precision farming company with the permission of the farmers, whose crop fields were included. The farmers and management of the company was willing to contribute the data to the study in order to address the growing concern of the agricultural community about the loss of agricultural land as a result of mining. The data sheets of the field data collected during the soil classification procedures were provided to the researcher with the understanding that the data will be used to illustrate the links between the soil physical properties and the yield potential of the study area and the level of detail required for proper valuation of soil.

The correlations of the different soil forms, soil depths and other soil properties with a predicted maize crop yield have been developed over several years by the lead soil scientists of this company. The formulas used by them are underlain by standard crop yield prediction models but have also been adjusted following statistical analysis of their data and correlation with harvest records over several years. The precision farming company has been very successful in refining yield prediction models and their products are highly valued by farmers as a production management tool.

Even though these formulas will contribute significantly to the current available scientific knowledge on this topic, it has commercial value to the company who developed it and it is outside the scope of the study to provide a detailed description of these formulas. The field data was analysed and presented by the researcher in such a way that it correctly reflects the heterogeneity of soil and the related agricultural potential of the areas affected by mining without compromising their intellectual property.

3.4.4 Crop yields of in situ and rehabilitated mine soil profiles

The yield results of two crop fields situated directly next to each other on the farm Brakpan was obtained from the landowner who is both a crop farmer and alluvial diamond miner that follows best practice rehabilitation guidelines. One of the fields have been mined for alluvial diamonds more than six years ago and has since been rehabilitated and planted with maize. The crop field situated directly next to it consists of the *in situ* soil profiles with the original soil physical properties. The annual fertilizer applications are identical for both these crop fields.

While the soil classification data is available for the original soil profiles, no pre-mining soil map of the rehabilitated crop field was available. The rehabilitated profiles are all classified as the anthropic Witbank soil form because the physical properties have been altered significantly by human interaction (MacVicar, 1991). To compensate for this data limitation, the land capability data obtained from DAFF (2017) was used to illustrate the land capability classes of both the study blocks.

3.5 Description of the study area

The case study area is the North West province. Together with the Free State, North West province forms the main production region for white maize in South Africa (DAFF, 2017). According to Durand (n.d.), approximately 38% of South Africa's grain volumes are produced in the North-West province, receiving an average of 500 mm rain per year. The area is part of a larger semi-arid agricultural region known as the Western Highveld (Walker & Schulze, 2008).

In this area, four diamondiferous gravel fields were identified. According to Marshall and Baxter (1995), 95% of the diamondiferous gravel fields is used for farming of predominantly maize and livestock. The majority of the data sources fall in an area referred to as the southern diamondiferous gravel fields of the south-western Transvaal (Marshall, 1990). The origin, nature, and development of these gravel fields were the focus of a doctoral thesis by Marshall (1990). This area has also been referred to as Area 4 or the Southern Field as part of four areas referred to as the North West province diamondiferous gravel fields (modified after Marshall, 1990, cited in Wilson, Henry and Marshall, 2006, p302).

The other three gravel fields present in the province are:

- The Mafikeng-Molopo or North-western field (Area 1)
- The Lichtenburg-Bakerville or Northern field (Area 2)
- The Ventersdorp-Potchefstroom-Klerksdorp or Eastern Field (Area 3)

T Marshall (2014, personal communication, 14 September) says boundaries of these areas are not based on geographical boundary but was assigned by her to be inclusive of the different diamondiferous gravel fields of this area.

3.6 Methodology

3.6.1 Reflection of pre-mining land capabilities and soil properties in the legislation and application of the administrative process of mining and prospecting authorisation

The first phase of the study was a review of the requirements of the legislation (NEMA and MPRDA) followed by a qualitative exploration of Environmental Management Programmes (EMPs), a basic assessment report (BAR) and Environmental Impact Report (EIR) submitted to the Department of Mineral Resources (DMR) as part of the application process (Table 3). Eight of the EMPs analysed, were compiled by one company for farms adjacent to each other and for the same applicant. These applications were initially submitted as one application but when it was met with resistance by the landowners, the area was split into eight separate applications. The farms subject to these applications are indicated in orange on the locality map (Figure 2). The documents are not dated but according to the legal representative of the landowners, submitted in February 2014, before the change in legislation necessitated that the application is accompanied by environmental authorisation from Department of Environmental Affairs (personal communication, Friedrich, October 2014).

The document contents were analysed to determine to what extent the soil and other agricultural properties of the proposed prospecting areas are measured and described. Various EMPs were also compared to determine whether the level of soil assessment differs because of current land uses and whether more detailed assessments are conducted in the case of crop fields present.

The different phases of the prospecting activities and its associated impacts on soil properties were listed and the mitigation measures proposed. The rehabilitation techniques prescribed for soil and agricultural potential were evaluated. The documents were also scanned for maps, generated to indicate the position of different soil forms in the landscape to be affected.

The third data source of information was obtained during participant-observer interactions with alluvial diamond miners, attorneys, and farmers on their views on the environmental authorisation application process. It also investigated how they value this process and if they understand the procedures and the responsibilities of all involved.

3.6.2 Determination of land capabilities and agricultural potential of soil in the study area

Quantitative soil survey data was obtained for three different crop fields (the locality of the fields indicated in green in Figure 2) to determine the soil properties valued by farmers for sustainable agriculture and crop production. The quantitative data sheets of the soil physical properties were generated through a precision farming soil classification process by a team of soil scientists. The soil was classified on a one-hectare grid using mechanical augering and a hand-held soil auger. The data logged for each survey point included the soil form as per the South African Soil Classification System (MacVicar, 1991) and the depth of each soil horizon in the profile and the plant available water capacity.

The different soil form units were then divided into sub-units distinguishing between soil of the same form with different soil depths and thickness and unique properties of the underlying C-horizon. These different sub-units could then be linked to a specific maize crop yield potential. The data of each soil survey point was mapped with ArcGIS 9.2 to show the location of the different soil forms and the sub-units within, as well as the yield potential of each of the management zones.

To determine how well the detailed assessment of agricultural potential correlates with information publically available through DAFF, the results of the precision soil classification analyses were compared with the soil capability raster data available from DAFF (2017). To contextualise the yield potential of the crop fields studied, as well as the correlating soil capabilities according to DAFF (2017), the yield potential of the different soil management zones were compared to the average provincial maize yields of North West province for the past eight years as calculated by Grain SA (www.grainsa.com).

3.6.3 Assessment of post-mining and prospecting land capability and agricultural potential

Several farms in the area subject to alluvial diamond or prospecting activities were visited to determine the degree to which soil properties and land productivity are rehabilitated after mining (study locations indicated in yellow in Figure 2). The research tools used to gather data include comparative analysis, field surveys to classify soil profiles and field observations concerning existing landscape damage (Table 2). As a participant-observer, the impact of alluvial diamond mining on soil was discussed with representatives from the each of the following groups:

- Landowners - farming but not involved in diamond mining and whose land had been subject to applications
- Landowners - both farmers and alluvial diamond miners
- Alluvial diamond miners

The purpose of the discussions were to get insight in the ways different groups consider soil management and rehabilitation processes and objectives. The discussions also investigated these groups' understanding of soil properties and impacts of mining and rehabilitation actions.

One of the landowners being both farmer and an alluvial diamond miner, presented a sub-unit used for comparative analysis between crop yields on both mined and undisturbed soil. The following data was obtained from the landowner:

- Soil classification
- Maize yield from 2010 to 2015 for both fields as obtained by a harvester equipped with a yield monitor computer
- Soil chemical analysis of the crop fields
- Rainfall for 2010 to 2015

All the other visited sites (to collect data) could be categorised into two main groups:

- Seven farms impacted upon by historical mining and/or prospecting and left derelict or recently mined and just left abandoned. For these farms, photographic evidence was collected on the extent and the damage to the land.
- Five farms were subject to prospecting or mining and where mine rehabilitation was already completed and the surface was level again. For the farms, four soil profile pits were dug (two of undisturbed and rehabilitated profiles each) to classify the soil properties. The control profile pits (undisturbed soil) were each dug in close proximity of the rehabilitated soil profiles to enable comparative analysis.

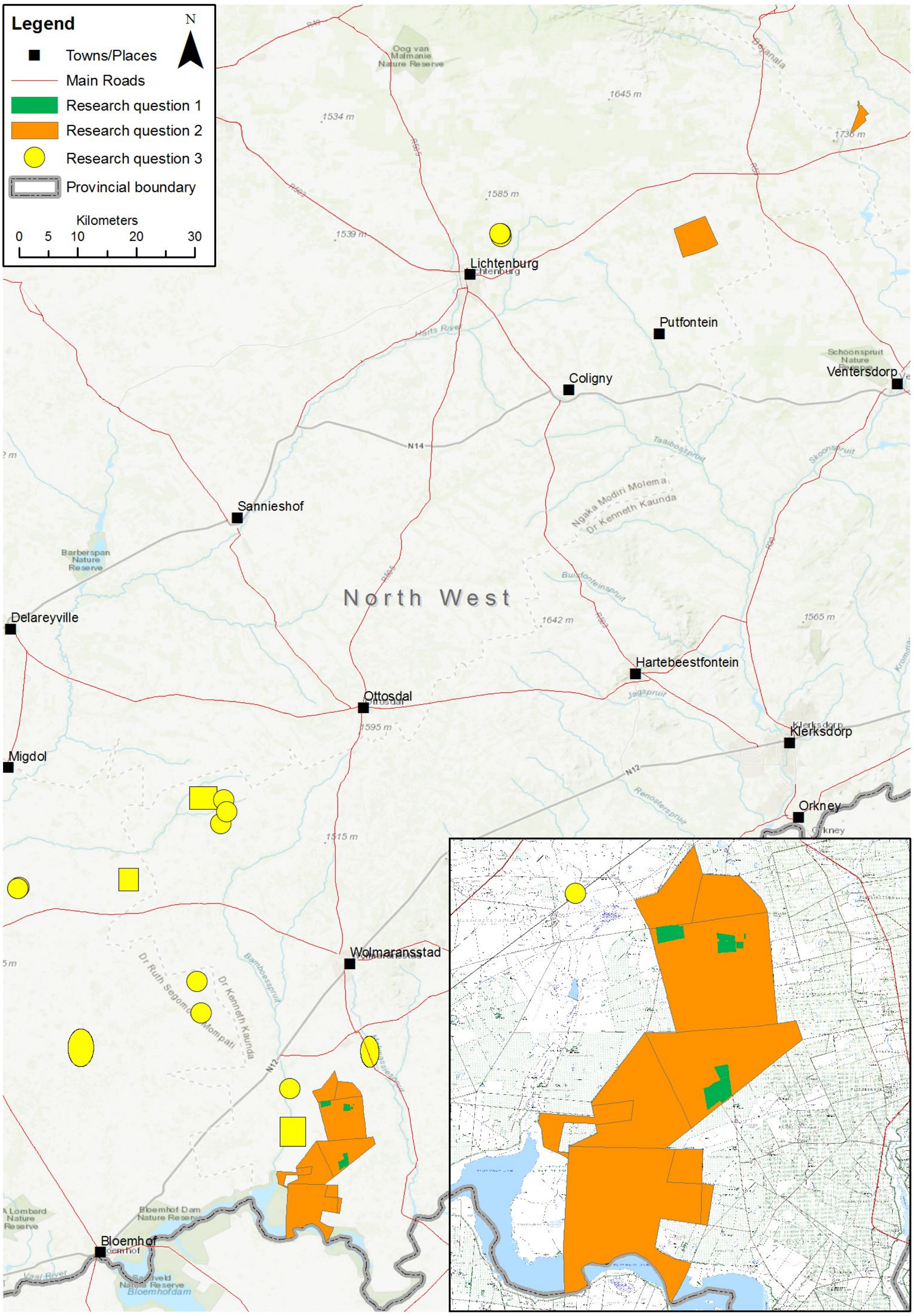

Figure 2: The position of data sources in the North-West province study area

Table 2: A summary of the data tools and sources used to address the research objectives

Research objective	Research tool	Data source	Data category	Map code
Pre-mining land capabilities and soil properties as part of the administrative process for alluvial diamond mining permits and prospecting rights	Review	MPRDA and NEMA requirements		
	Comparative analysis	Environmental Management Plans (EMP)	Qualitative	
		Basic Assessment Report (BAR)		
		Environmental Impact Assessment (EIA)		
	Participant-observer discussions	Alluvial diamond miners		Not applicable
		Attorneys		
		Farmers		
Characterisation of productive soil in the study area	Literature review	Publications	Qualitative	Not applicable
	Data analysis and mapping	Soil classification data	Quantitative	
Post-rehabilitation impacts on the plant available water capacity of soil	Comparative analysis	Maize yield data	Quantitative	
		Rainfall data		
		Soil classification data		
	Field survey	Classification of soil profiles	Quantitative	
	Comparative analysis			
	Field survey	Photographic evidence on site	Qualitative	
	Participant-observer discussions	Landowners	Qualitative	
		Landowners both miners and farmers		
		Alluvial diamond miners		

CHAPTER 4: RESULTS

4.1 How are the pre-mining land capabilities and associated soil properties reflected in the administrative process for alluvial diamond mining permits and prospecting rights?

4.1.1 Legislative requirements for addressing soil and land capability in authorisation process

The only reference made to soil in the MPRDA, is in Chapter 1 where a definition for topsoil is provided. Following this definition, topsoil is the “layer of soil covering the earth” that allows water penetration, harbours plant nutrients and micro-organisms and provides the environment for seed germination. While topsoil is only a synonym for the A-horizon or surface horizon for soil classification purposes (Brady & Weil, 2008), the MPRDA frames the definition for the purpose of mining and rehabilitation stating that it is “not of a depth of more than 0.5m” (Mineral and Petroleum Resources Development Act, No. 28 of 2002, 2002: chap 1). No definitions are provided by the MPRDA for subsoil.

Apart from that, the MPRDA makes no direct reference to soil, land capability or the agricultural potential of land in the entire Act. The Act states that an environmental impact assessment should be conducted once a mining permit or prospecting right application is accepted and that the results of such assessment should inform the EMP to be submitted to the DMR for approval.

Analysis of the MPRDA revealed that the approved EMP is considered the cornerstone of environmental management obligations through the entire mining project cycle, including mine rehabilitation and closure planning. While the Act explicitly state that both mining and prospecting rights must be granted if the associated activities “will not result in unacceptable pollution, ecological degradation or damage to the environment”, no reference is made if this damage includes the soil environment and its ability to sustain food production.

The preparation of the EMP does require that the applicant or appointed Environmental Assessment Practitioner (EAP) establish the properties of the baseline environment to be affected, how it will be affected and what measures will be taken to prevent or minimise the negative impacts. However, it does not stipulate the level of detail for the baseline assessment or the natural resources to be assessed. The MPRDA states that the principles and guidelines for the baseline assessment and environmental management planning should comply to the objectives stipulated in NEMA.

NEMA stipulates a list of information requirements for the EMP but also allows for the submission of a generic EMP if the environmental authorisation applied for is for “prospecting, exploration or extraction of a mineral or petroleum resource”. One of the requirements of the EMP as stipulated by NEMA, is a map indicating the environmental sensitivities of the area applied for and where the proposed project infrastructure will be located in relation to these properties. It also requires that such a map shows areas of high sensitivity that should be avoided with buffer areas around it. No mention is made that soil with high agricultural potential or unique agricultural land should be avoided or regarded as sensitive.

Both the NEMA and MPRDA explicitly states that the holder of a mining or prospecting right is responsible for environmental degradation caused by the mining and prospecting activities and that mined land must be rehabilitated to “a natural or pre-determined state”. It further states that land may also be rehabilitated to “a land use which conforms to the generally accepted principle of sustainable development”. Yet, the rehabilitation requirements are vague and non-specific on any measurable parameters for post-rehabilitated land with regards to soil properties and the related soil capabilities. It also doesn’t specify what the “accepted principles for sustainable development” encompasses and whether it includes sustainable dryland agriculture.

While the NEMA regulations of 2017 provides guidelines for specialist reports in Appendix 6, the guidelines pertain to all types of specialist studies and do not give any specific details on pre-mining soil and land capability assessments. The submission of a soil and land capability assessment specialist report is currently not a legal requirement of either NEMA or MPRDA but may be requested as part of the environmental authorisation process once the application or plan of study is submitting during the scoping phase report.

4.1.2 Pre-mining land capability assessment

In all of the EMPs accessed, the pre-mining land capability was indicated as "crop production and grazing land" and "old prospecting/mining sites". It was further stated, "the land is primarily used for crop production and livestock farming, with approximately 52% of the farmland in crop production, nearly two-thirds of this being of high and the other third of medium production potential." From this information, it was derived that the land capability classification system as outlined by the Chamber of Mines Guidelines (2007) was used.

The Basic Assessment Report (BAR) included a map indicating the location of current land uses in the area where the mining will be conducted. No reference was provided on the data source from which this map was generated.

4.1.3 Assessment of pre-mining soil properties

The level of soil assessment for the environmental authorisation documents assessed, are represented in Table 3. All the documents analysed except the Environmental Impact Assessment (EIA) for a diamond mining right, was void of a soil classification report. While the soil study data of the EIA's soil report were gathered from a soil survey on the site using a soil auger, it was the only exception in the documents analysed. The Environmental Assessment Practitioner (EAP) that compiled all eight of the EMPs stated that the soil information was obtained from "a specialist agricultural support organisation, and the knowledge and experience of consultants and the applicant's geologist". The BAR was void of any references used to gather soil information.

The BAR submitted towards a diamond-mining permit, only described the soil properties as dependent on the underlying geology without any inclination as to the potential soil forms in the affected area. The descriptions of soil properties of seven of the eight EMPs evaluated are identical with a minor difference for the farm Vaalbank. It describes a large soil group with mention of a few soil forms occurring in this group.

It is described as “winde-borne (aeolian) and gravity transported (colluvial) sand” and “mainly red or yellow structureless (apedal) soils”. The Avalon, Westleigh and Clovelly forms are the most prevalent. In the case of Vaalbank, differentiation was made between those soils and “the sediments on the banks of the Vaal River”. No maps were submitted that indicate the locality of these soil forms.

The report on soil types included in the EIA submission, showed the location of three broad soil types determined by a soil survey in the area to be affected. The description of these soil types included the soil forms grouped together, soil depth of the profiles observed and the texture of the A-horizons of these profiles. It indicated the erosion risk by wind, water, and the suitability of these types for dryland and irrigated crop production. No description is provided on the subsoil (B) horizons or any specific properties such as the presence of an underlying C-horizon.

The texture of soils described in the EMPs was all “mostly sandy loam to sandy clay loam” and the soil fertility status as “moderate (mesotrophic) to high (eutrophic)”. There is no description of the different soil horizons and the depths at which it occurs. The only differentiation made concerning horizonation is between topsoil, overburden and gravel layers. Topsoil is described to be “up to 2 metres thick”.

The presence of soft plinthite in the landscape was acknowledged in the EMPs described as “a greyish subsoil layer (plinthic) causing restricted water infiltration and root penetration”. It recognised the contribution of this horizon to the water storage capacity of soil profiles in a semi-arid crop production area. The presence of vertic clay soils with shrink and swell properties were attributed to the presence of shales at the bottoms of pans in the landscape. The potential presence of manganese and iron mottles that may harden gradually into concretions was attributed to the presence of a “seasonally fluctuating water table”.

4.1.4 Soil and land capability impacts according to the environmental documents

Various soil impacts were been identified. The process of removing topsoil and storing it will result in mixing soil layers that “may disturb the soil structure”. Differentiation is made between three layers (topsoil, overburden and gravel layers). All excavations should be preceded by separate removal and stockpiling.

The duration of most impacts is short-term except potential soil pollution because of oil and fuel spillages from construction vehicles and the loss of soil structure. The loss of soil structure because of soil stripping is mentioned as a long-term impact of severe magnitude while the loss of topsoil fertility because of the same action is a short-term impact. Loss of current land capability is also mentioned as a short-term impact and the impact will have been mitigated once rehabilitation was conducted.

4.1.5 Mine rehabilitation and closure planning

The practices prescribed for rehabilitation is considered to alleviate most impacts and restore the land capabilities of the affected areas. The separation of soil layers indicated in the EMPs are mentioned as one of the most important mitigation measures to restore soil properties. It is said, “All excavations should be preceded by separate removal of the topsoil layer and storing it apart from the overburden and gravel layers”.

To mitigate the loss of soil fertility, it is recommended that the soil must be used for rehabilitation as quickly as possible although “little can be done to contain the moisture status of the soil once it has been exposed.” A further measure is “soil deficiencies” of the rehabilitated area must be determined through “soil analysis” and “fertilizer and lime” must be ploughed into the soil to restore its fertility. To mitigate erosion, it is advised that cut-off trenches/berms must be implemented and maintained to prevent erosion. Compaction will be “alleviated” once rehabilitation of certain area starts. While certain roads may remain, those not required would be ripped and rehabilitated.

Table 3: Soil baseline descriptions as analysed from the environmental authorisation documents

Farm Name	**Size of application area (ha)**	**Authorisation applied for**	**Document type**	**Soil forms identified**	**No of classification units**	**Position of soil units indicated**	**Range of maximum disturbance depth**	**Highest yield potential**
Doorndam 251 HO	5071	Prospecting	EMP	Avalon, Westleigh, Clovelly	1	No	Not indicated	Not indicated
Vlakpan 226 HO	515	Prospecting	EMP	Avalon, Westleigh, Clovelly	1	No	Not indicated	Not indicated
Blydskap 382 HO	904	Prospecting	EMP	Avalon, Westleigh, Clovelly	1	No	Not indicated	Not indicated
Driepan 227 HO	631	Prospecting	EMP	Avalon, Westleigh, Clovelly	1	No	Not indicated	Not indicated
Witpan 354 HO	1027	Prospecting	EMP	Avalon, Westleigh, Clovelly	1	No	Not indicated	Not indicated
Hartebeestpan 252 HO	4368	Prospecting	EMP	Avalon, Westleigh, Clovelly	1	No	Not indicated	Not indicated
Vaalbank 355 HO	3094	Prospecting	EMP	Avalon, Westleigh,Clovelly, Oakleaf, Dundee, Shortlands, Glenrosa, Mispah	1	No	Not indicated	Not indicated
Danielsrust 350 HO	2344	Prospecting	EMP	Avalon, Westleigh, Clovelly	1	No	Not indicated	Not indicated
Goedvooruitzicht 120 IP	2908	Mining right	EIA	Hutton, Valsrivier, Mispah	3	Yes	Not indicated	Not indicated
Vlakfontein 466 JP	552	Prospecting	BAR	Nothing mentioned	1	No	Not indicated	Not indicated

4.2 What are the land capabilities and agricultural potential of soil in the study area?

The land capability metadata developed by DAFF (2016) indicated that the three crop fields evaluated consist of three different land capabilities ranging from low-moderate to moderate potential for dryland crop production (Figures 3, 4 and 5). The results obtained from the soil classification data showed that a variety of different soil forms with different yield potential occurs within short distances of each other at all three crop fields (Figures 3, 4 and 5).

Heterogeneity of soil physical properties were observed both horizontally across the landscape and vertically between soil profiles in close proximity. The organisation and thickness of the different horizons of a soil profile and the presence and characteristics of a water-restricting sub-surface horizon (referred to as a C-horizon) are the key determinants of the soil's inherent production potential.

While the study block on Doorndam 1 consists of 16 different soil forms within a crop field of 148,3 hectares, these 16 forms can be divided into 66 different management zones for soil management purposes (Figure 4). Similarly, the 10 soil forms present at Doorndam 2 can be sub-divided into 45 management units (Figure 5). While Hartebeestpan has 12 forms, compared to Doorndam 1, the management of this field is more intensive with 74 management units.

The management zones are determined by the variety of soil depths within a specific soil form and especially the depth of the underlying sub-surface horizon (C-horizon) that may have properties that improve the water-holding capacity of the soil profile. Four different types of C-horizons are present at Hartebeestpan and Doorndam 1 and three at Doorndam 2. The depths available for crop roots ranged between 50cm for the shallowest profiles and 300cm at the deepest (Table 3).

Table 4: Soil physical properties and related yield potential as determined by a detail soil classification procedure

Crop field	**Hartebeestpan**	**Doorndam 1**	**Doorndam 2**
Field size (ha)	258.9	148.3	135.1
No. of soil forms identified	16	10	12
No. of soil management units	66	45	74
No. of C-horizon groups	4	4	3
Range of plant available water capacities (mm)	96 - 408	72 - 292	36 - 304
Range of effective root depths (cm)	80 - 230	60 - 200	50 - 230
Range of maximum tillage depths (cm)	40 - 70	60 - 70	60 - 70
Thickness of soft plinthic C-horizon	30 - 150	30 - 80	40 - 70
Yield potential range for rain-fed maize production (t/ha)	2.5 – 6.7	1.5 – 7.5	0.8 – 6.2
Area above provincial average maize yield of 3.4 t/ha (ha)	244.24	84.44	92.19
Area below provincial average maize yield of 3.4 t/ha (ha)	14.69	64.17	42.98
Number of land capability classes according to DAFF (2017)	3	2	3

When the average yield potential calculated for each of the management units were compared with the average annual maize yield of North West province over the past eight years, it showed that the majority of land of all three the crop fields have above average yield potential (Table 4). The large portion of land with above average yield potential on the farm Hartebeestpan is as a result of the dominance of the Avalon soil form in this crop field. Similarly, the Avalon soil form was linked to the higher yield potential of soil management units on both Doorndam 1 and Doorndam 2.

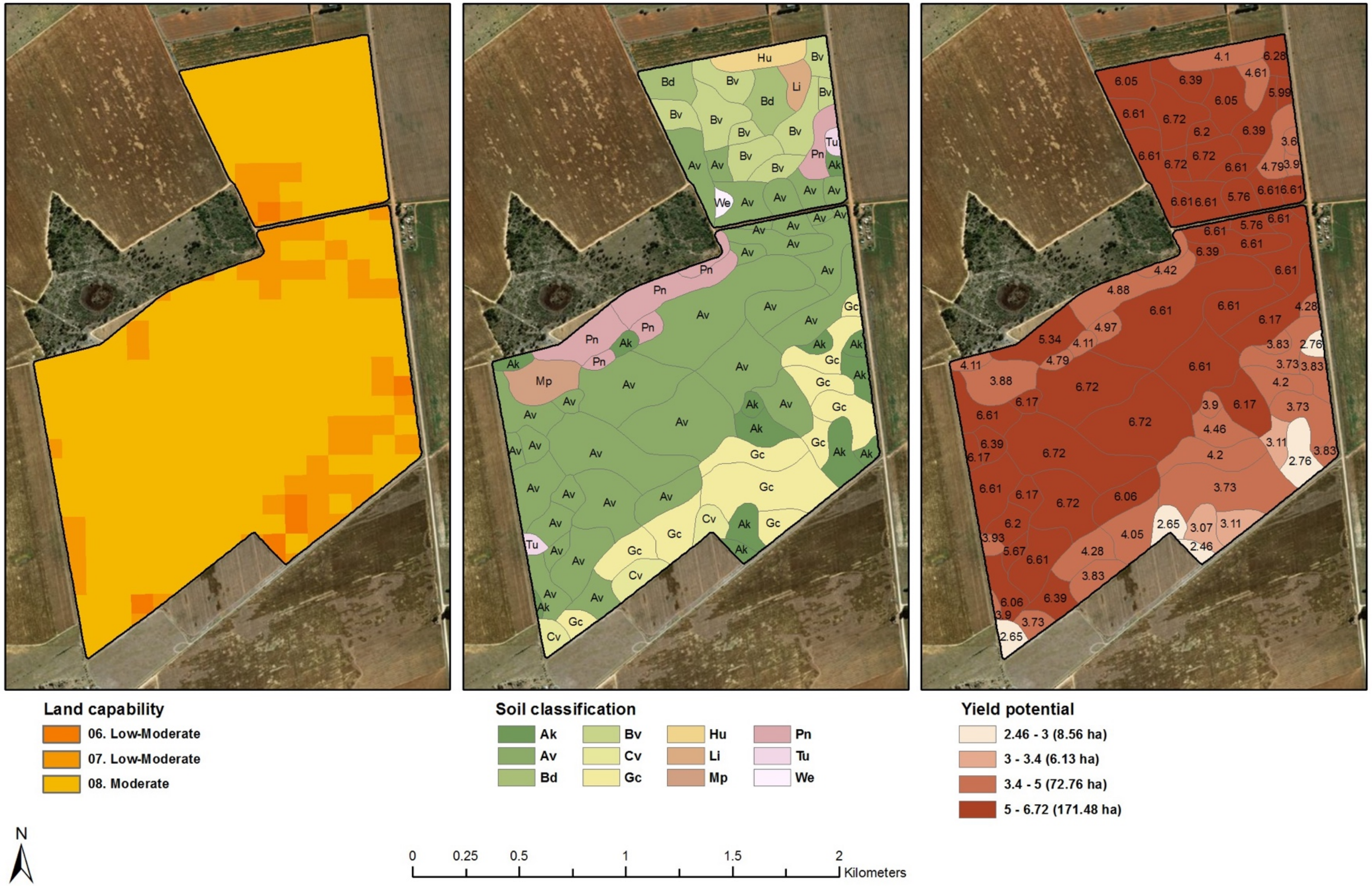

Figure 3: Comparative illustration of the land capability (left), soil classification units (middle) and rain-fed maize yield potential (right) of the Hartebeestpan crop field

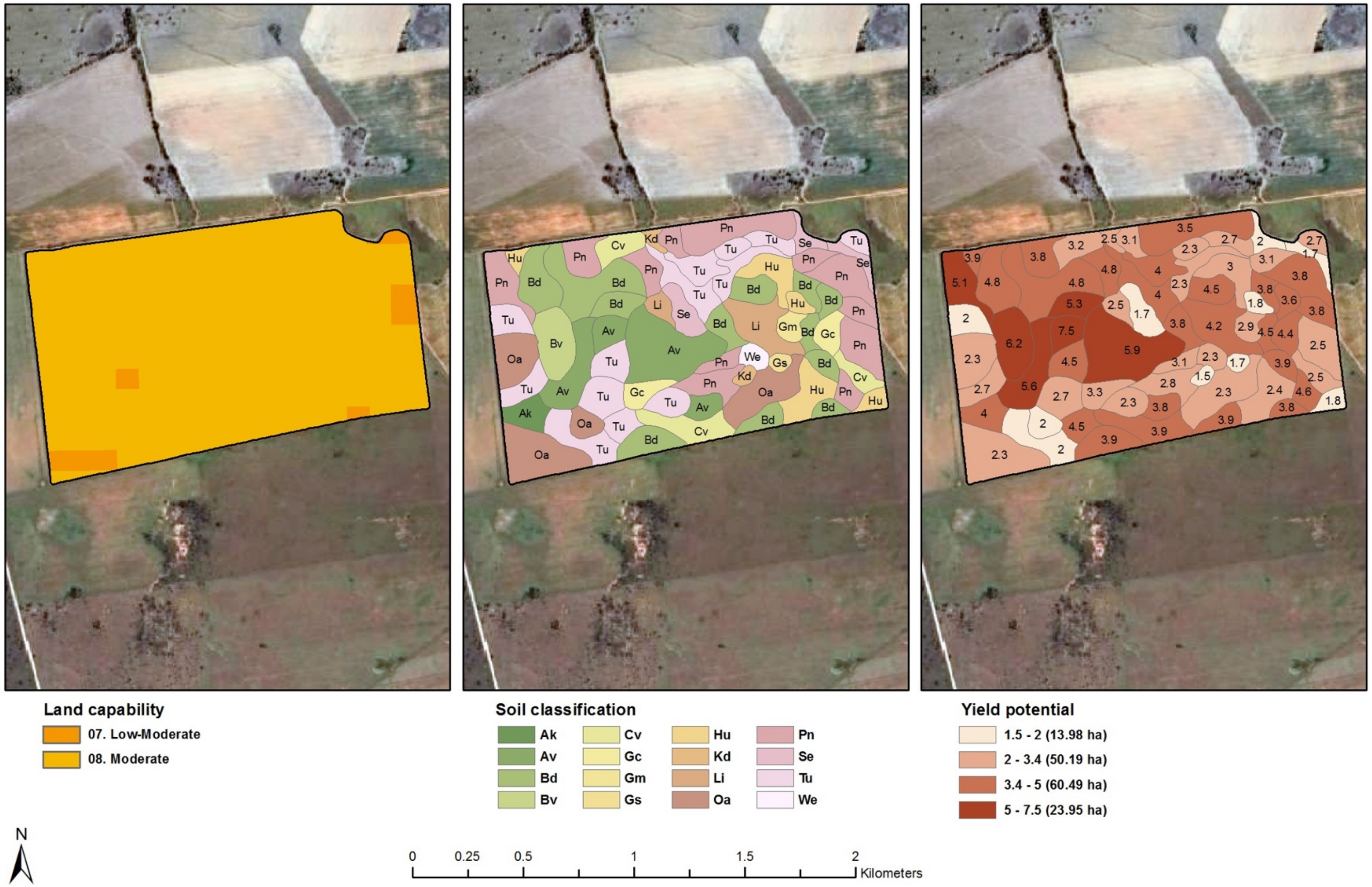

Figure 4: Comparative illustration of the land capability (left), soil classification units (middle) and rain-fed maize yield potential (right) of the Doorndam 1 crop field

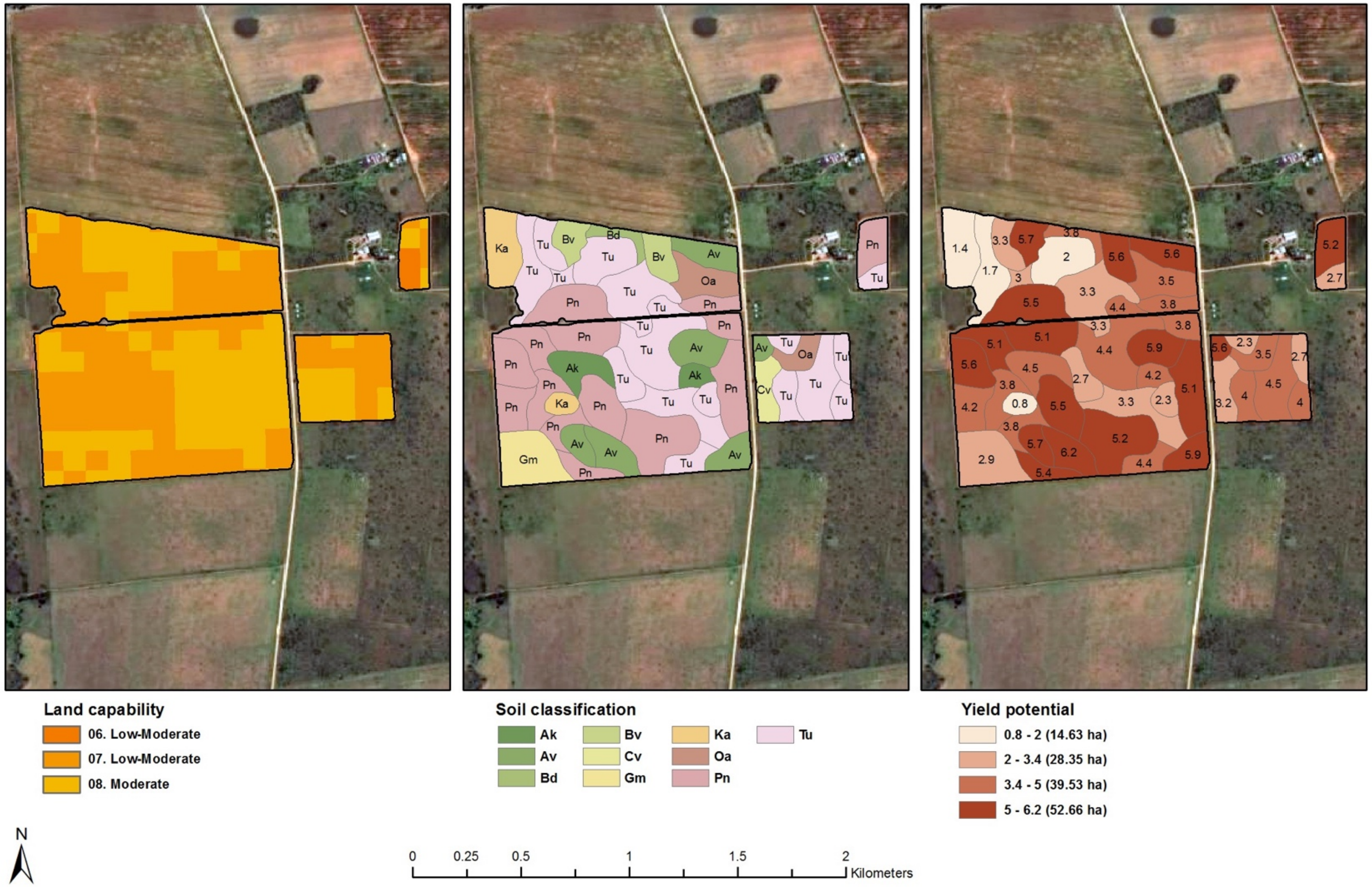

Figure 5: Comparative illustration of the land capability (left), soil classification units (middle) and rain-fed maize yield potential (right) of the Doorndam 2 crop field

4.3 Post-mining land capability of rehabilitated land once alluvial diamond mining and prospecting operations have decommissioned

4.3.1 Arable land capability of rehabilitated sites

The harvest data obtained over a period of six years indicated the high crop yield potential of undisturbed soil in these crop fields with average to high rainfall. The water-holding capacities of soil in the undisturbed area had the ability to store water from the 2011 rain season, resulting in increased yield by a sharp decrease in rainfall during 2012. While a long-lasting drought such as 2012 and 2013 combined resulted in a big yield decrease, the fluctuating rainfall pattern of the region can be mitigated through the soil-water storage capacity of the soils present.

In contrast, yields of the rehabilitated mine soil crop field were always lower than that of the undisturbed soil, except in 2015, a severe drought stressed year. The data show that rehabilitated soil has impeded hydropedological properties that can either cause waterlogging during high rainfall years such as 2011 or during dry years such as 2012. The results illustrate still yield losses on rehabilitated land when compared with undisturbed land, even in the case of best practice rehabilitation.

Table 5: Comparative analysis of yields measured over six years between undisturbed and previously mined land

Year	**Annual rainfall (mm)**	**Undisturbed field(t/ha)**	**Rehabilitated field (t/ha)**
2010	730	7.012	4.272
2011	891	6.280	2.836
2012	354	6.628	2.905
2013	372	2.731	2.127
2014	561	6.633	4.370
2015	276	0.900	1.096

In contrast to the undisturbed profiles where different soil horizons were visible, the rehabilitated soil profiles indicated an almost homogeneous matrix of soil and rock particles. In the case of the farm Kareeboom, stones were present on the soil surface where vegetation growth was sparse comparing to that observed in undisturbed fields neighbouring these mined areas. Apart from the profiles assessed, the physical scars in the landscape either were a further indication of how rehabilitation was completely absent previously, or did not succeed in restoring the agricultural potential of the land.

4.3.2 Grazing land capability of rehabilitated sites

The surface area of the farms Goedgedacht 197 HO and Mietjesdoorns 187 HO was severely affected by historical alluvial diamond mining activities. Apart from the visual scars including mounds of gravel between deep trenches, large areas are inaccessible by vehicle. Vegetation established itself through processes of natural succession but is a mixture of indigenous species such as Acacia and Karee trees interspersed with Bluegum trees and other alien invader species.

During the mining operations, excavations started alongside the property's boundary fence. A long shallow trench was dug here and the topsoil stripped for rehabilitation purposes were moved to one side. Large boulders remained on the soil surface. Pioneer grass and weed species established on the topsoil stockpiles because no further earthmoving activities occurred here (Figure 4A).

The vertical cuts of the trenches remained barren and without erosion control protection measures such as geotextiles. The soil form bordering on the trench area could be classified from these exposed soil profiles. The soil profiles revealed shallow to medium-deep red apedal soils underlain by red apedal subsoil with a high stone fraction. These soil forms are not suitable for crop cultivation because of the shallow soil depth, but moderately to highly suitable as grazing fields for livestock.

Six months after the mining permit holder left the site, the surface of the area where tailings were dumped, was barren and no grass or any other vegetation established on this land. Large cracks were visible on the soil surface (Figure 3A). The land -owner reported that he allowed cattle to graze in these camps around the mined areas but had to remove them because of cattle traversing these areas where they sank into the mud. The cattle were found too late to be rescued and suffocated in these areas.

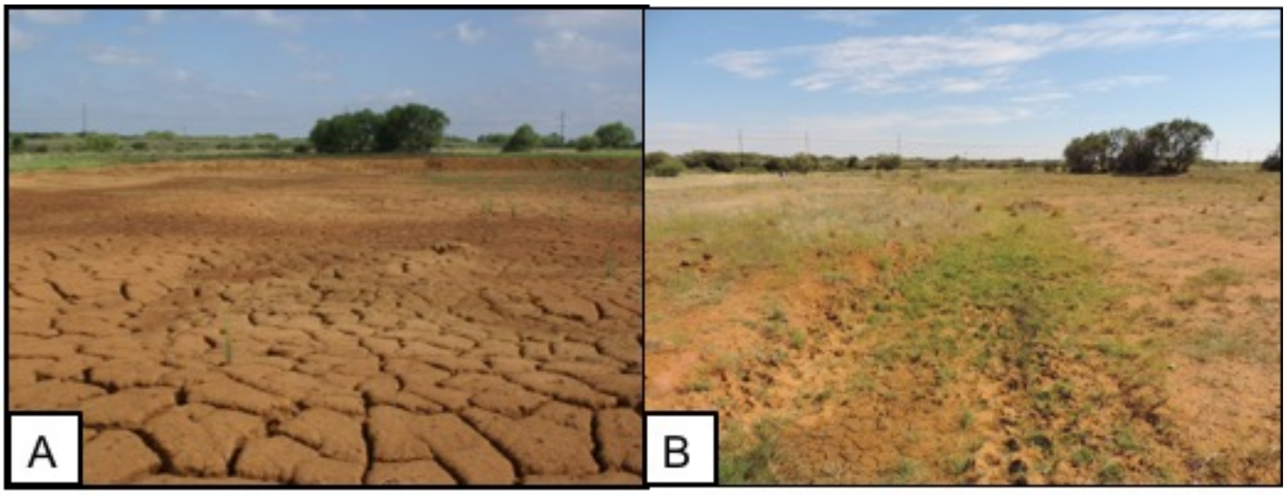

Figure 6: The tailings area four months after rehabilitation (A) and four years after rehabilitation (B)

During the second field observation four years later, pioneer grass species *Tragus berteronianus* and *Eragrostis cilianensis* started to grow in the old tailings areas (Figure 6B). Cracks were still visible on the soil surface, although much smaller. Tracks of the cattle traversing this area are visible, indicating soil compaction occurred during the rainfall seasons when the moisture content of the soil was high and it was easily compacted.

Figure 7 illustrates the effect of mixing the subsoil layer with a high stone fraction with the topsoil during the rehabilitation process. The soil surface was levelled by filling the trenches made during excavation with the soil material available. This resulted in mixing the stone fragments with the soil, creating a mixture with a large portion of stone on the soil surface. The effective soil depth of these areas is much shallower and water infiltration after rainfall periods are limited by these rocky surfaces.

After four years, vegetation re-established in these areas and a combination of grass species was observed during the field survey (Figure 5B). The grass species identified were *Eragrostis viscosa*, *Aristida adscensionis*, *A. congesta subsp. congesta* and *A. congesta subsp. barbicollis*. All of these grass species are hardy annual species known to establish first on land affected by earthworks or overgrazing.

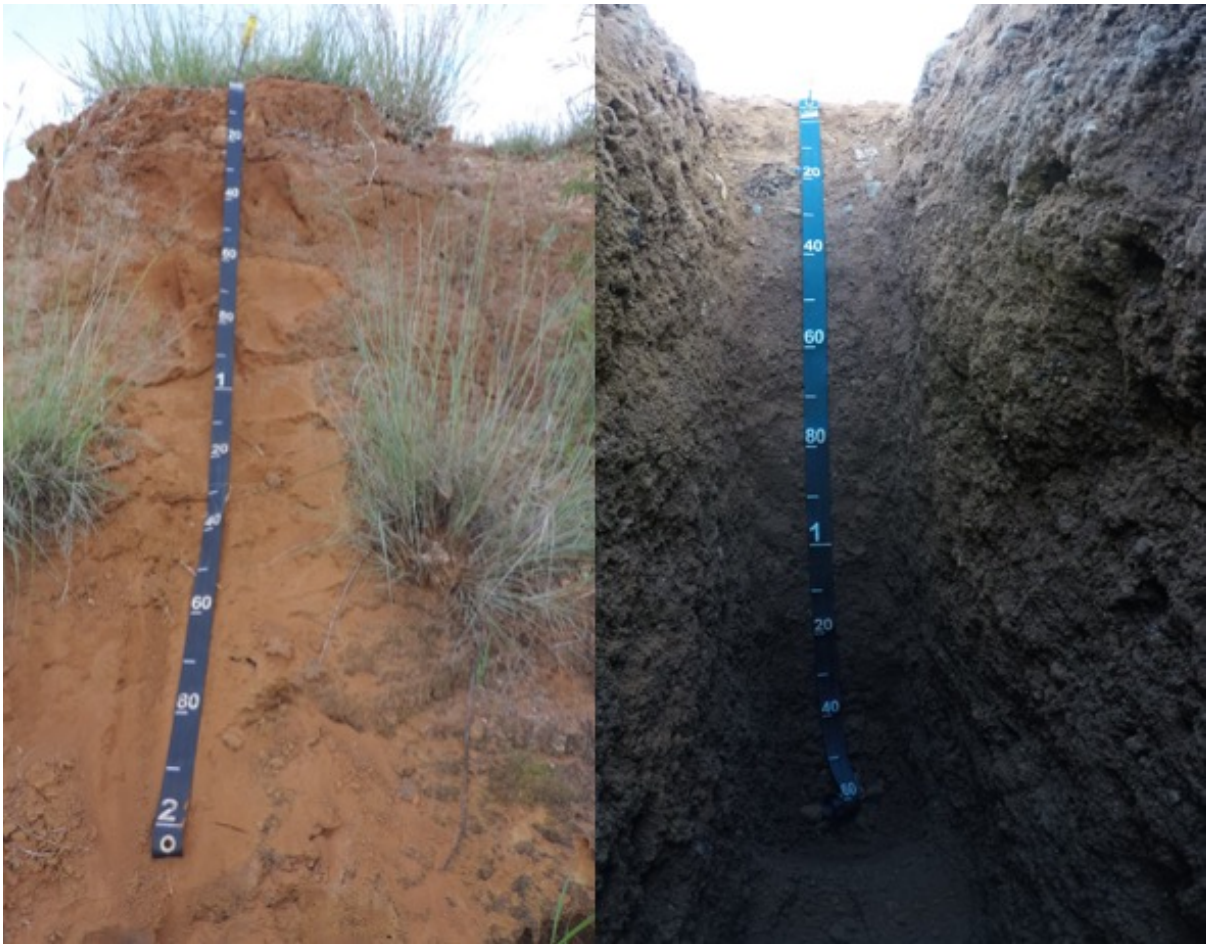

Figure 7: Photographic evidence of an undisturbed Hutton soil profile indicating red apedal soils of 2m deep without any impediments (left) and a rehabilitated mine soil profile high in rock fractions limited in depth at 1.6m because of compaction (right)

CHAPTER 5: DISCUSSION

5.1 Introduction

The overarching topic of the dissertation was the impact of mining on productive soil and whether these are adequately considered in the mining authorisation process. The thesis boundaries were delineated to the study of alluvial diamond mining as an example of non-polluting surface mining on the rain-fed production potential of soil in North-West province. The literature review illuminated the absence of scientific proof that reclaimed mine soil can deliver the same crop yield as undisturbed soil under rainfall conditions (O'Connor and Associates & Kuyler, 2006; Schoeman & Van Deventer, 2004; Prinsloo & Erasmus, 2000). The loss of production potential has been attributed to the altered soil properties including high bulk densities (caused by compaction), chemical impediments and loss of soil-water holding capacity (Prinsloo & Erasmus, 2000; Schoeman & Van Deventer, 2004). In contrast to rain-fed agriculture on rehabilitated mine soil, trials under irrigation with gypsiferous mine water had mixed results (Annandale et al., 2001). The important contribution of in-situ soil physical properties towards the improved water storage capacity of certain soil profiles and how it contributes to rain-fed crop production has been embedded in the newly refined soil capability classification system by DAFF (2017).

5.2 Failure of the mining and administrative processes to capture and manage the soil capability of agricultural land

Analysis of the legislation that holds the owners of mining and prospecting permits and rights responsible for the environmental damage caused by their operations showed that no specific consideration was given to the impact of mining on soil. While NEMA is the main legislation for the management and protection of the environment, it does not explicitly state a responsibility towards soil management. Similarly, the MPRDA does not make direct reference to the protection of soil quality or its productive potential and merely defines the concept of topsoil for the purpose of mine rehabilitation. As such, there is currently no legal obligation for a detailed assessment of the pre-mining soil properties and the associated agricultural capabilities to be affected by mining and prospecting activities as part of the environmental authorisation process.

This legislative gap has historically and is still currently well-exploited by the applicants and holders of alluvial diamond mining and prospecting permits. The documents submitted to DMR as part of the environmental authorisation process, whether those are EMPs, EIAs or BARs, provide superficial information about the soil forms present in the areas to be affected. Similarly, the description of the pre-mining land capabilities is vague and described as either grazing or arable without any indication of the rain-fed maize yield potential or grazing capacity of the land.
It gives a broad description of soil properties similar to that available on the Agricultural Research Council's database, without any map indicating the position of the soil forms or any sensitive areas that should be avoided.

Besides the vagueness of the data provided, it was clear that the exact same descriptions are used for seven of the eight properties for which EMPs were evaluated. The similarity of this data indicates a process of copying and pasting data between these documents, even for large areas applied for. While the EMPs submitted for the farms Doorndam and Hartebeestpan provided one soil description for both the farms, 20 different soil forms were identified by detailed classification of three crop fields on these farms.

While a detailed assessment of baseline soil properties is absent from the authorisation processes followed for alluvial diamond mining and prospecting rights, the Chamber of Mines recommends it as a best practice guideline for determination of rehabilitation objectives (Chamber of Mines, 2007). The need for determination of pre-mining baseline data of the environment and its relation to the pre-mining land uses is implied by the MPRDA but not explicitly stated. The MPRDA states that any mined area or area affected by prospecting have to be rehabilitated to "its natural or predetermined state" or an agreed post-closure land use that is based on the sustainable development principles.

The importance of pre-mining soil classification as source of information to aid the post-mining rehabilitation of the land is also valued in the USA (Sobek, Skousen &

Fisher, 2000). While the alluvial diamond industry of North West province do not follow the guidelines developed by the Chamber of Mines, the collieries in Mpumalanga do (Herb, 2010).

The results of this study has shown that although parameters for monitoring of rehabilitation success are described in the EMPs, it is vague and inconclusive and regards levelled soil surfaces with vegetation cover as rehabilitated land. No post-closure monitoring parameters are provided with regards to soil physical properties or agricultural productivity. The use of fertiliser during the rehabilitation process is considered an exception rather than a rule and recommended only when the establishment of vegetation seems to be problematic or when the Minister issued a directive for this. No special mention is made of the pre-mining crop yields and neither is post-mining crop yield on rehabilitated soils recommend as a monitoring parameter.

This is in contrast with the reclamation of farmland in the USA. Following Dunker and Barnhisel (2000), most states in the USA already implemented a post-mining yield verification process since the early 1990s. This system demanded that the crop yields on reclaimed land should be as high or in 90% of yield potential of a reference block or as determined by a statistical procedure. Although an attempt has been made to replace this system with a soil productivity index measuring five soil parameters directly after reclamation, it was found unreliable and crop yield remained the main measure for reclamation success (Dunker & Barnhisel, 2000).

5.3 Disproportionate approaches to sustainable soil management

The results showed that mining and agriculture has disproportionate approaches to soil assessment and management. This lack of proper baseline soil assessment stands in sharp contrast with the precision farming analysis approach of farmers. While precision agriculture maps are generated through a site visit including one sample point per hectare, the information provided in the EMPs are derived from databases such as that of the Agricultural Research Council (ARC) or the Environmental Potential Atlas of South Africa (ENPAT).

Even though detail soil classification is costly and time-consuming (Zhu, 2009), farmers still regard it as a long-term investment that will enable them to adjust their practices for maximum profitability (Burger, personal communication, 2016). In contrast to this, the cost associated with the environmental authorisation process for mining and prospecting applications, is an expense to the applicants. Since the submission of environmental documents without detail soil assessment is allowed, it is unlikely that they will volunteer to pay for such a study.

The new land capability data developed by DAFF (2017) may be useful as part of a pre-application desktop assessment by an applicant or EAP as an indication of the heterogeneity of the land capability of the area for which an application will be launched. While this classification illustrates the approximate capability of the soil to support rain-fed crop production, it does not provide the yield potential of the land in relation to the regional or national average for dryland maize production for each of the capability classes. Another limitation to using this land capability data, is that the factors contributing to the specific classification, be it soil, climate or terrain are not indicated and may differ for areas of land within the same land capability category. In order to determine the underlying reason for such heterogeneity, a detailed soil and land capability assessment should be conducted to ensure correct representation of the pre-mining properties to be affected. Such a study would be well-aligned with pre-mining agricultural capability assessment as is recommended in the guidelines developed by the Chamber of Mines (2007).

The results of this study agrees with the findings of Mbatani (2000) that the classification of many areas in the country, including North-West province, as marginal to sub-optimal for crop production, is a misconception. The deviation from the original low land capability classification of such areas by Schoeman et al. (2002) is explained through the concept of unique agricultural land (Schoeman, 2004). Schoeman (2004) defines unique agricultural land as “land that is or can be used for producing specific high-value crops”. This definition differs from high potential soil as recognising certain soil properties being beneficial under specific climate conditions, permitting the right management measures are applied (Schoeman, 2004).

The potential of the soil to store water and succeeding availability for crop production during periods of low rainfall was found to have high value to crop farmers in North West province as was reflected in the results correlating yield potential to soil forms. The results also indicated that it was not as much the depth of the soil profile as its ability to store plant available water that determines the yield potential. This contrasts the study by Herb (2010) about the importance of topsoil depth during the rehabilitation process. The soil water storage capacity largely depends on the ability of sub-surface horizons to prevent deep percolation of water.

In correlation with Henning (1991), the results showed that it is not only the presence of a slowly-permeable C-horizon that increased the water-holding capacity of a soil profile, but also the thickness of the soft plinthite (where present) that contributes to the soil water storage abilities of in situ soil profiles. It further recognised the contribution of other subsurface horizons such as carbonate horizons (also referred to as calcrete) and hard plinthite, as impeding water infiltration to depths where it is unavailable for crop roots.

The disturbance of the soil horizons was recognised as an impact of alluvial diamond mining and prospecting in the EMPs, BARs and EIAs submitted to DMR as part of the authorisation process. While the magnitude of the impact was rated as severe, it was considered a short-term impact and reversible through the rehabilitation process. The mitigation measure suggested to minimise this impact was the separate removal of topsoil from overburden and gravel. However, the disturbance of these beneficial soil horizons by mining activities is considered by Prinsloo (2005) as a permanent impact as he states that it is not possible to restore it.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study set out to assess the impact of alluvial diamond prospecting and mining on the agricultural potential of soil, and whether these are adequately considered in the mining authorisation process in South Africa. Using various examples from the case study area the research was able to show that the water-holding capacity of soil in the study area is a highly undervalued resource, especially for its potential to sustain agricultural production in a climate characterised by fluctuating rainfall patterns. It is the presence of specific sub-surface soil horizons such as soft plinthite that impedes vertical soil-water drainage and enable crop roots to access the stored soil water when required during the growth cycle. It also showed that soil as a growth medium is complex and heterogeneous, varying significantly over the area under study. Without detailed studies these unique properties are not accounted for, and so impacts cannot be avoided and managed. Alluvial mining is a destructive process which destroys the physical properties of the soil, even with rehabilitation, these can't be rectified, permanently compromising the agricultural potential of soil.

While the submission of EMPs to the DMR is considered efficient in determining the impacts associated with alluvial diamond mining, it fails to identify the potential of the land for crop production and the contributing soil properties. The documents submitted as part of the authorisation process for alluvial diamond mining are not sufficient to provide information on the environment that it will affect. The rehabilitation guidelines recommended are basic and standardised across the documents and is not site specific.

Since the aim of post-mining land rehabilitation is to restore the landscape and make it suitable for sustainable future land uses, monitoring is required to assess the post-rehabilitation land suitability. While EMPs provide monitoring parameters for the operational phase of the mining and prospecting activities, it does not provide post-rehabilitation soil productivity parameters and a period during which the productivity of the rehabilitated land can be determined. This is a loophole in the system, allowing the loss of productive land continuously without any attempts to address or minimise this loss. Even though the areas to be disturbed might seem insignificant on a national scale, it can result in permanently destroying valuable land resources used for sustainable food production.

As the Government is ultimately the custodian of the country's natural resources and responsible for providing its citizens with food, it should put policies and legislation in place to protect a limited resource such as the productive land.

6.2 Recommendations

From the results of the study, it is recommended that the current practice of DMR to accept a standard environmental management plan based on a desktop study of available soil data or no data, be replaced with more thorough documents. To assist DMR with tools to govern soil management of alluvial diamond mining sites, it is recommended that each environmental assessment accompanying a prospecting or mining application of any size and nature be inclusive of a comprehensive, detailed soil and agricultural potential assessment. This assessment should include a map providing the locality of each soil form and the different types of subsurface horizons present at the depths of these horizons. The soil map should also be accompanied by a yield potential map in crop fields or a species list in grazing land or pastures. These assessments can be used to evaluate post-rehabilitation success of mined land.

Closure planning as it is outlined in legislation should be altered to include for specific post-closure land uses as were determined before the mining commenced. It is recommended that the closure objectives for such prospecting and mining permits be changed from superficial signs of stable landscapes to productive landscapes. Such closure objectives should be proof of either yield potential restored or be able to provide records of reduced yield in order for compensation negotiations. Even though there is a current trend to evaluate landscape functionality, this measure is also limited to evaluate parameters of the landscape yet avoid the inherent capacity of land to support crop growth. It also fails to tie value to the presence of soil-water for crop production and restrictive soil, improving the water storage capacity of certain soil forms.

Following the polluter-pays principle, the responsibility for re-establishing a crop on previously mined land should be with a mining permit holder. Since grazing land is easier to restore to productivity, this principle can be followed for all farming land subjected to mining activity. Instead of allowing the application for a closure certificate once mining has ceased, the surface are levelled, and vegetation established, the permit holder should be allowed an extended period before the final closure application is handled.

During this time, the permit holder should aim to establish the pre-mining land-use whether it be cattle farming or crop production to determine whether that can be considered a financially viable end-land use once they evacuate their mining site and leave the property to the surface rights owner. In the loss of yield potential, the difference in yield can be calculated from harvest records, and the farmer compensated for the loss.

Since South Africa has limited high potential agricultural soil and many farmers rely on unique agricultural land with drought resilient properties, legislation should be formalised protecting this land from degradation. Such legislation should be in synchrony with the current international developments in the field of soil law and policy. This will be the only way to determine the food production capacity of the land and to work towards better planning and monitoring during the mining phase.

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