



**Geo-environmental and physical risk  
associated with the derelict and  
ownerless gold mines from Transvaal-  
Drakensberg and Barberton  
Greenstone Belt Gold Fields,  
Mpumalanga Province, South Africa**

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## **DECLARATION**

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not submitted in previously in its entirety or in part to any other university or institution.

Signature:

Date:

## OPSOMMING

Histories het myne 'n slegte reputasie gehad vir die aanspreek van omgewings- en veiligheidskwessies tydens en na mynbou aktiwiteit. Myngebiede is gesluit sonder dat daar enige aksie onderneem is om die gebied te herstel met gevolg dat groot oop putte, ongeseëde skagte gevul met water, verspreide besoedeling, en verlate slikdamme. Die huidige navorsing het deel gevorm van die groter nasionale projek wat gefokus het op die beoordeling van omgewings- en fisiese risiko's wat verband hou met verlate en eenaarlose myne van alle kommoditeite.

Goudmyne van twee geologiese eenhede naamlik; die Barberton Greenstone Belt en die Transvaalse Drakensberg Gold Field is gekies vir die studie as 'n streeksbenadering in risiko-gradering van verlate myne uit hierdie goudvelde vir rehabilitasie prioritisering. Die primêre doel van hierdie studie was om die potensiële omgewings, openbare veiligheids, en gesondheids gevare wat deur die verlate en eenaarlose myne van die Barberton Greenstone Belt en die Transvaalse Drakensberg-goudveld gelei het, te identifiseer en te vergelyk. Hierdie doel is bereik deur middel van geochemiese assessering van water, grond, slikdamme en afval rots stortings gebiede in beide mynterreine en omliggende landbousekstelsels en assessering van onwettige ontginning, en evaluering myngebiede se geologie.

'n Veld oefening wat bestaan het uit die identifisering van waarneembare fisiese soos horisontale skagte, skagte, putte, afval rotsstortings, slikdamme, graad van erosie en mynbou strukture en omgewingsgefare op die terrein, was aangewend om die doelstellings van die studie te bereik. Versamelde monsters was ontleed en sommige was na die Raad vir Geowetenskaplaboratorium gestuur. Watermonsters is geneem vir in-situ ontledings (pH & EC) en laboratoriumontledings (ioonchromatografie en ICP-MS). Grondmonsters was vir terplaatsse analise versamel deur gebruik te maak van 'n mobiele XRF-ontleder. Slikdam monsters was vir laboratorium ontledings versamel (XRF, XRD, ABA & ICP-MS) en mobiele XRF analise. Afval rots monsters was versamel vir laboratorium ontledings (XRF, XRD, ABA & ICP-MS).

Verlate myne uit die Transvaalse Drakensberg-goudvelde bied 'n hoë risiko vir besoedeling van water. Dit was bevestig deur die waarneming van meetbare erosie slote van slikdamme en PHE's in slikdamme wat waarskynlik tot suurmynwaterdreineringsal lei. Die hoë reënval en nabyheid van groot riviere aan die verlate myne van die Transvaalse Drakensberg-goudveld was geïdentifiseer as 'n groot omgewingsbekommernis. Myne uit die Barberton Greenstone-band sal waarskynlik alkaliese dreineringsal lei weens die teenwoordigheid van bufferminerale in uitskotmateriale.

Die teenwoordigheid van foute in die omliggende geologie van "Bourke's Luck" van die Transvaalse Drakensberg-goudveld lei tot 'n hoë risiko vir besoedeling van grondwater. Bonanza en Golden Snake-myn van die Barberton Greenstone Belt word ook gekenmerk deur 'n reeks foute, maar die aard van die dreineringsal van hul slikdamme het waarskynlik min impak op metaalmobiliteit.

Myne nader aan nedersettings, soos die Bonanza-myn van Barberton Greenstone Belt, is hoogste op die ranglys van gevalle van openbare veiligheid en gesondheid. Hoë konsentrasie van PHE's in die grond in die omliggende omgewing sal waarskynlik tot gesondheidsprobleme lei vir plaaslike inwoners wat naby die myn woon. Verdere mediese studies is nodig om die hipotese te bevestig. Tydens besoeke van terreine was oop skagte as hoogste veiligheidsrisiko deur die gemeenskap geïdentifiseer. In die geval van Bonanza-myn is dit nog 'n groter risiko as gevolg van die nabyheid van die Saba-gemeenskap. Dit vereis dus onmiddellike verseëling.

Hoë vlakke van onwettige mynbou-aktiviteit in die Transvaalse Drakensberg-goudveld bied 'n hoë risiko vir omgewingsverval en openbare veiligheid. 'n Onmiddellike ingryping om onwettige aktiwiteite in die ou mynbedrywighede te bekamp, word benodig vir die veiligheid van die publiek en omliggende landbou-ekostelsels.

Sleutelwoorde : verlate en eienaarlose myne, risikobepaling, blootstelling, prioritering, suurmyn dreineringsal, potensiele skadelike elemente, onwettige mynbou

## **ABSTRACT**

Historically mines had poor reputation for addressing environmental and safety concerns during mining and at mine closure as a result historic mining areas are left with large open pits, unsealed shafts filled with water and scattered waste spoils and tailings. The current research formed part of the larger national project that focused on assessing environmental and physical risks associated with derelict and ownerless mines of all commodities.

Gold mines from two geological units namely; the Barberton Greenstone Belt and the Transvaal Drakensberg Gold Field were selected for the study as a regional approach in risk ranking derelict mines from these gold fields for prioritization of rehabilitation. The primary aim of this study was to identify and compare the potential environmental, public safety and health hazards posed by the derelict and ownerless mines of the Barberton Greenstone Belt to that of the Transvaal Drakensberg Gold Field. This aim was achieved through geochemical assessment of water, soils, tailings dump and waste rock dumps in both mine sites and surrounding ecosystems and assessment of illegal mining and assessment of geology of the mining areas.

A field investigation which involved identifying observable physical, potentially hazardous mine infrastructure, such as adits, shafts, pits, waste rock dumps, tailings dumps, degree of erosion and mine buildings and environmental hazards on site was employed to achieve the objectives of the study. Samples collected were analysed onsite and some were sent to the Council for Geoscience laboratory. Water samples were collected for onsite analyses (pH & EC) and laboratory analyses (ion chromatography and ICP-MS). Soil samples were collected for on-site analysis using the handheld XRF analyser. Tailings samples were collected for laboratory analyses (XRF, XRD, ABA & ICP-MS) and handheld XRF analysis. Waste rock samples were collected for laboratory analyses (XRF , XRD, ABA & ICP-MS).

Derelict mines from the Transvaal Drakensberg gold fields presents a high risk for contamination of water. This was concluded through the observation of measurable erosion gullies of tailings dumps and PHEs in tailings dumps which are likely to generate acid mine drainage. The high rainfall and proximity of the derelict mines of the Transvaal Drakensberg Gold Field to major rivers was identified as a major environmental concern. Mines from the Barberton Greenstone Belt are likely to generate alkaline drainage due to the presence of buffer minerals within their tailings materials.

The presence of faults and joints in the surrounding geology of Bourke's Luck Gold Field of Transvaal Drakensberg Gold Field present a high risk for contamination of ground water. Bonanza and Golden Snake mine of the Barberton Greenstone Belt are also characterised by series of faults and joints which also provide pathway for percolation of plumes to contaminate groundwater.

Mines closer to human settlements such as Bonanza mine in the Barberton Greenstone Belt were ranked as highest in case of public safety and health. High concentration of PHEs in surrounding soil in the area are most likely to cause health problems to locals at proximity to the mine, therefore further medical studies are required to validate this hypothesis. Open shafts in all visited sites were documented as high safety risk to locals with Bonanza Mine presenting the worse-case due to its proximity to Sheba community, therefore requiring immediate sealing.

High level of illegal mining in the Transvaal Drakensberg gold field presents a high risk of environmental degradation and public safety. An immediate intervention to curb illegal activities in the old mine workings is required for the safety of the public and surrounding agroecosystems.

Key words : derelict and ownerless mines, risk assessment, exposure, ranking prioritisation, acid mine drainage, potential harmful elements, illegal mining

## IMPORTANT TERMS

**Exposure** -the state of contact of a stressor with a receptor.

**Hazard**- any source of potential damage, harm or adverse health effects

**Prioritising**- determined order of dealing with mining features for rehabilitation dependent upon available resources

**Ranking**- arrangement of mine features from highest to lowest rating

**Rating**- classification of mine features based on existing conditions

**Risk**- a situation involving exposure to danger

**Risk assessment**-identification of hazards and evaluating their associated risk

## **LIST OF ABBREVIATIONS**

AMD-Acid mine drainage

DMR-Department of Mineral Resources

DWS-Department of Water and Sanitation

EPA- Environmental Protection Agency

GPS-Global Position System

ICP-MS-Inductively Coupled Plasma-Mass Spectrometry

PHEs-Potential Harmful Elements

TWQR-Targeted Water Quality Range

WHO- World Health Organisation

XRD-X-Ray Diffraction

XRF-X-Ray Fluorescence Spectrometry

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## 1 INTRODUCTION

The South African Department of Mineral Resources (DMR) defines derelict and ownerless mines as “mines whose owners or mining right holders can no longer be traced, the operations have been neglected and no maintenance and management of the mine workings and mine waste have been done and no attention paid to their associated environmental, safety and health concerns (DMR, 2009). Historically mines had poor reputation for addressing environmental and safety concerns during mining and at mine closure (DMR, 2009; Hobbs *et al.*, 2008; Ogola, 2010). This has placed a huge burden on governments worldwide (UNEP, 2001).

Early mining operations paid little attention to sound environmental protection, mining laws and sustainable development and vast areas were left denuded, replaced by large open pits, unsealed shafts filled with water and scattered waste spoils and tailings which negatively impacted the environment and human health and safety (Adler & Rascher, 2007; Hobbs *et al.*, 2008).

Through the DMR, the Council for Geoscience has embarked on the development and implementation of a national strategy for the management of derelict and ownerless mines of South Africa (DMR, 2009). This thesis was based on part of the larger national project and follows a regional approach. The focus was on the derelict and ownerless mines from two geological units namely; the Barberton Greenstone Belt (BGB) and the Transvaal Drakensberg Gold Field (TDGF) (Figure 1-1).

Over 300 gold mines from these gold fields were left without any attempt to mitigate impacts and no rehabilitation has been attempted. Furthermore, the abandoned mine infrastructure could result in serious injuries to people entering the sites and may severely affect the local and regional environment. Two sites from each gold field were selected for detailed impact assessment to illustrate the potential for environmental destruction posed by all derelict and ownerless mines from these regions.

Details of the environmental evaluation and safety risk assessment are described, and an illustration given of how these activities align with the original objectives of the project. The environmental investigation included identifying areas where environmental impacts, specifically acid mine drainage (AMD) effects, as well as areas where soil contamination occurs. The assessment of physical hazards was focused on unsealed shafts or adits, unstable waste dumps and other neglected mine-related features.

## **1.1 Study area**

### **1.1.1 Barberton Greenstone Belt**

The BGB is in the South African Lowveld Region, Mpumalanga Province and Swaziland (Figure 1-1). The Belt is of Archean age and stretches in an east-north easterly direction within Archaean granites, gneisses and migmatites. This gold field is situated within the Komati River Catchment in the south west, the de Kaap River Catchment in the north and Mahlambanyathi River Catchment and Crocodile River Catchment in the north east (Figure 1-1). Land uses in the area comprise mainly agriculture which includes forestry, citrus, tobacco and sugar cane operations.

The topography of the area is deeply incised and undulating due to folded rocks, with altitude ranging from 600 to more than 1800 m above mean sea level. The average annual rainfall in this area is 672 mm per annum with temperatures varying between 4 and 39°C in summer and between -2 to 29°C in winter (SA Weather Service, 2013).

### 1.1.2 Transvaal Drakensberg Gold Field

The TDGF is in the Drakensberg Mountains in Mpumalanga Province of South Africa. The main economic centres of this gold field are the Lydenburg, Pilgrim's Rest and Spitzkop regions (Figure 1-1). The TDGF covers an area of about 600 km<sup>2</sup> characterised by mountainous terrain extending towards the deeply incised Great Escarpment of southern Africa. (Wilson and Anhaeusser, 1998).

Land use in this region is dominated by forestry, agriculture and several nature reserves. The TDGF is drained by the Crocodile River in the south and the Sabie and Olifants River in the north. The area receives more than 883 mm of rainfall per year with midday temperatures ranging from 17 °C in winter to 24 °C in summer (SA Weather Focus, 2013).

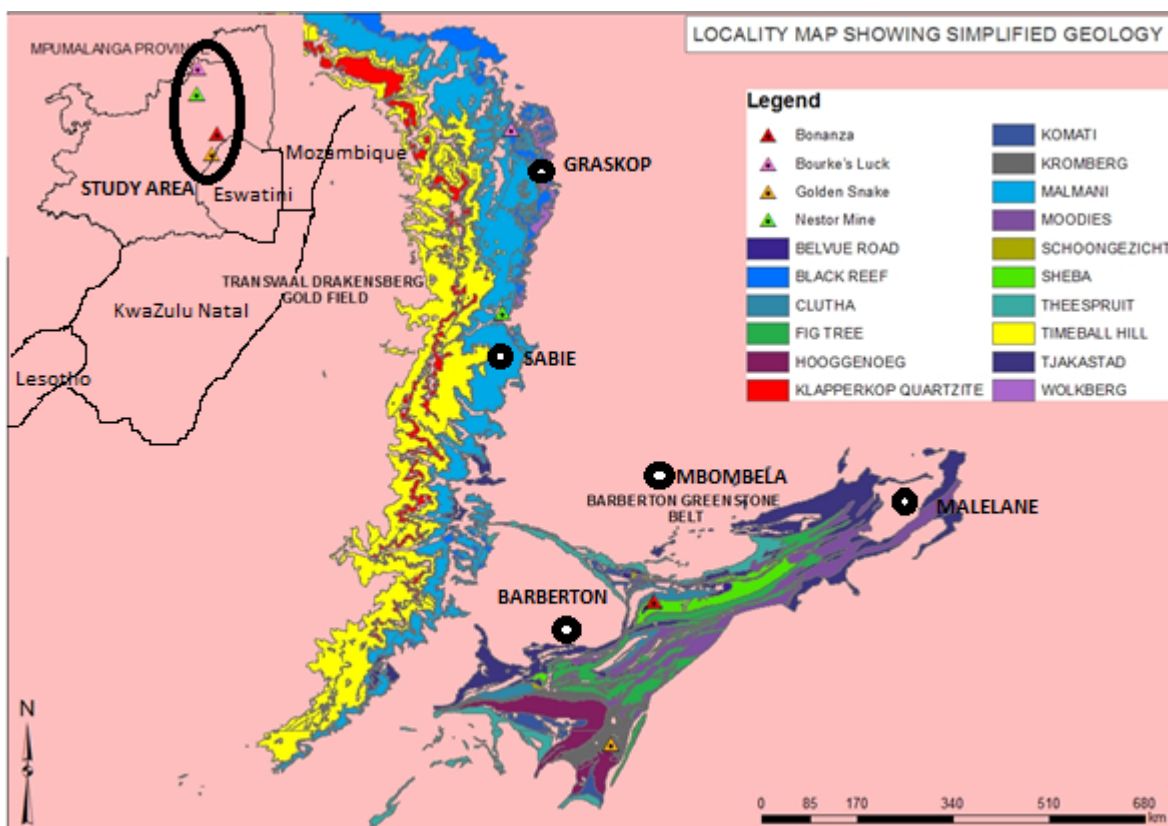


Figure 1-1 Locality map showing simplified geology of the study area

## 1.2 Research background

The historical practices in the mining industries were conducted with little to no regards for the environment, which led to significant ecological damages, contaminated rivers and large remediation cost for government (Hobbs *et al.*, 2008; Adler & Rascher, 2007). Most derelict and ownerless mines are characterised by large open pits, open shafts and waste materials which not only compromise health and safety of nearby communities but also affect the environment in these remote areas.

The potential environmental impacts of derelict and ownerless mines depend on numerous factors which include geochemistry of the country rocks, mining and mineral-processing methods that were used, current climatic conditions of the area, and the nature of the receiving environment (soil, water, flora and fauna) (Mhlongo and Dacosta, 2016). Derelict gold mines are known to generate acid mine drainage which is a major environmental concern (Ogola, 2010; Adler & Rascher, 2007; Lloyd, 2002).

Acid mine drainage (AMD) is generated through the oxidation of metallic sulphides, in most cases pyrite, arsenopyrite and pyrrhotite in the presence of water (Price, 2000). The nature of the drainage determines the solubility of potential harmful elements (PHEs) such as As, Cu, Zn, Cd, Co, Ni, and Pb which varies with the nature of the ore deposit and underlying geology of the area concerned (Ogola, 2010). AMD elevated concentrations of metals and salts in surface water bodies (Hobbs *et al.*, 2008; Munnik *et al.*, 2009; Ogola, 2010). Wet conditions increase the washing away of pollutants from the mine sites to downstream environments (Hobbs *et al.*, 2008). The gold deposits from the TDGF and the BGB are associated with sulphide minerals which are well known to generate acid rock drainage (Wilson and Anhaeusser, 1998).

Historically, mercury was used in the amalgamation of gold. Mercury released in water during amalgamation persists in the aquatic environment and transforms to methyl mercury. The bioaccumulation of methyl mercury in the food chain that is a human and aquatic health concern (Strode *et al.*, 2009). The amalgamation processing technique was employed in many of the older gold mines from TDGF and the BGB which poses potentially further environmental challenges.

### **1.3 Rationale and justification for the study**

Derelict and ownerless mines may threaten human health and affect surrounding ecosystems. The nature of the commodity mined, proximity to settlements, potential environmental and health impacts and the physical conditions of the defunct mine are major factors that determine the risk posed by a derelict and ownerless mine (DMR, 2009).

As of 2009, 819 of the 6000 derelict and ownerless mines in the National database of Abandoned Mines are gold mines (DMR, 2009; Auditor-General South Africa, 2009). These mines are found in the Witwatersrand Supergroup, the TDGF, the BGB and the Giyani Greenstone Belt. There are 305 derelict and ownerless gold mines in Mpumalanga Province distributed in the TDGF and BGB.

The derelict and ownerless mines from these regions may pose a threat to local surface water resources of major river catchments such as the Crocodile, Olifants, Komati and Sabie, whose waters later enter the Kruger National Park. These rivers also provide water to several communities and towns, including Mbombela for domestic, agricultural and industrial activities, which require clean water. There are several game farms and heritage sites which can be affected by pollution from the derelict and ownerless mines. Windblown dust from these derelict and ownerless sites poses health concerns to surrounding communities and may hamper agricultural activities.

This current study is a screening level risk assessment to determine the region which poses highest environmental and physical risks to surrounding environments and communities. Two derelict and ownerless mining sites from each region were selected for an environmental risk assessment and identification of potential threats to the surrounding environment and human health and safety.

### 1.3.1 Site selection

Mining in the TDGF and BGB dates to the early 1880's (Curren and Bornman, 2002; Ward and Wilson, 1998). Selected sites were chosen based on results from an inventory process of all the 305 derelict sites from both gold fields. The criteria used during the screening process included the proximity of the derelict mine to sensitive ecosystem and the public, the legal environmental liabilities, and human health and safety concerns. The derelict and ownerless mines selected were typical of local mines with the same environmental and physical concerns on each gold field. The representativeness of selected sites was based on current and potential environmental impacts and physical risks. The Bonanza Mine and Golden Snake Mine were selected from the BGB and the Nestor Mine and Bourke's Luck Mine were selected from TDGF (Table 1-1).

**Table 1-1 Selected sites for the study**

Gold Field	Mine name	Location		Proximity to settlement	Comments
BGB	Bonanza	Longitude (°)	Latitude (°)	20 m	Heavily eroded tailings and waste rock dump, dilapidated mine infrastructure, open shafts
		E31.1352768	S 25.715833		
BGB	Golden Snake	E 31.04005	S 26.03197	8 km	Waste rock dump, old shafts
TDGF	Nestor Mine	E 30.79941	S 25.07419	1 km	Heavily eroded tailings dump, dilapidated mine infrastructure, illegal mining, open shafts
TDGF	Bourke's Luck	E 30.81766	S 24.66646	1.5 km	Heavily eroded tailings dump, open shafts, dilapidated mine infrastructure

## 1.4 Aim of study

The primary aim of this study was to identify and compare the potential environmental, public safety and health hazards posed by the derelict and ownerless mines of the BGB and the TDGF.

The objectives of the study:

- To determine the potential for acid-base generation in the old mine tailings dump and waste rocks through on-site investigations, predictions and laboratory analyses.
- To determine the potential harmful elements (PHEs) from the derelict mines through water quality assessment at the mine settings and surrounding agroecosystems.
- To identify the geological features and structures on each mine site that relates to potential environmental and health and safety concerns.
- To evaluate the extent to which the physical conditions at the mine sites pose a risk to human and animal safety.
- To provide background data on environmental and health conditions at derelict mines from the two gold fields for design of appropriate monitoring and regulatory guidelines.
- To prepare an inventory of illegal mining activities in these regions and make recommendations on how these activities can be legalised or carried out in a more environmentally friendly manner.

To achieve the objectives of the project, the following activities were undertaken:

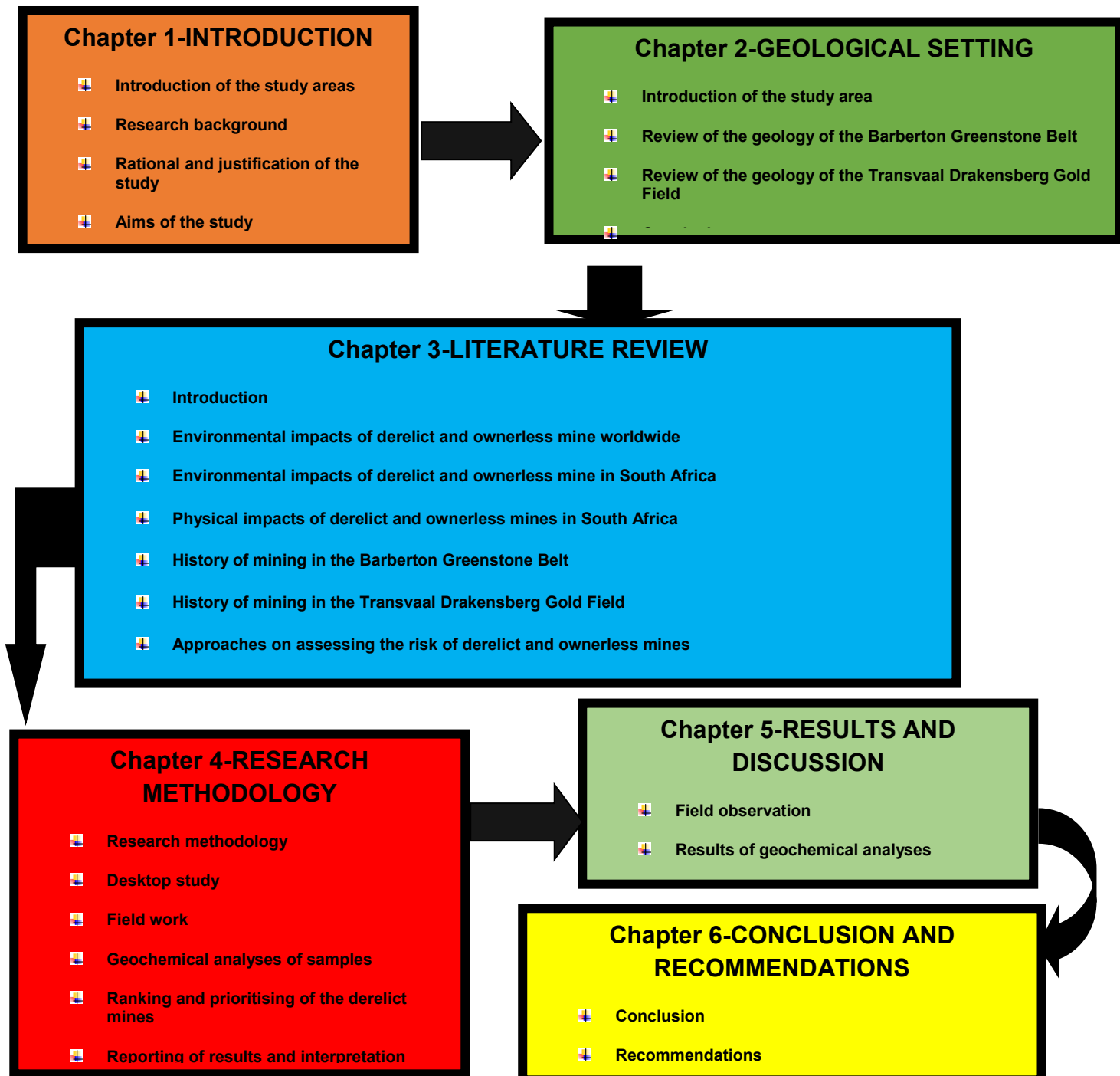
- **Development of an assessment scheme:** This was used as a ranking tool for the assessment of the environmental and physical risk posed by the sites.
- **Development of a consistent approach to collect data:** Previous studies of geo-environmental and physical risk assessment of derelict and ownerless mines was reviewed to compare different approaches used for assessing and

data collection. Data required include water samples collected from different mine features and surrounding environment, solid samples collected from the tailings dam, waste rocks, surrounding soils and stream sediments and field observations, with all existing conditions recorded on site.

- **Description of the study area:** This exercise included desktop studies and fieldwork. Previous literature on mining history, detailed geology of the study areas, mining methods used, documented environmental issues and physical risks were evaluated. Fieldwork involved identification of all possible environmental and physical risks.
- **Assessment of the risk posed:** Using field observations, onsite geochemical tests and laboratory analyses to make realistic assumptions and to rank each site.
- **Evaluate the sites based on the ranking:** To draw comparisons between the environmental audits from the two regions.
- **Recommend potential remediation actions:** To provide background information on the environmental concerns associated with the derelict mines from each region for future reference when developing a remediation plan.

## 1.5 Research framework

The research framework highlights the key topics covered on each chapter. The study consists of six chapters.



## **2 GEOLOGICAL SETTING**

### **2.1 Introduction**

The geochemical characteristics of host rocks are a major contributing factor to the acid-generating or neutralizing potential of mineable ore deposits (Zhao *et al.*, 2007). Carbonate rocks such as dolomites or limestones which are a source of alkalinity are known to produce an alkaline drainage which buffers acid drainage if any, produced from the hosted deposits. Mafic host rocks are also identified as having acid neutralising potential, due to the presence of calcic plagioclase (Plumlee *et al.*, 1999). Hosts rocks with high concentrations of PHEs can naturally elevate the background concentrations of these elements to the environment.

Geology of the two gold fields were reviewed to acquire an understanding of the different types of rocks and geological structures from each region and to further understand the mining methods and beneficiation techniques that were used during the historical gold rushes.

### **2.2 Barberton Greenstone Belt**

The BGB Supergroup comprises of three main groups namely; the Onverwacht Group, the Fig Tree Group and the Moodies Group (Figure 2-1) (Visser *et al.*, 1956; Viljoen and Viljoen 1969; Anhaeusser, 1973). This supergroup extends over 103 km with a width of up to 40 km and an approximate depth of 4-5 km (De Beer *et al.*, 1988).

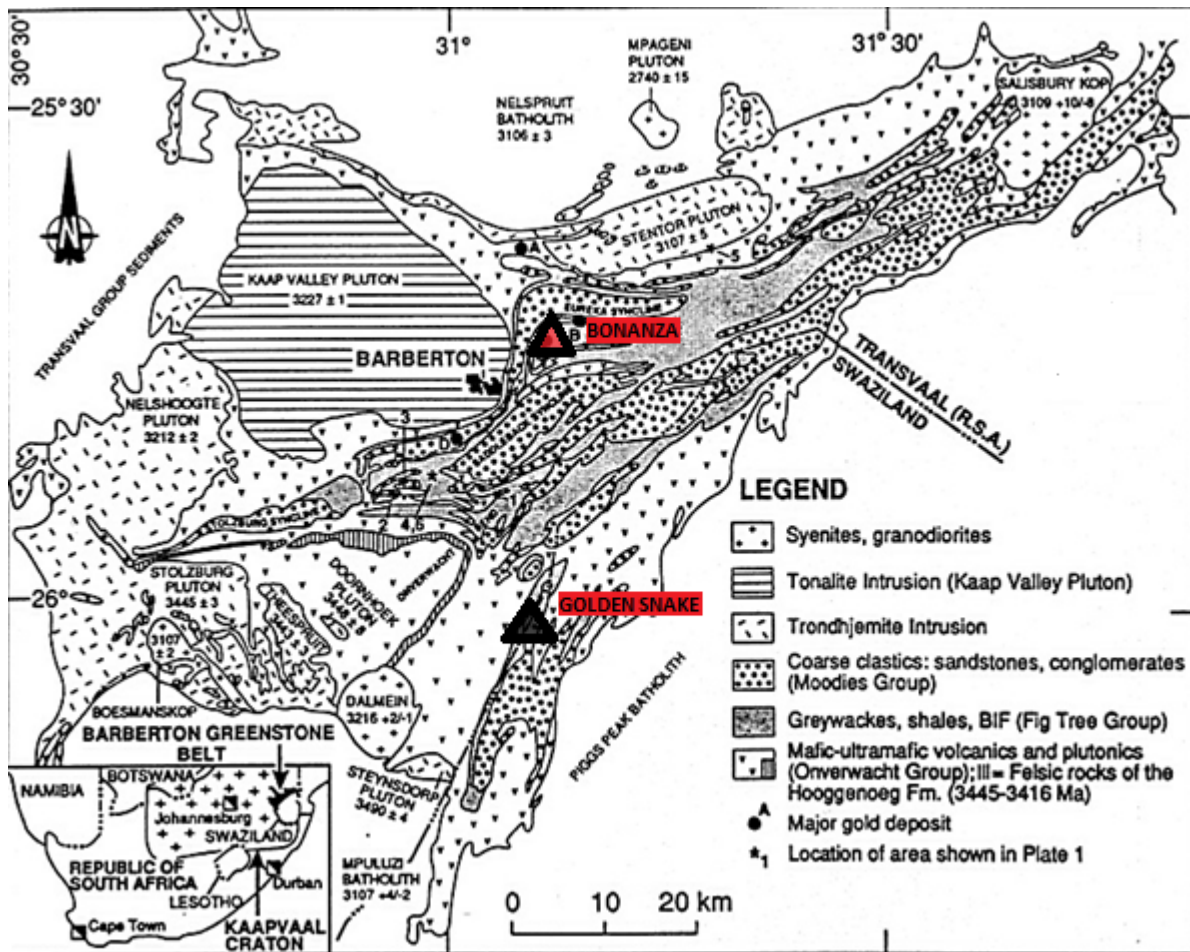


Figure 2-1 Generalised geological map of the Barberton Greenstone Belt (de Ronde and Wit, 1994)

### 2.2.1 The Onverwacht Group

The Onverwacht Group comprises ultramafic and mafic submarine volcanic rocks, including minor felsic and ultramafic-mafic igneous complexes. These submarine eruptions have been dated at 3550 and 3300 Ma (Visser *et al.*, 1956; Viljoen and Viljoen 1969; Anhaeusser, 1973). This group is subdivided into six lithostratigraphic sequences namely, the Sandspruit, Theespruit, Komati, Hooggenoeg, Kromberg and Mendon Formation (Figure 2-2) (Viljoen and Viljoen, 1969a; Lowe and Byerly, 1999).

The Sandspruit and Theespruit Formations form the base of the Onverwacht Group. The Sandspruit is mainly comprised of basaltic komatiites and magnetite with the

Theespruit Formation composed of metamorphosed basalts, basaltic komatiites and sericitic and aluminous rocks (Lowe and Byerly, 1999). The Sandspruit and Theespruit Formation are highly metamorphosed to greenschist facies in contact zones with intrusions.

The Komati Formation is defined by Viljoen and Viljoen (1969a) as perioditic and basaltic komatiites with pseudo-morphed olivine underlying the Hooggenoeg Formation. The Hooggenoeg Formation is comprised of tholeiitic basalts, basaltic komatiites, felsic igneous rocks and thin cherty units overlying the komatiitic volcanic rocks of the Komati Formations. This formation is largely characterised by felsic cycles which is well exposed along the Komati River (Viljoen and Viljoen 1969a).

The Kromberg Formation is marked by massive ultramafic rocks in contact with the Hooggenoeg Formation. This formation is largely composed of massive and pillowed basalts, komatiites, mafic lapilli tuff, lapilli stones, and black and banded chert (Lowe and Byerly, 1999). The Mendon Formation is largely composed of massive komatiitic volcanic rocks overlying the Footbridge Chert on the eastern and western limb of the Onverwacht anticline.

Rocks of the Mendon Formation are clearly visible throughout the central part of the BGB. The western central limb of the Mendon Formation is characterised by a series of narrow blocks of parallel faults localised in serpentinised ultramafic rocks. The southern limb is characterised by capping of Msauli chert and an overlying succession of black, banded and ferruginous cherts (Lowe and Byerly, 1999).

### 2.2.2 The Fig Tree Group

This group consists of greywacke sandstones, mudstones, banded ferruginous shales and fragmented volcanic rocks (Visser 1956; Anhaeusser, 1973; Condie *et al.*, 1970).

This Group overlies the Onverwacht and was deposited between 3260-3230 Ma. The Fig Tree Group has been subdivided along the northern facies into: Ulundi Formation, Sheba Formation, Belvue Road Formation and Schoongezicht Formation with the southern part divided into Ngwenya Formation, Mapepe Formation and Auber Villiers Formation, (Heinrichs, 1980; Lowe and Byerly, 1999; Hofmann, 2005).

The southern facies of the Fig Tree Group is well documented by Heinrichs (1980) as characterised by four units with the layer of shale, sandstone and chert forming the base. This unit is overlain by the Ngwenya Formation which is composed of shale, sandstone, conglomerates, jasper and iron formation. The Ngwenya Formation is overlain by the Mapepe Formation which is made up of a sequence of shale, immature sandstone, conglomerate and barite. The top unit is correlated to the Schoongezicht Formation of the northern facies which is made up of coarse quartz and feldspar-phyric dacitic breccia and fine-grained tuff (Heinrichs, 1980).

The northern facies of the Fig Tree Group is divided into four lithological units with the Ulundi Formation forming the base of the unit. The Ulundi Formation is made of a sequence of black, iron-rich shale, pyritic shale, thinly bedded chert and iron rich sediments (Lowe and Byerly, 1999). The Ulundi Formation is succeeded by the Sheba Formation which is chiefly made of immature lithic sandstones. The Sheba Formation is overlain by the Belvue Formation which consists of shale, sandstones and siltstones. The major parts of the Belvue are highly weathered. The Belvue Formation is overlain by Schoongezicht Formation.

### 2.2.3 The Moodies Group

This is the youngest of the stratigraphic units of the BGB with erosion remnants and was deposited at 3227 Ma (Kamo and Davis, 1994). This unit consists of shallow-water clastics and conglomerates with minor shale and banded iron formation. The Moodies Group has been subdivided into the Clutha, Joe's Luck and Baviaanskop

Formations (Anhaeusser, 1976). These formations represent a stratigraphic sequence of coarse conglomerates, fine grain quartzose sandstones, siltstone and shale (Eriksson, 1979). This group was documented to reach a thickness of 3700 m in the Eureka and Saddleback Synclines (Heubeck and Lowe, 1994).

The Clutha Formation is characterised by well-defined pebble and conglomerate sandstones. The middle part of the Clutha Formation is marked by amygdaloidal basalts overlain by iron-rich shale and jaspilite. These beds are observable in the Moodies Hills and north of the Inyoka Fault. The base of the Moodies Group is characterised by well-defined cobbles and pebble conglomerates overlying quartz rich sandstones.

Wilson and Anhaeusser (1998) hypothesised that the Moodies sedimentation was originally in a foreland basin, with environments which included deltas, braided alluvial plains and shallow water coastal systems and shelf facies

#### 2.2.4 Gold mineralisation

Major gold deposits of the Barberton Greenstone Belt have mesothermal characteristics (Wilson and Anhaeusser, 1998). Most gold mineralisation is hosted in greenstones, greywacke shales, banded ferruginous shales, quartzite and a variety of cherts (Schouwstra and De Villiers, 1988; De Ronde *et al.*, 1992). The gold ore is associated with sulphides commonly pyrite and arsenopyrite formed above 500°C and often occurs as free milling, moderately refractory or high refractory (Schouwstra and De Villiers, 1988). Some gold is recovered in quartz-carbonate veins, carbonated wall rock and fuchsite- and sericite rich alteration zones (Wilson and Anhaeusser, 1998).

Some gold ores associated with minerals such as graphite limited old techniques to recover gold (Wilson and Anhaeusser, 1998; De Ronde *et al.*, 1991). Recently, bio-oxidation processes are employed in recovery of refractory gold. Old mines used oxidised zones and gossans for further explorations at depth and exploration of disseminated and refractory deposits. Metallurgical difficulties inhibited several operations from furthering exploitation of deeper ores (De Ronde *et al.*, 1992).

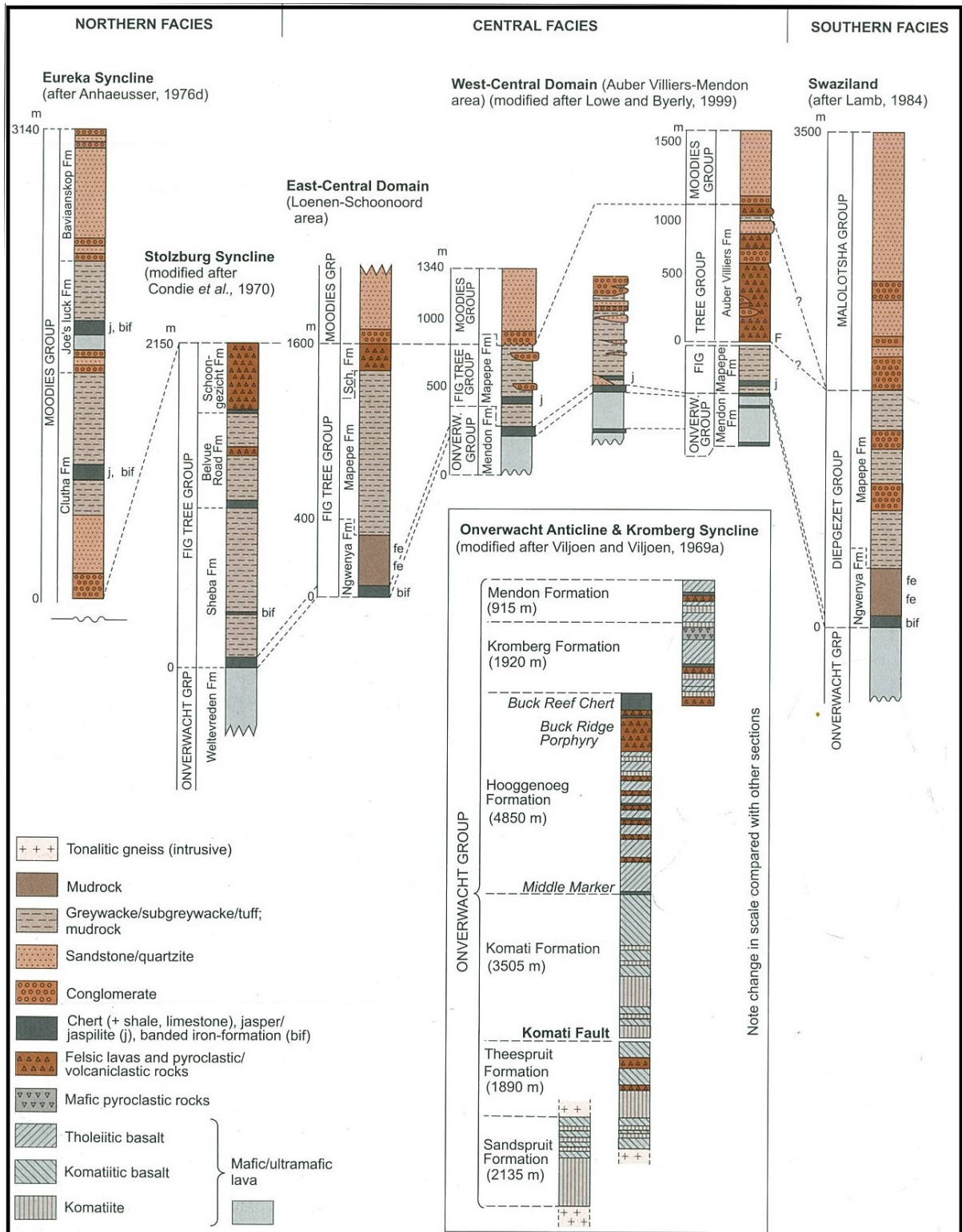


Figure 2-2 Stratigraphic sections of the Barberton Greenstone Belt (Lowe and Byerly, 1999)

## 2.3 Transvaal Drakensberg Gold Fields

The TDGF Supergroup comprises of the Black Reef, Chunniespoort and Pretoria Group (Figure 2-3). The Black Reef forms the base of the TDGF Supergroup and is overlain by the dolomite series of the Chunniespoort Group which is overlain by shales and sandstones the Pretoria Group (Eriksson and Clendenin, 1990).

### 2.3.1 Black Reef Formation

The Black Reef Formation is characterised by quartz arenites with conglomerates and subordinate mudrocks overlying older successions. The basal conglomerate is succeeded by a thick layer of sandstones and thin mudrocks (Henry *et al.*, 1990). Several studies (Button, 1973a; Key, 1983, Els *et al.*, 1995; Henry *et al.*, 1990; Eriksson and Reczko, 1995) suggested that the depositional processes of the Black Reef sandstones were a combination initial fluvial sedimentation followed by shallow-marine conditions (Wilson and Anhaeusser, 1998).

### 2.3.2 Chunniespoort Group

The Chunniespoort Group is divided into five formations, based on chert content, stromatolite morphology, intercalated shales and erosion surfaces (Wilson and Anhaeusser, 1998). The Oaktree Formation forms the base of the Malmani Subgroup which overlies the Black Reef Formation in the Transvaal Basin. . The Oaktree Formation, with an estimated thickness of 10-200 m, consist of carbonaceous shales, stromatolitic dolomites, quartzites and an upper layer of tuff dated at 2585 Ma (Martin *et al.*, 1998).

The Oaktree Formation is overlain by a Monte Christo Formation which consists of breccia, stromatolitic and oolitic dolomites. The Monte Christo Formation is overlain

by the Lyttelton Formation which consists of shales, quartzites and stromatolitic dolomites. This formation is overlain by the 600 m thick Eccles Formation which consists of cherty dolomites and a series of mineralised erosion breccias. The auriferous breccias of the Eccles Formation were mineralised by hydrothermal remobilisation due to the intrusion of the Bushveld Complex (Tyler and Tyler, 1996).

The Eccles Formation is overlain by a 400 m thick Frisco Formation, comprising mainly of stromatolitic dolomites and top layer of shale-rich dolomites (Wilson and Anhaeusser, 1998).

### 2.3.3 Pretoria Group

Gold mineralisation in the Pretoria Group occurs in the Timeball Hill Formation which consists of conglomerates, a quartzites layer with varying thickness of 40 to 230m and 80 to 580 m thick lower mudrock unit (Eriksson *et al.*, 1995). The base of the Timeball Hill Formation consists of minor basal lavas of less than 90 m thickness (Eriksson *et al.*, 1994). Gold also occur in the Dwaalheuwel Formation within sandstones, conglomerates and subordinate mudrocks (Eriksson *et al.*, 1995). The thickness of the Dwaalheuwel Formation varies between 3 to 110 m with depositional environments ranging from alluvial fan to fan-deltas (Schreiber and Eriksson, 1992).

### 2.3.4 Gold mineralisation

Gold mineralisation in the Transvaal Drakensberg gold field occurred mainly in the Black Reef Formation which consists of shales and quartzites, however, gold mineralization also occurred on the shale partings within the Malmani dolomites (Wilson and Anhaeusser, 1998). Some significant amounts of gold deposits were deposited in the lowermost units of the Pretoria Group. Most of the gold ores are associated with various sulphides of Fe, As, Sb and Bi and rarely with Cu ores (Boer *et al.*, 1993; Zietsman 1967; Tyler 1989; Harley 1993). The gold deposits of the

Transvaal Drakensberg gold field are epigenetic in character (Wilson and Anhaeusser, 1998).

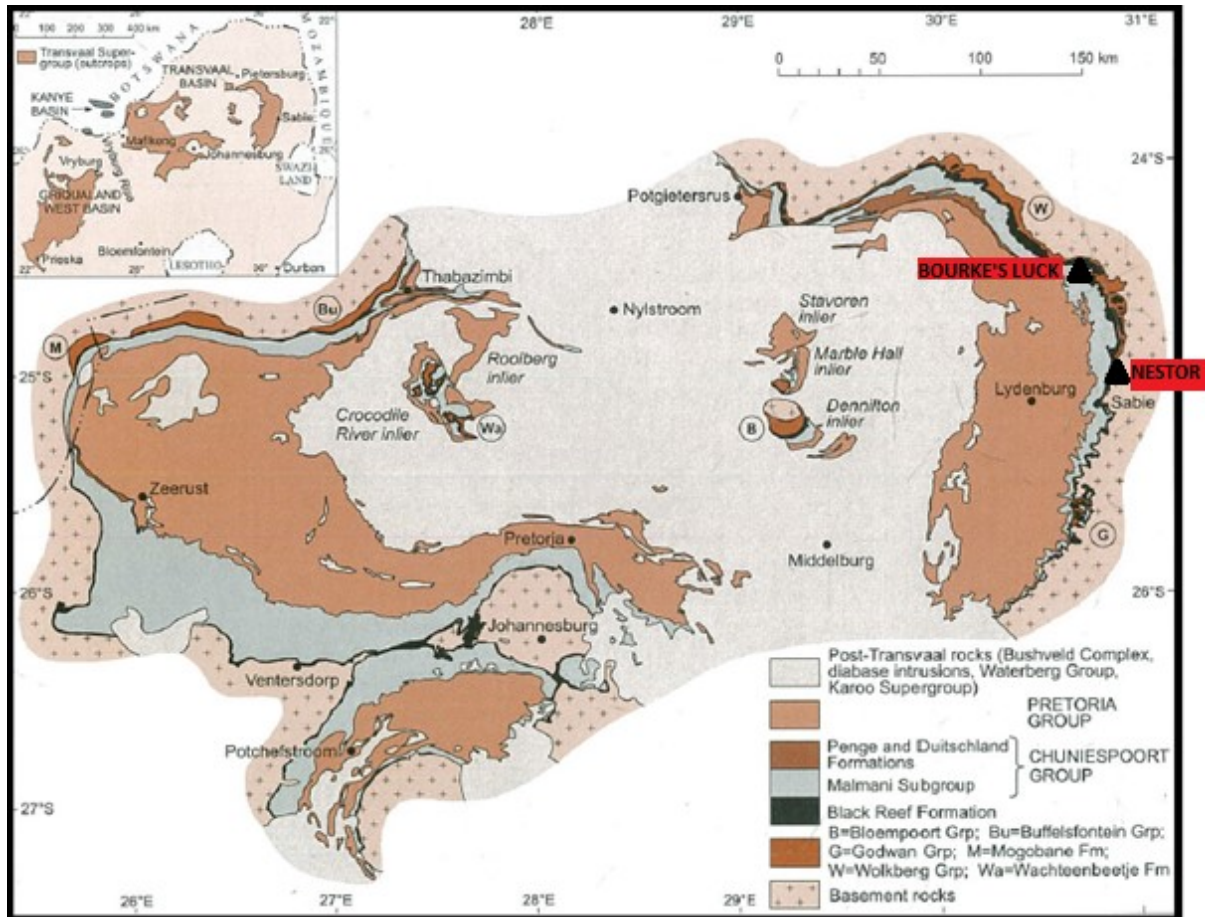


Figure 2-3 Geological map of the Transvaal Drankesberg Gold Field (de Ronde *et al.*, 1994)

## 2.4 Chapter summary

The review of ore characteristics and associated minerals is considered important in ascertaining the potential environmental impacts attached to each mineral and its associates. For example, gold deposit associated with arsenopyrite is largely known to release arsenic which compounds toxicity of AMD. Pyrite is known to be susceptible to oxidation producing acid water at a faster rate compared to other sulphide minerals.

The gold deposits from both the regions are associated with chalcopyrite, pyrite and arsenopyrite. Some variety of gold ores are known to be associated with PHEs which are released during oxidation, as well as during mining and processing of these gold ores. The release of PHEs from these processes and their migration into surrounding agroecosystems present an obvious threat to human and animal health.

Geological structures on each mine site were taken into consideration during the environmental degradation rating of the derelict and ownerless mines. The positions of the sites on geologic terrain were assessed to determine the potential and extent of contamination. For example, presence of faults and joints present a risk of percolation of fluids to deeper environments. Mine wastes dumped on fractured rocks or permeable rocks can allow percolation of poor-quality water into groundwater thus contaminating these sources of water supply upon which nearby communities are dependent for domestic and agricultural water requirements.

### **3 LITERATURE REVIEW**

#### **3.1 Introduction**

Derelict and ownerless mines are common in countries with a long history of mining (Balkau, 1999). The environmental health and safety issues associated with these mines are a serious concern globally (UNEP, 2001). Countries such as Brazil, Canada, France, Germany, Philippines, South Africa, the United States and China, where mining commenced before stringent environmental and closure legislations were instituted, are facing a huge financial burden of rehabilitation (Oelofse and Turton, 2008). Several investigations attributed the environmental concerns and health and safety issues associated with derelict and ownerless mines to inadequate or improper rehabilitation prior to mine closure (UNEP, 2001).

In South Africa, the large number of derelict and ownerless mines is a result of the cessation of mining operations prior to the promulgation of strict environmental regulations governing mine closure (Davenpoort, 2006). Historically, mines in South Africa paid little attention to sustainable development and environmental protection as a result mines operated without proper planning for rehabilitation during mine closure (Balkau, 1999).

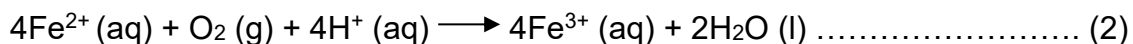
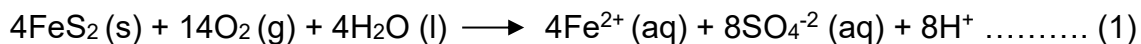
The physical impacts of derelict and ownerless mines include: altered natural landscape, open pits and shafts and unmanaged tailings dumps which can be subjected to landslide (Balkau, 1999; CSIR, 2009). The environmental impacts of derelict and ownerless mines can also include the release of chemical contaminants that threaten the environment, surface water and groundwater (Hobbs and Cobbing, 2008).

### 3.2 Environmental impacts of derelict and ownerless mines.

Mining wastes from gold, coal and other metal sulphides mines generated during operational stages often contain high concentrations of PHEs which are a source of pollution (Davies, 1980; Davies, 1983; Price 2000; Ogola, 2010). The presence of sulphide minerals and their by-products in tailings, waste rocks and old mine workings is commonly attributed to the formation of AMD upon exposure to oxygen and water (Salomons, 1995).

Pyritic and iron-bearing minerals are susceptible to weathering when exposed to the atmosphere and water, thus producing acid waters (Ricca and Schultz, 1979; Atkins and Pooley, 1982; Salomons, 1995; Adam *et al.*, 1997; Canovas *et al.*, 2007; Zhao *et al.*, 2007). The oxidation rate is catalysed by the availability of oxygen, temperature, pH, humidity and the availability of acidophilic oxidising microorganisms (Nordstrom and Alpers, 1999; Aubertin *et al.*, 2002).

Due to the oxidation of pyrite, acidic mine drainage is formed according to equation (1) and (2) (Komnitsas *et al.*, 2001; Seal and Hammarstrom, 2003). This chemical reaction is often accelerated by acidophilic oxidising microorganisms such as *Acidithiobacillus ferrooxidans* (Komnitsas *et al.*, 2001).



The oxidation of pyrite to form AMD exacerbate the solubility of PHEs such as Al, Fe, Cu Sb, As, Cd, Mo, Se, and Zn (Bell and Bullock, 1996; Kelly, 1988). Some of these PHEs such as Sb, As, Cd, Mo, Se, and Zn remain soluble even under neutral pH. These PHEs pose negative impacts on aquatic ecosystems once liberated into surface water systems.

Water contamination is PHEs speciation such as the nature of ions, complex molecules or ion pairs and combinations, colloids and precipitates (Fernando, 1995). Bioavailability of metals in the environment also varies depending on speciation and surrounding condition such as temperature, amount of oxygen in the environment and velocity of water (Kelly, 1988).

The generation of acid water has detrimental effect on surface waters, groundwater and soils (Atkins and Pooley, 1982; Rubio and Del Olmo 1995; Dinelli *et al.*, 2001). Seepage of AMD from tailings and waste rock dumps not only affected the surface water bodies but also cause elevated concentrations of dissolved salts on groundwater (Hobbs and Cobbing, 2008).

AMD also suppresses the amount of dissolved oxygen in the water system thus debilitating aquatic life (Dallas and Day, 1993). Plants and organisms such as dragon flies and gastropods often succumb to low pH water. Precipitation of iron hydroxides on aquatic plant leaves inhibits photosynthesis thus hampering plant growth (Dallas and Day, 1993).

Open shafts have severe impacts on the hydrology of surface water and groundwater (Hobbs and Cobbing, 2008). Runoff water percolates through open shafts, tension cracks and subsided ground into underground mine workings thus reducing surface runoff and increase groundwater recharge and the build-up of contaminated water in derelict and ownerless mines (Chapman, 2011; Hobbs and Cobbing, 2008; Akcil and Koldas, 2006).

Alper *et al.*, (2005) documented other environmental impacts of historic gold extraction where mercury contamination has occurred in Zimbabwe. The study was carried out to assess the environmental impacts of large scale historical gold extraction which used the mercury gold amalgamation technique to beneficiate gold. Results document mercury contamination along the Bear River and Yuba River where invertebrates, fish and frogs were killed. Mercury is also commonly used by illegal gold miners for processing gold (Marsden and House, 1992).

Green, (1968) documented that artisanal gold miners used mercury to recover gold unaware of the environmental and health impacts attached to mercury. Emission of mercury to surrounding environments from historic gold mines was depended on the variability of the recovered ore and the availability of the mercury (Strodea *et al.*, 2009). Mercury was released as mercury vapour during the burning of the mercury gold amalgam and some were lost during the mixing of the mercury with gold ore (Strodea *et al.*, 2009).

The released mercury eventually settles in soil, water and food where and it is further it taken up and processed by a variety of living organisms. Mercury in water transforms to methyl mercury which is easily absorbed by worms and insects and become concentrated in upper feeding chain (Strodea *et al.*, 2009). The use of mercury by gold panners during the amalgamation process poses health threat to humans and aquatic life through bioaccumulation in the food chains (Tunhuma, 2006).

According to the UNDP report (2005), mercury is a carcinogenic substance known to cause lung cancer and skin disease. Cases of mercury contamination due to artisanal gold miners are reported in Zimbabwe (Gill and Fitzgerald, 1985), Sierra Leon (Smith, 1994) and Tanzania (Mpendazoe, 1996).

Dreschler, (2001) further documented the negative impacts of artisanal gold miners to be deforestation, water pollution, air pollution, the disturbance of hydrologic systems and reduction of biodiversity. Artisanal gold miners use metal detectors which operate in non-vegetated areas. As a result, bushes are burnt, and trees are chopped down leaving denuded ground susceptible to erosion (FAO, 2004). Artisanal mining requires large amounts of water for gold panning, performed by gravity separation. As a result, huge amounts of silt and toxic metals are released into the river systems during the panning processes (Dreschler, 2001).

Erosion is very common in abandoned mines without post restoration (Ayuba, 2005). Erosion is dependent on the physical characteristics of the overburden, topographical conditions of the mining area, the stability and slopes of the tailing dam and waste rock

dumps, amount and rate of rainfall, wind speed and the degree of vegetation cover (Sengupta, 1993). Tailings materials are susceptible to wind erosion when dry and subjected to erosion during wet season. Furthermore, poorly constructed tailings dams are subjected to failure, thus leading to fatalities, economic impacts and environmental damages (WISE, 2007).

Mine tailings dumps are subjected to gradation processes leading to siltation of streams and deposition in surrounding environment. Little vegetation grows in poorly managed tailings material due to poor top soil. As a result, more erosion occurs in tailings dumps and less water is retained. Fine tailings materials also lack clay materials and organic or microbial activity to support vegetation.

Soil destruction is well documented by Mummey *et al.*, (2002), as one of the environmental impacts associated with both active and derelict and ownerless mines. Original soil is buried with waste during mining thus altering the normal functioning of microbial communities (Mummey *et al.*, 2002). This has long term negative impacts on the ecological stability especially in derelict and ownerless mines where post closure rehabilitation was ignored (Kavourides *et al.*, 2002).

Soil contamination is also common in derelict and ownerless mines (Kibble and Saunders, 2001). Agricultural lands are commonly contaminated by toxic metals such as cadmium and lead which affect plant growth (Kibble and Saunders, 2001). A study by Zhai *et al.*, (2008) in agricultural lands close to derelict mines in Chenzhou City documented a high concentration of cadmium in soils. Zhai *et al.*, (2008) further reveal that the cadmium enters the food chain through root uptake by vegetables grown in the contaminated agricultural lands.

Miththapala (2008) alluded that soil contamination leads to reduced food security. Soil contamination due to unscientific mining methods has led to the deterioration of large hectares of agricultural lands in many countries in Africa (FAO, 2004). The presence of PHEs in agricultural lands causes considerable impact on the plant growth and thus restricting soil use (Adriano, 1986).

Derelict and ownerless mines are also known for air quality deterioration due to unsuppressed dust from tailings dam and stock piles and gaseous pollutants (Ghose and Majee, 2000; Ghose, 2003). Dust and gases from derelict and ownerless mines can be a health hazard, exacerbating respiratory disorders. Exposed mine wastes and workings of many derelict and ownerless mines may continue to release persistent and toxic metals into the local and remote environments over a long period of time (Blowes et al., 1992; Nordstrom and Alpers, 1999; Aubertin *et al.*, 2002).

Therefore, it is not only crucial to have a detailed environmental impact assessment prior to mining, but is also important to critically identify in advance, the nature of the mine wastes that could be generated during mining, to implement the appropriate mine waste management strategies and meaningful rehabilitation (Ritcey, 1989; Morin and Hutt, 1997; Bussière et al., 2002; Benzaazoua *et al.*, 1998; Chamber of Mines of South Africa 2008).

### **3.3 Environmental impacts of derelict and ownerless mines in South Africa**

Derelict and ownerless mines in the Witwatersrand Basin have received significant media attention due to incidence of AMD and issues of illegal mining (Coetzee, 2005; CSIR, 2009; McCarthy 2011; Mkhize, 2017). According to McCarthy (2011) the gold bearing conglomerate in the Witwatersrand Basin is acid producing containing about 3% of pyrite. Exposed pyrite in the mine dumps forms a low pH drainage which mobilises metals (including uranium) into groundwater and surrounding surface streams (Naiker *et al.*, 2003; Tutu *et al.*, 2008).

The study by McCarthy, (2011) revealed that several streams including the Klip River, Vaal River, Suikerbos River draining from the derelict mines of the Witwatersrand Basin contains higher concentration of toxic metals and sulphates. Derelict and ownerless mines have also negatively affected natural wetlands such as the Blesbokspruit in Springs, Klip River south of Johannesburg (Chapman, 2011; McCarthy, 2011).

The build-up of contaminated water in the derelict and ownerless mines is due to ceased operations and the continuous percolation of rain water that contains dissolved oxygen which eventually becomes acidic and metal enriched (McCarthy, 2011). Ingress of water in interconnected mine workings of derelict and ownerless mines occur due to the continuous percolation of rain water.

Dissolved oxygen from the ingress water result in oxidation of sulphide minerals and the formation of acidic and metal rich water in underground mine workings (McCarthy, 2011). The build-up eventually lead to the decant of acidic and metal rich water from mine openings as has been witnessed in the Western Basin of the Witwatersrand goldfield north in the Krugersdorp area (McCarthy, 2011).

Matshusa *et al.*, (2012) carried out research on the environmental impacts associated with abandoned mines in the Giyani Greenstone Belt. The study revealed that the old mine tailings from the mine sites released acidic water during wet seasons, thus contaminating the surrounding water bodies and negatively impact local agriculture. The study by Matshusa *et al.*, (2012) attributed the elevated concentrations of metals in soil at the Louis Moore Mine in the Giyani Greenstone Belt to the neglected tailings dump. The concentration of metals in the environment varies seasonally (King, 1995).

A study by Ogola, (2010) on the dispersion of (PHEs) on the surrounding environment and their potential impacts at Fumani Gold mine in the Giyani Greenstone Belt revealed the elevated metal concentration in surrounding soils and plants can be attributed to erosion and weathering of old tailings dams. Ogola, (2010) postulated that these toxic metals eventually enter food chain through grass intake by the lower feeding levels.

Illegal mining activities in most derelict and ownerless mines are a major drive for environmental impacts in South Africa (Mkhize, 2017). Illegal miners cause irreversible environmental destruction which include water pollution, deforestation and air pollution (Davis *et al.*, 1994). Mercury and cyanide contamination are regarded as the major environmental concern associated with illegal mining (World Bank, 1995; Mkhize,

2017). illegal miners in the Giyani area, Barberton area, Witwatersrand and Pilgrim's Rest are known to use mercury for processing the gold bearing material (Mkhize, 2017; Mineral Council of South Africa, 2018; Steenkamp and Clark-Mostert, 2012)

### **3.4 Physical impacts of derelict and ownerless mines in South Africa**

Derelict and ownerless mines are subjected to vandalism and scavenging for steel infrastructure (Steenkamp and Clark-Mostert, 2012). Some of the supporting structures such as steel timbers are often removed and sold as scrap metal. This practice jeopardises the stability of the old underground workings (Steenkamp and Clark-Mostert, 2012). Illegal miners also destroy barricades to gain access to old underground working (Steenkamp and Clark-Mostert, 2012).

Open shafts and steep deep excavations are common causes of fatalities and injuries associated with derelict and ownerless mines (Mine for the Future, 2002). Recently, a group of illegal miners were trapped in old underground workings due to rock fall in Benoni, on the East Rand (Chadderton, 2014). Accumulated lethal gases due to poor ventilation in old underground workings can also pose physical and health threat. Recent fatalities of illegal miners in Roodepoort were attributed to toxic gases underground (Chadderton, 2014).

Botha, (2013) reported cases of illegal miners trapped underground in derelict and ownerless mines near Robertville in the Central Rand Gold Field. Four illegal miners were recovered from the collapsed mine workings injury free (Botha, 2013). Nkosi, (2014) also reported another case of illegal miners trapped in a derelict mine around the Roodepoort area. The deeper underground workings in many of the South African mines are a major safety concern for illegal miners (Nkosi, 2014). Nkosi (2014) attributed the collapse due to poor support and suspected use of explosives.

Steel pillars of derelict and ownerless mines have fallen prey to artisanal miners (Mining for the Future, 2002). Derelict and ownerless mines of the Giyani Greenstone Belt have been subjected to extensive vandalism. Scavenging of all types of steel

infrastructure including the steel pillars is common (Steenkamp and Clark-Mostert, 2012). Removal of pillars reduces ground stability and increases overburden stress (Bell *et al.*, 2001).

Surface subsidence in derelict and ownerless mines is common in South Africa especially in the coal mines (Bell *et al.*, 2001). The length of mine workings and seismic intensity of an area also contribute to subsidence (Bell *et al.*, 2001). Subsidence is the function of pillar failure with accompanying void migration. Wooden timbers are subjected to spontaneous combustion and weathering after mining operation has ceased and easily crumble to any tension (Bell *et al.*, 2001). Local geology is amongst the factors attributing to pillar failure in unmanaged old underground workings.

### **3.5 History of mining in the Barberton Greenstone Belt**

The first gold in the BGB was discovered by Tom McLachlan in the early 1881 around the town of Pigg's Peak and Popiyana Creek (Curror and Bornman, 2002). The first gold nugget, weighing 58 oz, was discovered in Jamestown by Jim Murray and Ingram James in the early 1880s (Curror and Bornman, 2002). Prospectors used among other indications, the nature of the oxidized zone, to search for potential ores (Wilson and Anhaeusser, 1998). In 1883, the malaria outbreak led to relocation of these diggers from lower to higher grounds of the Moodies area, where they later discovered alluvial gold in the Concession creek and the Pioneer Reef (Curror and Bornman, 2002).

Gold motivated diggers, Fred and Henry Barber discovered the first payable gold in 1884 in the Valley of the Kaap along the depositional zones of Noordkaap River (Curror, 1967; Meiring, 1976). The Barberton town was named after the Barber brothers and their cousin by the Gold commissioner David Walson (Curror and Bornman, 2002). Sheba Gold mine was the first mine established along the Sheba Reef and was controlled by the Gold Area Gold Deposit.

In 1885 the New Consort Mine was established and was followed by the Fairview Gold mine, discovered by the Kidson Reef Gold mining Company, in 1887. The Fairview

mine is the only mine which used a large-scale biological-oxidation plant to recover gold. The Agnes gold mine was discovered in 1888 and produced silver and gold. The New Consort mine was formed in 1933 from conglomeration of several small operations. Aggressive exploration methods resulted in the discovery of deeper gold mineralisation and resulted in over 350 operations (Anhaeusser, 1986a). More gold was discovered in the southern part of the BGB in the Steynsdorp-Komati valley and Fullerton Creek areas (Wilson and Anhaeusser, 1998).

The depletion of ore deposits closer to the surface led to increase in operational costs for deeper ores which contained a variety of different sulphide minerals (Pretorius, 1965; De Villiers, 1957). The introduction of health and safety guidelines governing mine workers also led to several operations shutting down (Wilson and Anhaeusser, 1998).

Other mineralisation types in the BGB include asbestos, haematite, barite, magnesite, talc, tin, antimony, mercury, nickel-copper, zinc, lead (Hall, 1921, 1930; Anhaeusser, 1976b, 1986b; Laubscher, 1986; Barton, 1982, 1986; Ward, 1999; Ehlers and Vorster, 1998; Dart and Beaumont, 1971; Goodwin 1973; Strydom, 1998; Toulkeridis et al., 1993; Trevor 1920; Antenen, 1991).

### **3.6 History of mining in the Transvaal Drakensberg gold field**

Mining operations started as early as 1872 along the Sabie River on the farms Hendriksdal 216 JT and Spitskop 195 JT (Ward and Wilson, 1998). Payable gold in this region was recovered as alluvial deposits and later in deeper ore bodies which required underground operations.

The declined in the alluvial gold led to prospecting of deeper ores and primary sources (Ward and Wilson, 1998). The diminished alluvial gold curtailed several small scale operations due to diminished profitability against operational cost (Ward and Wilson, 1998). Low grade ore and increase in chemical complexity of ore bodies resulted in unprofitable operations forcing other operations to close. Some operations

amalgamated in 1885 to form the Transvaal Gold Mining Estates (Ward and Wilson, 1998).

Gold was recovered through sluice box and panning of gravel from the depositional zones of streams and the amalgamation technique was employed to concentrate the gold from sluice gold. Some gold were recovered as free gold trapped in the pockets along the river banks (Ward and Wilson, 1998). Mining ceased during the Anglo-Boer War, between 1899 to 1902, and reopened shortly after the war in 1913 but declined steadily after 1914 (Bulpin, 2002).

### **3.7 Approaches on assessing the risk of derelict and ownerless mines**

#### **3.7.1 Background**

Derelict and ownerless mines present numerous environmental and public health and safety worldwide (UNEP, 2001). These mines are principally responsible for death and livestock losses due to falling and drowning in water filled shafts and pits (Bureau of Land Management, 2014). Other public health risks associated with derelict mines include the presence of harmful gases and radioactive substances in old mine workings and explosives (Chadderton, 2014). Some derelict and ownerless mines continuously release contaminated water into streams which threatens the aquatic species.

Rehabilitation of the derelict and ownerless mines requires a huge budget making the task impossible for a huge number of derelict mining sites (UNEP, 2001). In many countries the rehabilitation task on derelict mines is a problem for the ruling government (UNEP, 2001). To achieve the site-specific rehabilitation task, it is therefore required to prioritize the derelict mining sites based on their risks to public safety and proximity to heritage sites, sensitive environment or/and culturally significant sites (Bureau of Land Management, 2014).

Rehabilitation of derelict and ownerless mines varies from site to site due to different mine-site characteristics which influences rehabilitation costs (Renner *et al.*, 2009). South African government have a mammoth task in rehabilitating the derelict and ownerless mines and the rehabilitation costs exceed funding capacities year in year out (UNEP, 2003; Mineral Resource of South Africa, 2018). Ranking the derelict and ownerless mines is an efficient tool to rehabilitate the sites that require an urgent remediation (DMR, 2009; Renner *et al.*, 2009).

The risk assessment approach provides a sound scientific pecking order of derelict and ownerless mines according to their urgency for rehabilitation (Renner *et al.*, 2009). The priority to rehabilitate the derelict and ownerless mines is dependent on the societal needs and well-being especially human health and safety and the well-being of the environment (UNEP, 2001; DMR, 2009; Renner *et al.*, 2009). Rehabilitation of derelict and ownerless mines aims at improving human health, safety and environmental standards (DMR, 2009).

The South African government guarantees every citizen living conditions that are not harmful to their health or well-being and pristine environment (DMR, 2009). The state is therefore compelled to rehabilitate all the derelict and ownerless mines that threaten human health, safety and the well-being of the environment (DMR, 2009). There are numerous physical risks and environmental impacts associated with derelict and ownerless mines (Renner *et al.*, 2009). To completely rehabilitated them to acceptable standards requires an enormous budget and often impossible (UNEP, 2001). It is therefore required to prioritise sites with significant risk to human health and safety (Renner *et al.*, 2009; Ndaluliwa *et al.*, 2011)

The constitutional guarantees equal rights and treatment to all South African it is therefore equally important to employ a transparent and efficient technical risk assessment approach (Renner *et al.*, 2009). Employed assessment procedures must be efficient and produce accurate information regarding the existing conditions in each derelict and ownerless mine for accurate ranking purposes (DMR, 2009).

### 3.7.2 Risk assessment of abandoned mine sites in Namibia (Ndaluliwa *et al.*, 2011).

Historic mines in Namibia, neglected environment consciousness as a result many mines were left without rehabilitation (Ndaluliwa *et al.*, 2011). The derelict mine posed environmental concerns, safety hazards and had severe impacts on livestock and human health. The Geological Survey of Namibia compiled an inventory of 157 abandoned mines. Due to the high cost of rehabilitation a risk assessment was conducted to prioritise the sites based on their risk to human and/or environmental health and safety.

The Geological Survey of Namibia adopted the risk assessment approach prescribed for the Chilean government (Ndaluliwa *et al.*, 2011). The approach prioritizes the risk potentials of the derelict mine sites based on public safety and contamination risks. The approach also includes assessment site according to the geological and existing physical conditions.

The approach was not able to assess all the 157 abandoned mine sites (Ndaluliwa *et al.*, 2011). The intensity of the study on each site made the inventory impossible to achieve for the entire site within a constrain budget (Ndaluliwa *et al.*, 2011). The risk assessment approach adopted by the Namibian government is achievable and present scientific bases. However, the amount of data required to full assess and prioritise the site is impossible to achieve within a short period of time (Ndaluliwa *et al.*, 2011).

### 3.7.3 Assessment of derelict and ownerless mines in the United States of America (Bureau of Land Management, 2014).

The United States government facies a huge financial burden to rehabilitate over 500 000 derelict mines (UNEP, 2001). The Bureau of Land Management was catered with the responsibility to address the issues associated with derelict mines in the United States (Bureau of Land Management, 2014). The risk assessment approach employed

by the Bureau of Land Management prioritizes and remediates hazards at abandoned mine based on the location of the derelict mine to settlement and recreation areas.

GIS mapping system was used to calculate the distance of each site to human settlement. Proximity to human settlement was further analysed using the following criteria: High priority was given to sites a quarter mile from densely populated places or schools. Medium priority was given to sites a quarter mile from historic valuable places and low priority sites are those located more than a quarter mile away from human settlement.

The quarter-mile approach to prioritise the derelict mining sites which is based on their relative proximity to human and schools undermines the nature of the mineral mine and the physical conditions on the sites. The approach lacks scientific bases as low risk sites can present more safety risks that can cause injuries and death.

#### 3.7.4 Environmental degradation associated with abandoned and inactive mines on National Forest System lands in Colorado (Sares *et al.*, 1998).

The National Forest System Lands in Colorado inventoried approximately 18,000 abandoned mine to prioritise rehabilitation (Sares *et al.*, 1998). This inventory process involved literature review of existing river health information, mining and geologic literature, previous mine inventories, and current and historical maps. Aerial photographs were used to identify the location of the derelict mine sites. Existing information on water quality of surrounding rivers was used to identify affected streams. Standardised field-data forms were used by scientists to record field data on numerous field observations. The field work included a detailed geological investigation, water quality assessment, and observable characteristics on sites, water bodies and surrounding vegetation.

Collected data was used to assign a qualitative “Environmental Degradation Rating” (EDR) to the individual mine site (Sares *et al.*, 1998). Ratings guidelines were designed to facilitated consistency in the data; however field scientists were given a

room to consider site-specific conditions such as geology, effluent discharge volume, surface water interactions and precipitation (Sares *et al.*, 1998) (Table 3-1)

**Table 3-1 Guidelines for assigning environmental degradation rating (Sares *et al.*, 1998)**

Rating (EDR)	Feature usually displays one or more of the following characteristics:
1=EXTREME	<ul style="list-style-type: none"> <li>• Contamination off-site is severe.</li> <li>• Receiving stream is "dead" or sterile at the mine and downstream.</li> <li>• Effluent has extremely low pH (&lt;4).</li> <li>• Effluent has extremely high conductivity (&gt;1500 microsiemens per centimeter - <math>\mu\text{S}/\text{cm}</math>; &gt;1000 <math>\mu\text{S}/\text{cm}</math> in alpine areas).</li> <li>• High flows of poor-quality water, relative to the receiving stream.</li> <li>• Abundant precipitate at the mine and in the receiving stream.</li> <li>• Very large dumps or tailings piles with evidence of severe erosion, especially if they have abundant sulfides.</li> </ul>
2=SIGNIFICANT	<ul style="list-style-type: none"> <li>• Receiving stream is significantly or obviously adversely affected, but not "dead" or sterile.</li> <li>• Effluent has low pH (&lt;5).</li> <li>• Effluent has high conductivity (&gt;1000 <math>\mu\text{S}/\text{cm}</math>; &gt;500 <math>\mu\text{S}/\text{cm}</math> in alpine areas).</li> <li>• Moderate flows of poor-quality water, relative to the receiving stream.</li> <li>• High flows of moderate-quality water, relative to the receiving stream.</li> <li>• Moderate to abundant precipitate at the mine and/or in the receiving stream.</li> <li>• Large sulfide-rich dumps or tailings piles with evidence of moderate erosion.</li> <li>• Large dumps with sparse or no sulfides, but evidence of significant erosion.</li> </ul>
3=POTENTIAL SIGNIFICANT	<ul style="list-style-type: none"> <li>• Evidence of degraded water quality, but serious effects are not obvious or detected.</li> <li>• Effluent has low pH (&lt;5.5).</li> <li>• Effluent has moderate conductivity (&gt;600 <math>\mu\text{S}/\text{cm}</math>; &gt;200 <math>\mu\text{S}/\text{cm}</math> in alpine areas).</li> <li>• Poor-quality water with low or no flow (standing water).</li> <li>• Moderate flows of moderate-quality water, relative to the receiving stream.</li> <li>• Minor amounts of precipitate.</li> <li>• Very large dumps with little or no evidence of erosion and sparse or no sulfides.</li> <li>• Small and moderate-sized sulfide-rich dumps or tailings piles with evidence of moderate erosion.</li> </ul>
4=SLIGHT	<ul style="list-style-type: none"> <li>• Effluent with slightly acidic pH (&lt;6.5).</li> <li>• Effluent with slightly elevated conductivity (&gt;400 <math>\mu\text{S}/\text{cm}</math>; &gt;100 <math>\mu\text{S}/\text{cm}</math> in alpine areas).</li> <li>• Sparse or no precipitate.</li> <li>• Small to moderate-sized sulfide-rich dumps or tailings piles with little evidence of erosion.</li> </ul>
5=NONE	<ul style="list-style-type: none"> <li>• No effluent.</li> <li>• Effluent of high quality water.</li> <li>• Small dumps distant from surface water with little or no evidence of erosion.</li> </ul>

### 3.7.5 Chapter summary

The derelict and ownerless mine legacy is a major concern in many countries around the world (UNEP, 2001). The derelict mines pose environmental problems and threatens human health. It is therefore required to rehabilitate all derelict mines for the safety of the public and the environment. But due to the high costs of rehabilitation it is therefore to prioritise the sites based on their risk to human health and the environment.

Different approaches are used worldwide to achieve this goal (UNEP, 2001). From the case studies above, the approach used by Ndaluliwa *et al.*, (2011) requires a huge budget and intensive assessment. The quarter-mile approach used by the Bureau of Land Management of the United States of America lack scientific basis as it undermines the existing conditions on each site. The quarter mile approach only considers the mine location in relation to human settlement as a major factor. For this study, the approach used by Sares *et al.*, (1998) was adopted and further modified into the South African situation.

An inventory study can prioritize all the abandoned mines for reclamation within a reasonable time and delivered credible scientific data. The approach requires a low budget and achieves tangible data. The approach was modified to cover issues of public safety and illegal mining. The modification includes combination of different parameters in different permutations to accurately rank each site. A standardised rating technique was employed to for consistency to transparently rank of all the sites.

## **4 RESEARCH METHODOLOGY**

### **4.1 Desktop study**

The desktop study included a review of geological information, climatic information and hydrogeological characteristics of the areas concerned. Previous environmental studies conducted around these regions were also reviewed together with baseline surveys of the mines.

Google Earth images and topographic maps were used to compile the spatial information and attribute data of all the derelict mines. These tools aided in determining the exact locations of the derelict mines and to obtain road networks for accessing the sites.

### **4.2 Field-work**

The fieldwork exercise comprised of ground verification and observations as well as sampling of water and solid samples (soil, stream sediment, tailings and waste rocks). Two derelict and ownerless mining sites were then selected based on the reconnaissance survey.

#### **4.2.1 Ground-truthing**

This exercise involved identifying observable physical and environmental hazards on site. This included verification of desktop data about the areas of concern. All mine features such as adits, exploratory shafts, prospect pits, waste rock dumps, tailings and spoil dumps were identified and recorded on a standardized field book form and, where possible, mapped in detail. Geographical coordinates of each mine feature were determined and recorded with a Garmin 62s GPS receiver. Physical and specific conditions of mine features and accessibility of the area by public were also noted.

#### 4.2.2 Field observations

All field observations were noted and classified in the standardised rating tables. The observations of the distribution of potential sources of environmental pollution, and the extent of co-occurrence or contact with the environment were noted. The potential environmental impacts of contaminants were analysed by examining stressor-response relationships, *i.e.* the evidence for stressed vegetation, the evidence stressed aquatic life in surrounding surface water.

The environmental and physical conditions of each mine feature were rated based on the approach adopted from Sares *et al.*, (1998). The rating of the mine features were based on their potential to pose danger to human accessing the site and awareness of the people accessing these sites.

#### 4.2.3 Sampling

##### 4.2.3.1 Water sampling.

Sampling was limited to the Summer season. Water samples were collected to measure specific parameters such as: Fe, Al, cyanide, Cu, nitrate and sulphates, pH, dissolved oxygen, alkalinity, temperature and electrical conductance. A bailer was used to collect mine water from vertical openings and deep excavations. A bucket was used to collect surface water. Water samples were collected in a beaker for on-site analysis. Water samples taken for laboratory analyses were collected in High Density Polyethylene bottles. Water samples were taken for on-site analysis in a beaker. Powder free gloves were used throughout the water sampling procedures.

Three sets of water samples were collected from each sampling point. Each set had a sample for analysis of metals, anions and alkalinity. Samples for analysis of metals were filtered and acidified with approximately 1 ml of concentrated nitric acid. Samples for analysis of anions were filtered and not acidified and alkalinity and dissolved

oxygen were determined in non-acidified and non-filtered water. All water samples were kept below 5°C in a cooler box with ice bricks.

#### 4.2.3.2 Solid sampling

Solid samples were collected from soil around the mining area, waste rocks and tailing dumps for:

1. Total metal content
2. ABA and NAG
3. Paste pH
4. Batch leaching
5. Mineralogical composition

#### I. Soil samples

Soil samples were randomly collected around the mining area to evaluate the potential contamination by potentially harmful elements. Methods described by Tan (2005) were adopted for soil sampling. Soil samples were collected using a stainless-steel scoop placed into a clean PVA tray. Moist and wet samples were air dried prior to sieving, grinding and homogenization. Dry samples were sieved using the stainless steel Labotec 200mm test sieve of 2.0 mm mesh size. Sieved samples were further ground with mortar and pestle until the particles were fine and homogenous. An Olympus made handheld X-ray Fluorescence was used to analyse the geochemistry of the soil samples.

The handheld XRF provide fast measurement for elemental and metal analysis. This equipment have an excitation range of 4W Ag, Rh, Au, or Ta anode (per application) X-ray tube and it uses a Si drift detector for analyses. Two of the handheld XRF modes were used for analyses: Soil Mode which utilizes Compton Normalization for PPM to 3% levels of elements in light matrices in soil for collected soil samples and Geo Chem Mode which combines the low concentration capability of Soil Mode with the accurate

handling of percent level concentrations of Mining Plus Mode to analyse the for analysing trace elements and major oxides. Analytical results are displayed in a 32 bit colour resolution touch screen of 57 x 73 mm (2.25 x 2.9 inch).

## II. Tailings samples

Tailings samples were collected for laboratory analyses and handheld XRF analysis. Procedures described by Tan (2005) were adopted during the sampling of the tailing dump.

The hand auger was used to collect tailings dam samples from different depths (0 m to 2 m) to determine the concentration of metals up to 2 m depth. In each sampling point an auger hole was sunk to a depth of 2m and a total of 4 samples were collected. Each sample was withdrawn at an interval of 0.5 m and placed into a PVA tray. The sample withdrawn between 0-0.5m was labelled D1, D2 being 0.5-1 m, D3 being 1-1.5m, and D4 as the deepest sample. Each of the 4 sample was transferred into a labelled plastic bag for laboratory analyses.

## III. Waste rock samples

Waste rock materials were collected for laboratory analyses and handheld XRF analysis (Figure 4-1a). A stainless steel Labotec 200mm test sieve of 2.0 mm mesh size was used to obtain fine materials from the waste rock (Figure 4-1b). Fine waste rock samples were collected to analyse the potential for environmental contamination which could result from leaching of potential harmful elements from the waste rock. Fine grained materials which are generally the most reactive with almost all the mineral grains present in waste rock dumps (Price and Kwong 1997). The procedures described by Price and Kwong (1997) were adopted during the sampling of waste rock samples.

The waste rock samples were collected as 20 subsamples in different points of each waste rock dump using a stainless scoop. Collected samples and were successively placed in a PVA tray upon collection. Moist and wet samples were air-dried prior to

sieving. A stainless steel Labotec 200 mm test sieve of 2.0 mm mesh size was used to obtain sieve (Figure 4-1b). The sieved sample was thoroughly homogenised. The homogenised sample was transferred into a labelled plastic bag for laboratory analyses.



a) Sieving waste rock sample using Labotec 200mm test sieve of 2.0 mm mesh size

b) Sieved waste rock sample

**Figure 4-1 Collection of waste rock dump samples**

#### 4.2.4 Quality assurance

The water samples were collected based on procedures described Dallas and Day (1993). Sampling equipment used to collect the water samples were decontaminated using deionised water before use. New filters (0.45  $\mu$ m cellulose acetate membrane) were used to filter water samples collected for anions and metals analyses. Pure nitric acid was used to acidify the samples in which metal content were to be determined.

Water sample bottles were well labelled and stored in a cooler box at 5°C. All samples were transported to the laboratory and analysed the following day. Water multi-parameter was used to measure the geochemical parameters directly at each sampling site. Calibration of the water multi-parameter was done on each site. All the calibration solutions for the water multi-parameter were checked for expiry date.

Soil, tailings, and waste rock samples were collected based on procedures described by Barth *et al.*, (1989). Sampling equipment were decontaminated by the deionised water. All samples collected except for soils, were stored in transferred into a well-labelled plastic bag and taken to the laboratory the following day. Handheld X-ray Fluorescence used to analyse trace elements and major elements was calibrated on each site.

All sampling points were coordinated using the GPS. Information of all collected samples, sample identification, sample type, sampling date and time and conditions were recorded on the field sheet.

### **4.3 Geochemical analyses of samples**

#### **4.3.1 Onsite field analysis**

All soil samples were analysed using the DELTA handheld X-ray Fluorescence's analyser. Water samples were tested using the WTW Multi 3430 Digital Multi Parameter Meter.

##### **4.3.1.1 DELTA handheld XRF analyser**

DELTA handheld XRF analyser was used to analyse 24 analytes which are considered PHEs. These include; Sb, As, Ba, Cd, Cr, Co, Cu, Pb, Hg, Ni, Se, Ag, Ti, Sn, V, Ca, Fe, Mn, Mo, K, Rb, Sr, Th, Ti and Zr and limited to the detection of elements with an atomic number less than 16 such Li, Be, Na, Mg, Al, Si, and P. The detection limit of the instrument is dependent on factors such as: the analytes of interest, times the sample is irradiated, physical matrix effects, chemical matrix effect and inter-element spectral interferences. The handheld XRF is equipped to store coordinates of sampling point.

The instrument was calibrated before use at every site as specified by the manufacturer. The calibration process takes approximately 15 seconds. Proper use of the instrument was followed as specified by the manufacturer. Energy calibration checks were done as manufacturer's recommendations to determine whether the instrument is operating within resolution and stability tolerances. Two types of blank samples were analysed for the instrument analysis, specifically, method blanks using lithium carbonate to monitor for laboratory-induced contaminants and instrument blanks using a lithium carbonate to verify that no contamination exists on the instrument window.

Soil samples analysed with handheld XRF were dried in a PVA tray and sieved using a 2 mm sieve mesh. Each sieved sample was well homogenized and a portion of the homogenised sample enough to fill the analyser cup was taken from the PVA tray for handheld XRF analysis. Samples were placed in an analyser cup and tested after successful calibration of the analyser. The measurement period for each sample was 5 minutes to meet higher precision and accuracy requirements. Data were transferred to a laptop using a USB cable in an excel format.

#### 4.3.1.2 WTW Multi 3430 Digital Multi Parameter Meter

The equipment was calibrated for pH and EC meter respectively using buffer solutions with pH values 4.01, 7.00 and 10.01 and electrical conductivity standard solution (0.01 mol/l KCl). Calibration of the equipment was done on each site to obtain accurate results. The multi parameter meter probes were dipped into the collected water sample or paste solution to obtain readings. Upon completion probes were cleaned with distilled water after use and stored appropriately.

#### 4.3.2 Laboratory analyses

Laboratory analyses were carried out in the Council for Geoscience laboratories. Analyses included X-ray diffraction to determine the mineralogical composition of collected samples (Zhao *et al.*, 2010). X-ray Fluorescence analysis was used to

determine the total metal content in tailings and waste rock samples (Zhao *et al.*, 2010). Paste pH and Batch Leach test were performed to determine the mobile metal fraction in tailings and waste rock samples (Nordtest, 1998).

Acid Base Accounting were used to determine the potential for materials to produce acid drainage in tailings and waste rock samples (Zhao *et al.*, 2010). Inductive Coupled Plasma-Mass Spectrometry (ICP-MS) was used analyses for metal content in water (Briggs and Meier, 2002) and Ion chromatography to determine the anions in water samples (Zhao *et al.*, 2010).

Obtained trace elements results in solid samples were compared to the international allowable limits for agricultural soil, soil remediation and bio-solids application. Results for metal content in water samples were compared to the South African Water Quality Standards Guidelines. Analyses for metal composition of the water samples were determined by ICP-MS analytical method. Paste solution samples were using procedures and sample preparations described by Briggs and Meier (2002).

Paste solution was prepared from a crushed 1g of sample mixed with 10 ml of deionised water. The paste solution was measured after 24 hours. The ratio 1:10 and the 24 hours sample preparation allows adequate solubility reactions and more accurate determination of the available leachable elements. Value of pH was recorded by placing the pH electrode into the supernatant solution.

Procedures documented by Zhao *et al.*, (2010) were adopted for acid base accounting. Subsamples were submitted to the Council for Geoscience central laboratory.

The calculations were done according to the following formula:

1. Neutralization Potential (NP)

$$NP=50a[X-(b/a) y]/c$$

Where:

a= Normality of HCl

b=Normality of NaOH

c= Sample weight in grams

x=Volume of HCl added in ml

y= Volume of NaOH added to pH 7.0 in ml

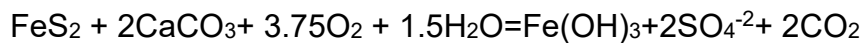
## 2. Acid Potential (AP)

$$AP = \% S \times 31.25$$

Where:

S = total sulphur result determined by high temperature furnace method.

31.25 is the number of tons of CaCO<sub>3</sub> required to neutralise 1000 tons of pyritic material containing 1% S as per stoichiometric equation below.



## 3. Net Neutralization Potential (NNP)

Procedures described by Sobek *et al.*, 1978 were used to determine the NNP. a pulverised sample was treated with a known quantity of HCl. Sample was then heated completely to remove bases and titrated with sodium hydroxide (NaOH) (Sobek *et al.*, 1978). Fizz rating was done during the titration using and scaled based on (Table 4-1).

HCl was classified as either 20 or 40 ml of 0.1M or 0.5M based on the fizz rating (Sobek *et al.*, 1978). Titrated sample was heated for complete reaction and was cooled and titrated with 0.5M NaOH. This was done to determine the amount of HCl used to neutralized the sample.

The mathematical formula for NNP:

$$NNP = NP - AP$$

where NNP-Net Neutralization Potential

NP-Neutralisation Potential

AP-Acid Potential

**Table 4-1 Sample fizz rating scale and the amounts and strengths of HCl required per rating (2g sample)**

Fizz Rating Scale	Rating Strength	Volume HCl/(mℓ)	HCl Strength/(N)
1	Strong	80	0.5
2	Moderate	40	0.5
3	Weak	40	0.1
4	None	20	0.1

#### 4.3.2.1 X-ray Diffraction (XRD)

Analyses for mineralogical composition of the samples were determined by XRD with emphasis on the minerals which could be the source of acid and neutralisation potentials. The procedures described by Zhao *et al.*, (2010) were adopted for this study.

#### 4.3.2.2 X-ray Fluorescence (XRF)

The objectives of the geochemical analyses by XRF were to determine the various metals that may be of environmental concern and to estimate trace mineral proportions to be used as input data for geochemical modelling. The laboratory XRF data were used to identify the metals' potential to be pollutants and compared with water quality data and handheld XRF data. The procedures described by Zhao *et al.*, (2010) were adopted for this study.

### 4.4 Ranking and prioritising of the derelict and ownerless mines

The ranking of derelict and ownerless mines was based on risk for human health and safety and the risk for the environment. Modified approach from Sares *et al.*, (1998)

was employed to rate all the observable condition on site and on site geochemical tests and laboratory results. Standardised guidelines were used to rate each factor considered during the risk assessment exercise. The standardised guidelines were used to ensure consistency and to yield reliable and reproducible results. A field sheet was used to record the existing physical and environmental conditions and potential negative impacts predicted on site and from geochemical tests (Appendix I-IV).

The approach considered several attributes to yield sound results which include; the proximity and accessibility of the site, likelihoods of severe hazards to people accessing the site, flexibility to sound scientific justification for high risk site that require immediate rehabilitation to high risk site that do not require immediate interventions, flexibility of approach to combine combining different parameters in public health, public safety, environment degradation and level of illegal mining, and rating based only on existing scientific data and observable conditions.

Factors that were considered during overall ranking of the derelict and ownerless mines included public safety, public health, environmental degradation and level of illegal mining (Table 4-2).

#### 4.4.1 Public safety.

Public safety is related to mine workings such as shafts, pits, adits and stopes. The risk evaluation of physical conditions of all mine features took into considerations the nature and size, conditions of the mine feature proximity to settlement and conflict to current and future land use. Guidelines for public safety hazard rating were created based on conditions that need to be considered to ensure public safety from derelict and ownerless mines (Table 4-3).

#### 4.4.2 Environmental impacts

Environmental contamination in derelict and ownerless mines is related to mine residues. Environmental degradation rating includes assessment of potential

contamination, nature and extent of contamination (Table 4-4). Environmental components investigated included soil, surface water, groundwater and air. Assessment process include observation of all evidence of stress in vegetation and aquatic life, surface staining of soil and presence precipitates, presence of salts on surface water, evidence of soil erosion in tailings and waste dump, evidence of oxidation and evidence of erosion by air.

Assessment details the possibilities of pollution to occur, the potential source of pollution, targeted receptor/s, the extent of the pollution and the sensitivity of the receptor/s. Site-specific conditions such as geology, topography and climatic conditions were considered during environmental degradation rating.

#### 4.4.3 Public health

The health impacts associated with derelict mines can be classed according to short-term and long-term effects. Short-term health effects are experienced almost within a short period of time to exposure to mine waste. Short-term health effects can be due to high degree of exposure to pollution. Long-term health effects recognised after a long period of time. Long-term health effects can be due to low degree of exposure to pollution (Table 4-5).

#### 4.4.4 Illegal mining

Illegal mining is common in historic sulphide metalliferous, gold, diamond and PGMs mines. Illegal mining hazard rating estimates the degree of illegal mining based on the number of illegal miners, different ethnic groups, the proximity of the mine to human settlement and the mining methods used (Table 4-6).

Rating of mine features on derelict and ownerless mines was preceded by amassing the derelict and ownerless mines into a prioritized list based on their urgency for rehabilitation. The overall ranking of each site was achieved through the combination

of public health, public safety, environmental risk and level of illegal mining. The overall ranking approach was used to combine these parameters to rank each site (Table 4-2).

**Table 4-2 Overall ranking table to guide the ranking of each derelict and ownerless mine**

CATEGORY	RATING				
	1-Very low	2-Low	3-Moderate	4-High	5-Very high
Public health					
Public safety					
Environmental degradation					
Level of illegal mining					
<b>Overall Ranking of the site</b>	<b>AVERAGE (Public health+Public safety+Environmental degradation+Level of illegal miningl )</b>				
Justification					

Prioritisation of the sites was influence by public safety and later the environment. Sites that are closer to communities are considered high priorities compared to sites that are far. The decision to priorities a site for public safety also further investigate the age of the people at proximity to the site and knowledge of the site and its risk. A site closer to school or pose a danger to children is considered a high priority compared to a site only accessed by older people with knowledge of the site. This flexibility approach reduces biasness in the prioritisation process and allows prudent order in rehabilitation.

**Table 4-3 Guidelines for Public Safety Hazard Rating (PSHR) (modified from Sares et al., 1998)**

<b>PSHR</b>	<b>Conditions</b>	<b>Proximity</b>	<b>State of Hazard</b>	<b>Type of Hazard</b>
5 VERY HIGH	• Open shafts	>50 Population	Present	Fatality likely or possible
	• deep pits with steep slopes			
	• Mine dumps with unstable slopes			
	• Underground subsidence > 10sq. M	Less 1km		
	• Blasting agents & chemicals.			
	• Old collapsing mine buildings			
• Evidence of blown dust.	Paved road to site			
4 HIGH	• open shafts with partial seal	0-50 population	Present	Fatality likely or possible
	• larger Pits with moderate slopes			
	• large mine dumps with instabilities			
	• Underground subsidence	Less 1km		
	• Blasting agents & chemicals present			
	• Old mine buildings with cracks			
	• Evidence of blown dust.	Gravel road to site		
3 MODERAT E	• open shaft fenced	Remote area	Probable hazard in the future	injury likely
	• deep open pits with gentle slopes			
	• Partial rehabilitated mine dumps			
	• Underground subsidence	Greater than 10km		
	• Minor evidence of subsidence			
	• Old mine buildings with cracks			
	• Evidence of blown dust.	Bush road to site		
2 LOW	• sealed Shaft	Remote area	Potential hazard in future	injury likely
	• shallow trenches and pits			
	• evidences of erosion in mine dumps			
	• no subsidence	Greater than 10km		
	• Blasting agents & chemicals.			
	• Old mine buildings			
	• Little evidence of blown dust.	4x4 access road/foot to site		
1 None	• sealed Shafts	Remote area	No hazard predicted	No injuries predicted
	• Minor diggings/gentle slope pit			
	• Vegetated mine dumps with gentle slopes			
	• No subsidence	No access		
	• Site is cleared.			
		Water or air access only		

**Table 4-4 Guidelines for Environmental Degradation Hazard Rating (EDHR) (modified from Sares et al., 1998)**

EDHR	Conditions	Scale
<b>5 VERY HIGH</b>	• Contamination off-site is severe.	Proven impacts over 10 km
	• High concentration of metals and salts (, XRF, ICP-MS)	
	• High concentration of Potential Harmful Elements (XRD, XRF, ICP-MS results)	
	• Evidence of stressed aquatic life in receiving stream.	
	• Mine discharge with low pH (<4).	
	• Mine discharge with extremely high conductivity (>1500 μS/cm).	
	• High volume of mine discharge to surrounding environment/ stream.	
	• Observable precipitates on mine site and surrounding environment.	
	• Very large sulphide rich mine dumps with evidence of severe erosion (XRF, XRD).	
<b>4 HIGH</b>	• Moderate contamination off-site.	Proven or potential impacts over between 1-10 km
	• Mine water with low pH (<5).	
	• Mine water with high conductivity (>1000 μS/cm).	
	• Moderate flows of mine discharge to relative to the receiving stream.	
	• Moderate concentration of metals and salts.	
	• Moderate to abundant precipitates at the mine and surrounding environment.	
	• Large sulphide-rich mine dumps with evidence of moderate erosion (XRF, XRD).	
	• Moderate concentration of Potential Harmful Elements (XRD, XRF, ICP-MS results).	
<b>3 MODERATE</b>	• Little contamination off-site/ pollution over a small area	Potential impacts between 100m-1km
	• Mine discharge with low pH (<5.5).	
	• Mine discharge with moderate conductivity (>600 μS/cm).	
	• Poor-quality water with no flow.	
	• Low concentration of metals and salts	
	• low concentration of Potential Harmful Elements (XRD, XRF, ICP-MS results)	
	• Minor observable precipitate on site.	
	• Very large dumps with no sulphides and little or no erosion.	
	• Small and moderate-sized sulphide-rich dumps or tailings piles with evidence of moderate erosion (XRF, XRD).	
<b>2 LOW</b>	• Mine discharge with slightly acidic pH (<6.5).	Potential impacts between 0-100m
	• No evidence of contamination	
	• Mine discharge with slightly elevated conductivity (>400 μS/cm).	
	• Low concentration of Potential Harmful Elements (XRD, XRF, ICP-MS results)	
	• Low concentration of metals and salts	
	• Mine discharge of moderate quality water	
	• No evidence of precipitate.	
	• Small to moderate-sized sulphide-rich dumps or tailings piles with little evidence of erosion (XRF, XRD).	
<b>1 NONE</b>	• No mine discharge.	No impact identified
	• Low concentration of metals and salts	
	• Mine discharge with high quality water (ICP-MS).	
	• Small dumps distant from surface water with little or no evidence of erosion and no sulphides.	

**Table 4-5 Guidelines for Public Health Hazard Rating (PHHR) (modified from Sares at al., 1998)**

<b>PHHR</b>	<b>Conditions</b>	<b>Proximity</b>	<b>Exposure</b>
<b>5 VERY HIGH</b>	• Exposed mine dumps	Less 1km	> 50 population
	• Evidence of windblown dust		
	• High concentration of Potential Harmful Elements(PHEs) (XRD, XRF)		
	• Evidence of stressed aquatic life in receiving stream.		
	• Mine discharge with low pH (<4).		
	• Extreme contamination off-site		
	• High volume of mine discharge to surrounding environment/ stream.		
	• Observable precipitates on mine site and surrounding environment.		
	• Very large dumps with evidence of severe erosion		
<b>4 HIGH</b>	• Moderate contamination off-site.	Less 1km	0-50 population
	• Mine water with low pH (<5).		
	• Mine water with high conductivity (>1000 µS/cm).		
	• Moderate flows of mine discharge		
	• Moderate concentration of metals and salts.		
	• Evidence of windblown dust		
	• Large dumps with moderate erosion		
	• Moderate concentration of PHEs (XRD, XRF).		
<b>3 MODERATE</b>	• Little contamination off-site/ pollution over a small area	Greater than 10km	Remote area access by bush road
	• Mine discharge with low pH (<5.5).		
	• Mine discharge with moderate conductivity (>600 µS/cm).		
	• Poor-quality water with no flow.		
	• Low concentration of metals and salts		
	• low concentration of Potential Harmful Elements (XRD, XRF)		
	• Minor observable precipitate on site.		
	• Very large dumps with little or no erosion.		
	• Moderate evidence of windblown dust		
<b>2 LOW</b>	• Mine discharge with slightly acidic pH (<6.5).	Greater than 20km	Remote area access by 4x4 / foot
	• No evidence of contamination		
	• Mine discharge with slightly elevated conductivity (>400 µS/cm).		
	• Low concentration of Potential Harmful Elements (XRD, XRF)		
	• Low concentration of metals and salts		
	• Mine discharge of moderate quality water		
	• Rehabilitated dumps.		
	• Small tailings piles with little evidence of erosion (XRF, XRD).		
<b>1 NONE</b>	• No mine discharge.	Greater than 50km area	Remote area access by water or air
	• Low concentration of metals and salts		
	• Mine discharge with high quality water (ICP-MS).		
	• Rehabilitated dumps no evidence of erosion and no sulphides.		

**Table 4-6 Guidelines for Illegal Mining Hazard Rating (IMHR) (Sares et al., 1998)**

<b>IMHR</b>	<b>Conditions</b>	<b>Proximity</b>	<b>Size of operation</b>
<b>5 VERY HIGH</b>	• Evidence of illegal underground and surface mining	< 1km	> 100 miners  3 or more ethnic groups  > 10 foreign nationals  Different generations
	• Use of mercury for processing		
	• Frequent cases of riots/Criminal acts onsite		
	• Illegal miner use of blasting agents.		
	• Recent cases of territorial battles		
	• Re-opened old workings		
	• Secondary ingress points		
• Armed illegal miners			
<b>4 HIGH</b>	• Evidence of illegal underground and surface mining	<5 km	<100 miners < 3 ethnic groups different generations < 10 foreign nationals
	• Use of mercury for processing		
	• Recent cases of riots/Criminal acts onsite		
	• Illegal miners work 2 or more shifts		
	• Evidence of tempering on sealed shafts		
	• Miners camp on site		
	• Armed illegal miners		
<b>3 MODERATE</b>	• Evidence of illegal surface mining	> 5 km	<50 miners < 2 ethnic groups  same age group No foreign nationals
	• Use of mercury for processing		
	• moderate cases of riots/Criminal acts onsite		
	• Illegal miner sieve material on the surface		
	• Sealed shaft not tempered with		
	• No cases of territorial battles		
<b>2 LOW</b>	• Evidence of illegal surface mining	> 20km	< 20 miners 1 ethnic group same age group
	• Use of mercury for processing		
	• No shafts on site		
<b>1=NONE</b>	• No evidence of illegal mining	> 50 km	Remote area access by water or air
	• Cleared site		

## 4.5 Reporting of results and interpretation

The following methods were used to report and interpret results.

### 4.5.1 Water quality data.

There were two sets of water quality data: On-site analyses (pH and EC) and laboratory analyses (Hydrogeochemical analyses). These sets of data were presented in a tabular format using excel sheets and compared to target water quality standards set out in the South Africa Water Quality Guideline for domestic use. Piper diagrams were used to plot the effluent. Scatter plot was used for the ABA results for each derelict mine.

### 4.5.2 XRF and XRD results

XRF and XRD data were reported in tables from excel tools providing information such as potential harmful elements and mineralogical composition. Word excel was used to plot box and whiskers diagrams to show the distribution of selected trace elements and major oxides in tailings dump and surrounding soil from the different derelict mines. The concentration of trace and major elements from each mine was used to conduct the Environmental Degradation Rating and were further compared to international guidelines for maximum allowable concentrations of metals in soils and sediments.

### 4.5.3 Paste pH

The paste pH results of tailings and waste rock samples from each site were reported as one graphical representation. These was done to compare the susceptibility of tailings material and waste rock dumps from each region to chemical weathering and the pH of the leachate produced thereafter. A neutral pH and above suggests the presence of reactive buffering minerals such as carbonates and that the materials can

be classed as alkaline producing. Materials with a paste pH below 7 were hypothesised as acid generating (Coasttech Research Inc., 1994).

#### 4.5.4 Batch leach test

The leach test data were presented in tabular format and interpreted in graphic representation using Excel tools. The leach test results from each region were compared against one another to identify the region which potentially leaches high concentrations of potential harmful elements.

#### 4.5.5 Acid base accounting

ABA results were presented on a tabular form and further expressed in graphical presentation. Word excel was used to plot the NP vs AP and paste pH vs NNP scatter plots. The NP vs AP scatter plots were used to the nature of sample for being either acid or alkaline generators. The paste pH vs NNP scatter plots were used to show the show the potential nature of samples to neutralise acid.

#### 4.5.6 Risk assessment

The main aim of risk assessment was to identify the “high” hazardous mines from the two gold fields based on their existing physical danger, potential environmental impacts and scale of illegal mining. The guidelines in table 4.2, 4.3, 4.4 and 4.5 were used in collecting data. The standardised guidelines have ratings assigned numerical values of 1,2,3,4 and 5 to the ratings of “none”, “low”, “moderate”, “high” and “very high” associated to the risks. No risk is assigned the numerical value 1, with 2 assigned to low risk, 3 is moderate, 4 is high and 5 assigned very high risk.

Standardised guidelines served as guiding principles for risk assessment describing all the conditions and observations of rating. The guidelines reduced biasness during

field assessment. Modified Risk Matrix method was used to determine the overall ranking of each site. The Risk method was modified to allow flexibility and sound justification by a field geologist. Since proximity is considered a major factor in the rating phase of mine features, likelihood was omitted in the Risk Matrix method. The overall ranking table was used to write all the collected data and the overall ranking.

## 5 RESULTS AND DISCUSSION

### 5.1 Field Observations

#### 5.1.1 Barberton Greenstone Belt

##### 5.1.1.1 Bonanza

Bonanza Gold Mine was one of the largest gold producers in the BGB. The mine operated as an underground mine in the valley of the Sheba Fault. The physiographic region of the area is characterised by undulating topography. The mine is located about 15 km from Barberton Town and 2 km from Sheba Mine. This derelict and ownerless mine is now surrounded by Sheba Community (Figure 5-1).

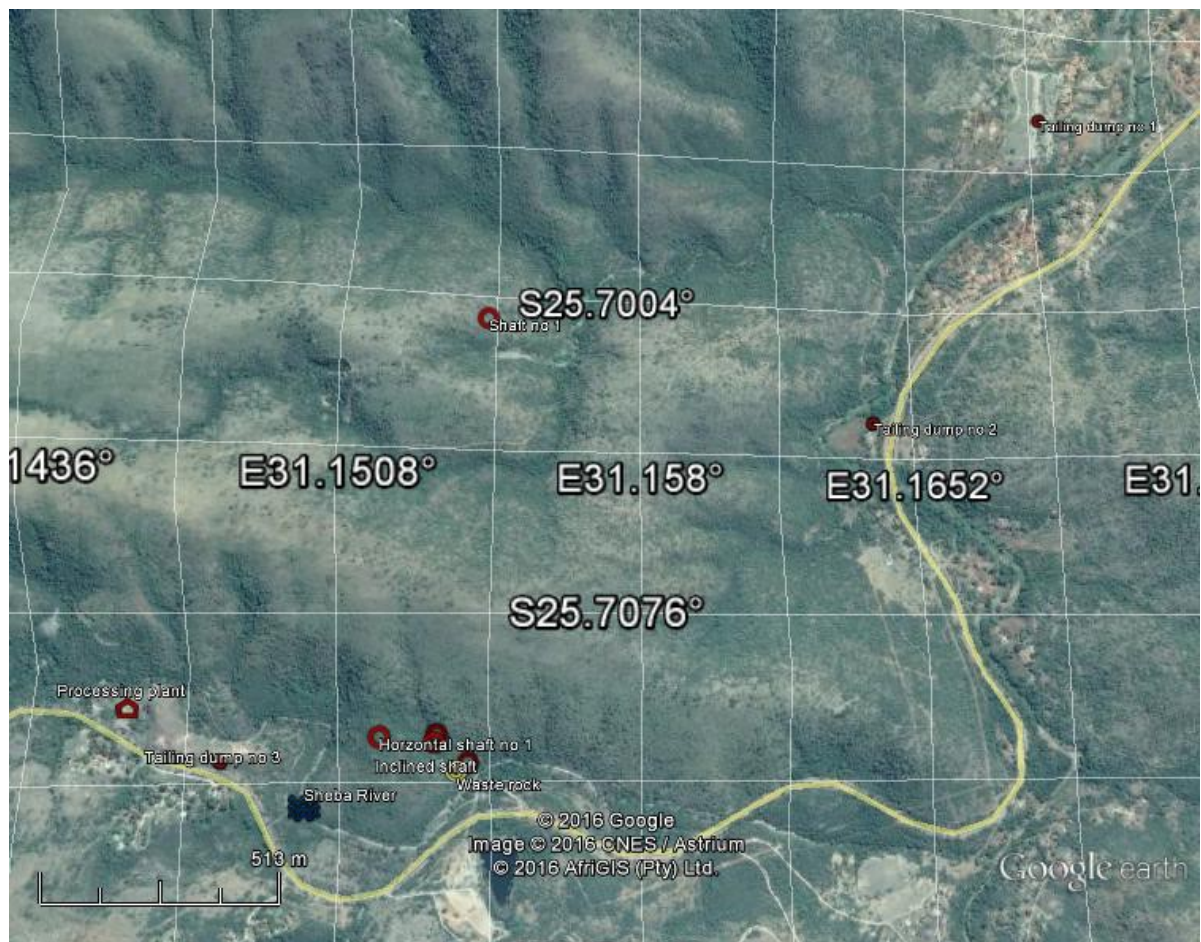


Figure 5-1 Image of Bonanza Gold Mine showing the main mine features

## I. Mine openings

There were 3 horizontal openings also observed within the mining area. These horizontal openings are used by livestock and other wild animals to shelter (Figure 5-2). An inclined shafts were discovered onsite obscured by shrubs and dense ground vegetation. These openings pose significant physical hazards to individuals that may get close to them. One cattle herder reported that several cases of livestock falling into these shafts were experienced. These open shafts are likely to be recharge points for rain water which may accumulate in the old mine workings.



a) Horizontal Shaft no 1.



b) Horizontal shaft no 2 close approximately 5 m from to Fig Tree River.



c) Horizontal shaft no 3



d) Inclined Shaft no 1.



e) Vertical Shaft no 2. approximately 20 m from horizontal shaft no 2

**Figure 5-2 Mine openings at Bonanza Gold Mine**

## II. Infrastructure

Mine infrastructure observed on site include old processing plant with steel structures (Figure 5-3a), dilapidated mine buildings (Figure 5-3b), steel structures from an old head gear (Figure 5-3c) and dilapidated power plant (Figure 5-3d). Parts of the steel structures had been scavenged by artisanal miners.



a) Derelict processing plant.



b) Derelict mine buildings.



c) Neglected steel structures.



d) Derelict power plant 20 m from the Sheba road.

**Figure 5-3 Old mine infrastructure at Bonanza Gold Mine**

### III. Tailings dumps

Three tailings dumps were observed at this site. Rehabilitation was done in one of the tailing dump which approximately 20 m from the Sheba community (Figure 5-4a). Erosion gullies were observed in the other two tailings dumps (Figure 5-4b & c). These the tailings dumps are approximately 50 m from the Sheba River and 10 m from households of the Sheba community (Figure 5-4b & c).



a) **Vegetated tailings dump surrounded by settlement.**

b) **Heavily eroded dump close to the processing plant.**



c) **Heavily eroded dump close to Fig Tree Greek River.**

**Figure 5-4 Tailings dump at Bonanza Gold Mine**

#### IV. Illegal mining

Members of the Sheba community practiced illegal mining at some stage for a very short period after the mine closed. Illegal miners used the old mining shafts to access the underground workings. Illegal mining in the area was halted due to the rising water level in the mine workings (Mineral Council of South Africa, 2018).

#### V. Geology

The geology of the area around Bonanza Gold Mine is characterised by the layers of shale, greywacke, sandstone (Figure 5-5a & b) and banded ferruginous shales (Figure 5-5c) of the Fig Tree Group. Thin quartz veins cross-cutting the sandstones of the Fig Tree Group were observed in some parts of the area (Figure 5-5a). The area is characterised by a series of faults which run from the south-west to north-east and includes the Sheba Fault.



a) Quartz vein cross-cutting the sandstones of the Fig Tree Group.



b) Contact between quartzite of the Moodies Group and sandstones of the Fig Tree Group.



c) Banded ferruginous shales of the Fig Tree Group along the Fig Tree Greek River.

**Figure 5-5 Typical geology at Bonanza Gold Mine**

## VI. Physiography and drainage

The Bonanza Gold mine is found along the Sheba Fault of Barberton Greenstone Belt. The area is generally characterized by steeply incised mountainous terrain. The altitude ranges from 400 to 1 050 m above mean sea level (Figure 5-6a). The mountains are characterized by patchy grasses and low growing shrubs. The area is drained by the perennial the Fig Tree Greek River (Figure 5-6b). The area receives an annual rainfall of approximately 670 mm and the local rivers flow strongly during summer.



a) Typical topography of the area.



b) Fig Tree Greek River.

### Figure 5-6 Physiography and drainage of Bonanza Gold Mine

#### 5.1.1.2 Golden Snake Mine

Golden Snake Gold Mine is in the western part of the BGB approximately 10 km from the Msauli Asbestos Mine and 20 km from Lukwatini Town. The mine is located within a fenced area preserved as pasture for livestock for local Ngoneni Community. The site is drained by the Nkomazi River. Mine features identified onsite include an old processing plant, waste rock dump and shafts (Figure 5-7).

##### I. Mining openings

Three shafts were identified onsite. Evidence of rehabilitation efforts in sealing the mine shaft were observed on site (Figure 5-8). These efforts have been rendered futile by artisanal miners as some of the steel have been stolen leaving the shafts partially open (Figure 5-8a & b). Fresh footprints going into the horizontal shaft suggesting the presence of illegal artisans during the ground truthing were observed (Figure 5-8c). The openings in the shafts are likely to be recharge points for rain water which may accumulate in the old mine workings.

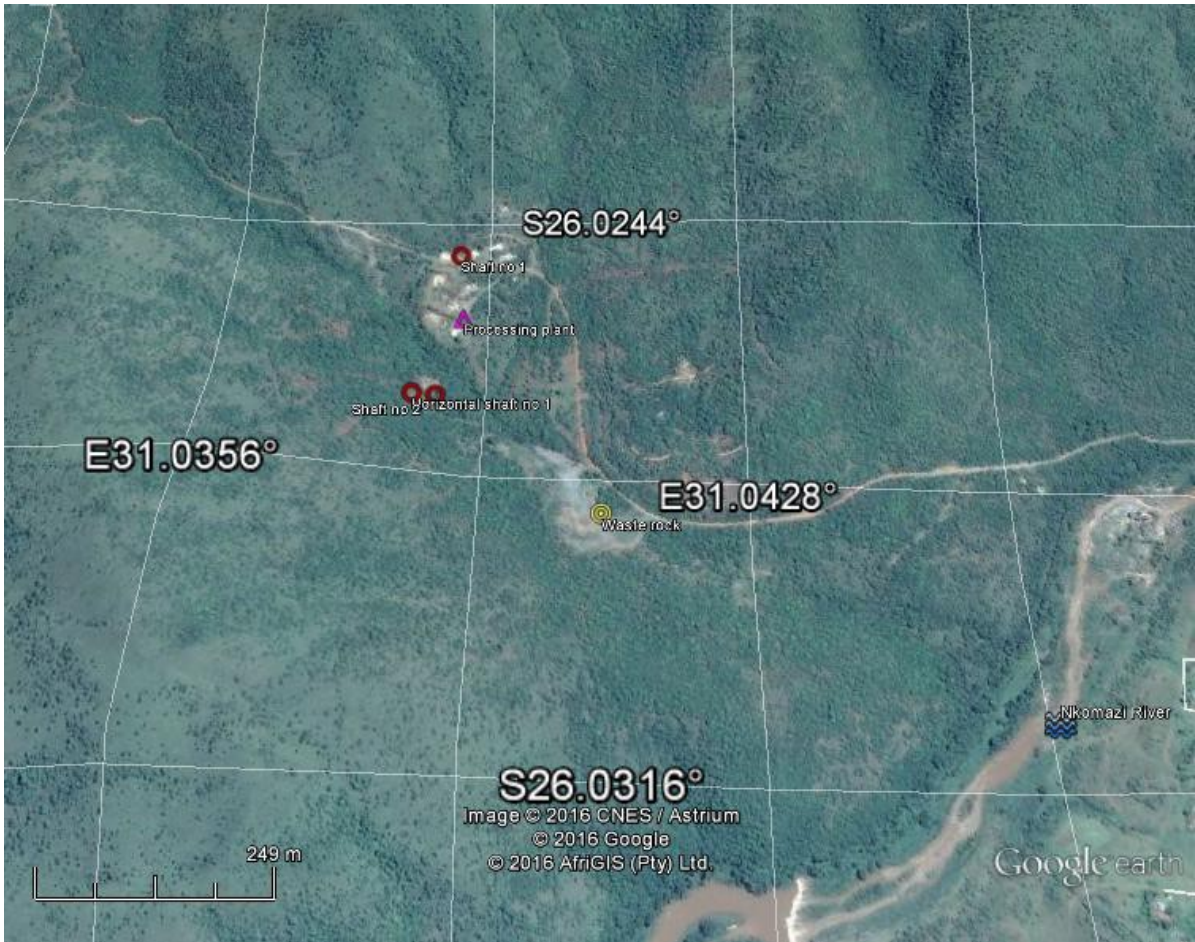


Figure 5-7 Image of Golden Snake Mine showing the main features



a) Vertical shaft.



b) Vertical shaft with water.



c) Horizontal shaft.

**Figure 5-8 Mine openings at Golden Snake Gold Mine**

## II. Infrastructure

Mine infrastructure observed on site includes dilapidated mine buildings (Figure 5-9a) and dilapidated processing plant (Figure 5-9b). Steel material from the mine infrastructure has been scavenged by illegal miners.



a) Dilapidated mine building.



b) Dilapidated processing plant.

**Figure 5-9 Old infrastructure at Golden Snake Gold Mine**

### III. Waste rock dumps

A waste rock dump of 6 400 m<sup>2</sup> with a height of approximately 5 m was observed on site. The waste rock dump is partially covered by vegetation which stabilises the slopes (Figure 5-10a). The waste rock dump is approximately 500 m from the Nkomazi River. The local community collect the waste rock material for construction purpose (Figure 5-10b).



a) Stable slope of the waste rock dump.

b) Evidence of collection of waste rock dump material for construction purpose.

**Figure 5-10 Waste rock dumps at Golden Snake Gold Mine**

### IV. Illegal mining

Evidence of illegal mining was observed on site. According to the Ngoneni Tribal Authority, illegal miners originate from Barberton Town. The illegal miners are known to scavenge steel material and collecting gold bearing material. According to the Ngoneni Authority, these illegal miners are well equipped with drilling machines, water pumps and lamination. The illegal miners are known to use the horizontal shaft to access the old mine workings.

### V. Geology

The mining area is characterised by dense vegetation of shrubs and grasses (Figure 5-11a) and thick layers of top soil (Figure 5-11b). The Golden Snake Mine is within the Kromberg Formation of the BGB which is largely composed of massive and

pillowed basalts, komatites, mafic lapilli tuff, lapilli stones, and banded chert (Lowe and Byerly, 1999).



a) Densely vegetated mining area.



b) Thick soil profile around the mine site.

**Figure 5-11 General physiography of Golden Snake Gold Mine**

## VI. Physiography and drainage

The Golden Snake mining area is drained by the Komati River Catchment with main streams including Komati River and other periodic tributaries (Figure 5-12a). The area receives summer rainfall with average of 600 mm and the local rivers flows strongly during the rainy seasons. Geomorphology of the area is characterized by undulating mountainous terrain (Figure 5-12b), with altitude ranging between 750 to 1 050 m above mean sea level. The mountains are densely vegetated with thick soil cover and no outcrops were observed (Figure 5-12b).



a) Komati River approximately 500 m from Golden Snake Mine.



b) Typical geomorphology of the Golden Snake mining area.

**Figure 5-12 Drainage and typical geomorphology of Golden Snake Gold Mine**

## 5.1.2 Transvaal Drakensberg Gold Field

### 5.1.2.1 Nestor gold mine

Nestor Gold Mine is located within a Sappie Plantation approximately 10 km north of the Sabie Town and 2 km from Simile Village. Observable mine feature on site include waste rock dump, shafts, tailings dump, processing plant and dilapidated houses (Figure 5-13).

#### I. Mining openings

The mining area is characterised by dense vegetation. Shafts identified on site are covered by grass and shrubs and may poses a risk of sudden fall to people wandering around the site (Figure 5-14a, b & c). These shafts can pose immediate danger to people walking around the site without knowledge of these shafts. Of the three shafts, is one horizontal shaft which is partially sealed by waste material as a remedial measure to curb illegal mining in the area (Figure 5-14b). Evidence of illegal mining was observed on site. Illegal miners use the vertical shafts to acquire access into the old mine workings. The open shafts are likely to be recharge points for rain water which may accumulate in the old mine workings.



**Figure 5-13 Image of Nestor Gold Mine showing the main mine features**



**a) Vertical shaft covered by trees.**



**b) Horizontal shaft partially sealed with waste material.**



c) Vertical shaft covered by trees.

**Figure 5-14 Mine openings at Nestor Gold Mine**

## II. Infrastructure

Mine infrastructure observed on site includes old processing plant (Figure 5-15a) and dilapidated houses (Figure 5-15a). All steel material have been scavenged by illegal artisans, this include corrugated roof, windows, door frames, and old mills from the processing plant.



a) Derelict processing plant.



b) Derelict mine building.

**Figure 5-15 Old infrastructure at Nestor Gold Mine**

### III. Tailings dump

A tailing dump of approximately 38 000 m<sup>2</sup> was identified on site (Figure 5-16). The height of the tailing dump varies between 10- 25 m. The tailings dump is characterised by steeper slopes as a result erosion of the tailings material is high (Figure 5-16a). Erosion gullies are visible at along the facies of the tailings dump (Figure 5-16b).



a) General profile of the tailing dump.



b) Erosion gullies on the sides of the tailing dump.

**Figure 5-16 Tailings dump at Nestor Gold Mine**

### IV. Illegal mining

According to the Simile Tribal Authority, illegal mining in the area has gain momentum over the past years. Local members from Simile community and foreigners collect gold bearing material and steel material from the old mine working. These illegal miners gain access through the open shafts. According to the Simile Tribal Authority, the Sabie South African Police Services are working together with the Transvaal Mining Group to curb illegal mining in the area.

### V. Geology

The area is characterised thick layers of top soil with dense vegetation and no outcrops were identified on site. Nestor Gold Mine is located within the Chunniespoort Group of the Transvaal Supergroup which overlies the Black Reef Formation (Wilson and Anhaeusser, 1998).

## VI. Physiography and drainage

Nestor mining area is drained by the Sabie River Catchment with main streams including Sabie River and Klein Sabie River (Figure 5-17a). The geomorphology of the area characterized undulating mountains with altitude range between 1 050 m at the mountain peak and 900 m at the foothill. The mountains are characterized by dense vegetation and thick soil cover with few rock outcrops (Figure 5-17b).



a) Tributary to Sabie River draining the Nestor mining area.



b) General geomorphology of the Nestor mining area.

**Figure 5-17 Drainage and typical geomorphology of Nestor Gold Mine**

### 5.1.2.2 Bourke's Luck Gold Mine

Bourke's Luck Gold Mine is located within the Blyde River Canyon Nature Reserve which is a protected area (Figure 5-18). Bourke's Luck Mine operated as an underground mine along the valley of the Blyde River. The area is characterised by undulating slopes covered by dense vegetation. Mine features identified onsite include shafts, tailings dump, old processing plant and dilapidated mine buildings.

#### I. Mining openings

Bourke's Luck Gold Mine was a typical large scale mine. The mine operated as an underground mine using vertical shafts to access the deeper ore (Figure 5-19a & b). Efforts to seal these shafts were rendered futile by the illegal miners (Figure 5-19b).



**Figure 5-18 Image of Bourke's Luck Gold Mine showing the main mine features**



**a) Vertical opening.**



**b) Partially sealed vertical shaft.**

**Figure 5-19 Mine openings at Bourke's Luck Gold Mine**

## II. Infrastructure

Mine infrastructure observed on site includes an old processing plant (Figure 5-20a) and steel structures (Figure 5-20b).



a) Derelict processing plant.



b) Steel structure used for conveyor system.

**Figure 5-20 Old infrastructure at Bourke's Luck Gold Mine**

## III. Waste rock and tailings dumps

Mine residues from the old mine had been exposed to erosion (Figure 5-21a & b). Measurable gullies were observed on tailings dump suggesting that tailings material had been subjected to erosion from time to time (Figure 5-21b). The tailing dumps are located approximately 20 m from Blyde River (Figure 5-21a).



a) Waste rock dump and tailings dump.



b) General profile of the tailing dump.

**Figure 5-21 Tailings dump at Bourke's Luck Gold Mine**

#### IV. Illegal mining

According to the Blyde River Nature Reserve game rangers, Illegal mining is largely practised in the area. The practise involves local people from the surrounding communities and foreigners largely from Zimbabwe. According to the game rangers most of the illegal miners previously worked in the mine and seek financial refuge in mining illegally. Evidence of illegal mining was observed on site during the field survey (Figure 5-22a). The illegal miners are well equipped with water pump engines for processing the fine material from the old processing plant and the old mine workings (Figure 5-22a & b). Evidence of pollution due to illegal mining was observed on site (Figure 5-22c).

According to the game ranger cases of crimes associated with the illegal miners at the Blyde River Canyon Nature Reserve were reported. Illegal miners on this site are known to be armed and dangerous and threaten residence of the Blyde River Canyon Nature Reserve.



a) Water pump used by illegal miners.



b) Bags with gold bearing material collected from old mine working.



c) Stagnant water accumulating during processing of gold.

**Figure 5-22 Evidence of illegal mining at Bourke's Luck Gold Mine**

## V. Geology

The geology of the area varies between sandstone and mud rocks of the Black Reef Formation. Layers of shales, dolomites and quartzites were observed in some parts of the area. The exposed rock outcrops have been oxidised and altered and this is also evident in waste rock material (Figure 5-23 a & b). Series of faults were observed in quartzite rocks at the foot of tailings dump and around the mining area (Figure 5-23c).



a) Evidence of oxidised waste rock material.



b) Typical rock type at the foot of the tailing dump.



c) Typical faults within the mining area.

**Figure 5-23 Typical geology at Bourke's Luck Gold Mine**

## VI. Physiography and drainage

Bourke's Luck Gold Mine is found at the northern part of the TDGF. The area is drained by the Olifants River Catchment with main streams including Blyde River and Treur River (Figure 5-24a). The geomorphology of the area is generally characterized by steeply incised mountainous terrain with prominent peaks between 1 090 and 1 150 meters above mean sea level (Figure 5-24b).



a) Blyde River.



b) A section of the area showing its typical geomorphology of the Bourke's Luck mining area.

**Figure 5-24 Drainage and typical geomorphology at Bourke's Luck Gold Mine**

## 5.2 Results of geochemical analyses

Table 5-1 show the sample collected. Geochemical results of all the collected samples from the four derelict mining sites were tabulated (Table 5-2 to 5-7) and some presented in graphs, scatter and piper diagram (Figure 5-24 to 5-36)

**Table 5-1 Samples collected**

Gold Field	Mine area	Sample Id	
Barbeton Greenston Belt	Bonanza Mine	BRW	River water sample
		BSS	Soil sample
		BW	Waste rock sample
		BTD	Tailings dump sample
	Golden Snake Mine	GSMW	Mine water sample
		GSRW	River water sample
		GSW	Waste rock sample
		GSSS	Soil sample
Transvaal Drakesberg Gold Field	Nestor Mine	NMW	Mine water sample
		NRW	River water sample
		NW	Waste rock sample
		NTD	Tailings dump sample
	Bourke's Luck Mine	BLMW	Mine water sample
		BLRW	River water sample
		BLW	Waste rock sample
		BLTD	Tailings dump sample

### 5.2.1 Onsite analyses

#### 5.2.1.1 Water quality data

##### *pH*

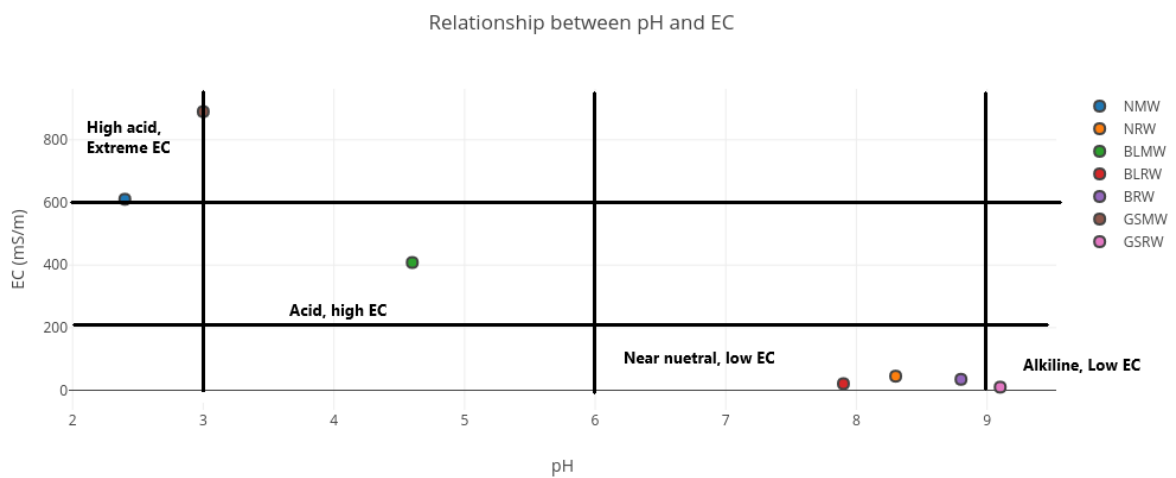
The pH and EC relationship and variation of all water samples is presented in Fig-5a. Water samples from Nestor Mine (NMW) recorded the lowest pH of 2.4, with Golden Snake Mine (GSMW) recording 3 and Bouke's Luck Mine (BLMW) recorded

4.6 (Figure 5-25). An improvement of the water quality in terms of pH was observed in the water samples collected in the nearby streams (Figure 5-25).

The Klein Sabie which drains the Nestor Mine (NRW) have pH values of >8.0. This is the same with Blyde River which drains the Bourke’s Luck Mine (BLRW) which have pH values > 7.0 of and Komati River draining the Golden Snake Mine (GSRW) have a pH values > 9.0. No water samples were collected from Bonanza Mine as mine feature were dry during the field work. Water sample from Fig Tree Greek River which drains the Bonanza Mine (BRW) have pH values > 8.0

### Conductivity

Electrical conductivity measure the amount of effluents in the water to define its level of pollution. The concentration of EC of GSMW was found to be 890 *mS/m* and this value was exceeding the recommended 70 *mS/m* by a far-flung margin (DWAF, 1996). NMW and BLMW have a relatively high EC of 610 *mS/m* and 408 *mS/m* respectively. An improvement in water quality was also observed in the river draining these derelict and ownerless mines.



**Figure 5-25** Scatter plot showing the relationship between pH and EC

## *Sulphates*

Water samples collected from Nestor Mine (NMW), Bourke's Luck Mine (BLMW) and Golden Snake Mine (GSMW) contained high concentration of  $\text{SO}_4^{2-}$  exceeding the maximum allowable concentration of 200 mg/l as set by the Department of Water and Sanitation (Table 5-2). No water could be collected from the Bonanza mine workings. High values of  $\text{SO}_4^{2-}$  were further articulated in the rivers draining the derelict mines from the TGDF. Water collected from the Klein Sabie (NRW) which drains the Nestor mining area contained 265 mg/l. Blyde River draining the Bourke's Luck Mine (BLRW) contained 340 mg/l of  $\text{SO}_4^{2-}$ .

Samples from the Komati River drained by Golden Snake Mine (GSRW) and Sheba River drained by Bonanza Mine (BRW) contained acceptable concentration of 5 mg/l respectively. Of all the salts analysed  $\text{SO}_4^{2-}$  was the only salt of concern from all the collected water samples. Analysis using the Piper diagram indicates that the water collected from derelict mines of the TDGF has high abundance of calcium sulphate compared to the BGB mines (Figure 5-25). Water samples from the derelict mines of the BGB contain high sodium chloride (Figure 5-26).

## *Iron*

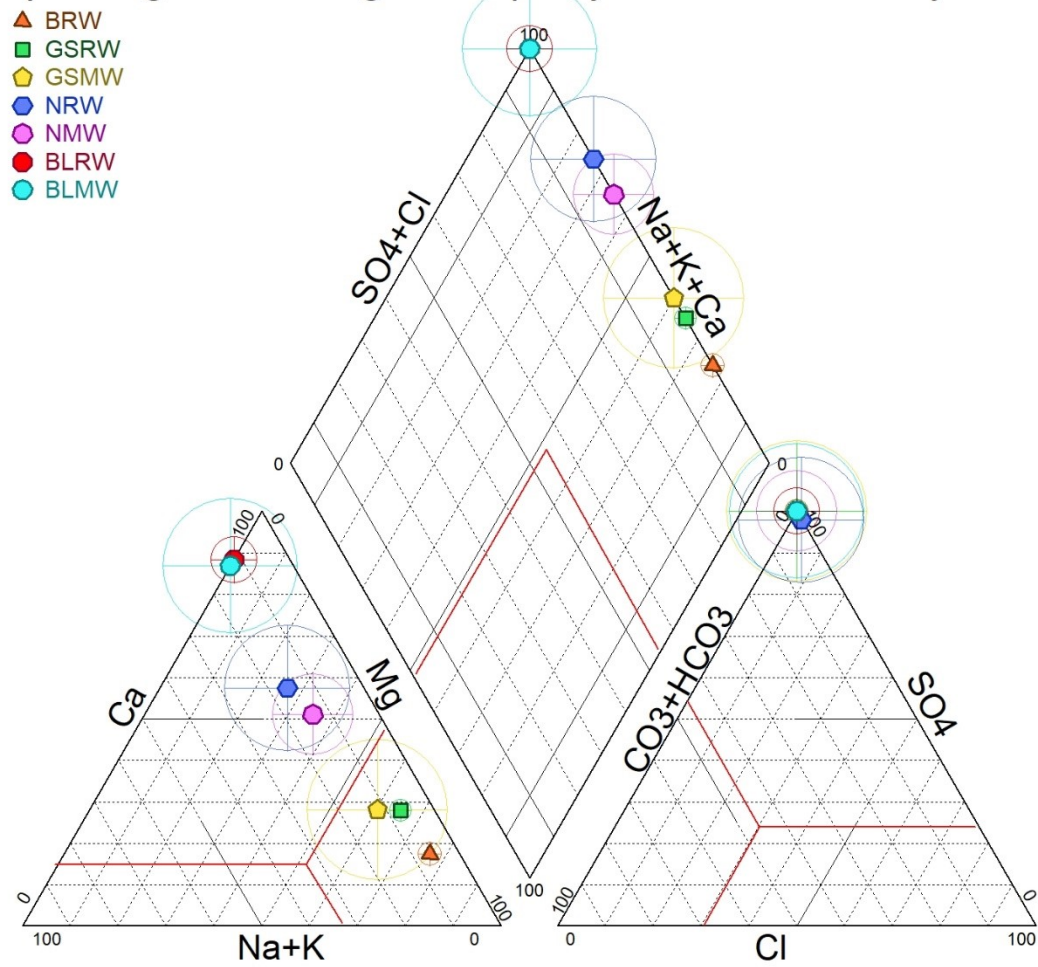
GSMW contained Fe contents as high as 486.61 mg/l. This value was paralleled to the lowest pH and high EC recorded in the for the GSMW. NMW and BLMW also have high values of Fe of 354.8 mg/l and 290.1 mg/l respectively. A red hydroxide precipitate, formed during the oxidation of Fe (II) to Fe (III), and the subsequent precipitation of Fe(III) (oxy)hydroxide minerals, was observed in the Bourke's Luck Mine along the Blyde River and along the foot of the tailings dump. Tailings dump at Nestor Mine have been heavily oxidised and the red (oxy) hydroxide was observable along the horizon of the tailings dump.

Dominant cations in water samples from the mines of the TDGF are; Ca and Mg (Figure 5-25).  $\text{SO}_4^{2-}$  is a major anion in waters from the derelict and ownerless mines of the TDGF. Derelict mines from the BGB have high concentration of K (cation) and  $\text{SO}_4$  (anion) (Figure 5-26).

#### *Other metals*

BLMW contained high concentrations of Fe (290.1 mg/l) and As (1.26 mg/l) which were above the allowed concentration in domestic water (DWAF, 1996) (Table 5-2). GSMW contained high content of Al (32.91 mg/l), Mn (23.19 mg/l), Zn (11.25 mg/l), Cu (6.75 mg/l) and As (2.76 mg/l). (NMW) contained high concentration Al (43.61mg/l) which exceeds the maximum concentration permissible in domestic water (Table 5-2). The concentrations of other metals and metalloids (Al, As, Cu, Mn, Cr and Zn) were observed to be elevated at within the mining areas and were relatively low in the nearby rivers.

Piper diagram showing water quality data from the study areas



7

Figure 5-26 Piper diagram showing water quality data from the study area

Table 5-2 Water quality data from the derelict and ownerless mines and adjacent rivers

Sample ID	Field parameter		Major anions				Major cations				Trace elements						
	pH	EC	Cl	NO <sub>3</sub>	PO <sub>4</sub>	SO <sub>4</sub>	Ca	Mg	K	Na	As	Fe	Al	Cr	Mn	Cu	Zn
NMW	2.4	610	47	5	0.23	3000	0.3	0.2	1.2	ND	1.57	354.8	43.61	0.15	1.1	1.23	0.58
NRW	8.3	45	ND	ND	201	265	ND	0.02	1.03	ND	<1.2	15	0.001	ND	ND	ND	ND
BLMW	4.6	408	0.18	1.1	0.05	3420.3	24.4	0.92	0.09	0.4	1.26	290.1	0.25	<0.005	<0.01	<0.02	<0.3
BLRW	7.9	21	ND	ND	ND	340	1.2	0.03	ND	ND	1.2	47	0.21	ND	ND	ND	ND
BRW	8.8	35	ND	ND	ND	5	13.2	3.5	3.5	0.98	ND	12	ND	0.12	2.98	1.3	ND
GSMW	3	890	12.6	ND	11.3	3020	15.6	7.34	2.4	1.2	2.76	486.61	32.91	0.79	23.19	6.75	11.25
GSRW	9.1	10	ND	ND	ND	5	1.3	1.5	0.4	0.023	ND	16	ND	ND	ND	ND	ND
SA TWQR for domestic use	6-9*	0-70*	0-100	0-6	N/A	0-200	N/A	N/A	N/A	N/A	0.01*	0.1*	0.15*	0.05*	0.05*	0-1*	3*

ND- below detection limit; N/A- not detected

## 5.2.1.2 Concentration of major and traces elements

### I. Soil samples data

Soil samples were only analysed for trace elements. Most trace elements are the common cause of health problems when exposed to them (Coelho *et al.*, 2007).

#### *Arsenic*

As concentrations levels were high in all collected samples from the different mining sites exceeding the maximum allowable concentration (MAC) of metal content in soils as set by the South African National Standards. Bonanza mining area (BSS) have the highest recorded As values ranging from the a minimum of 100 ppm to the highest 400 ppm (Figure 5-27).

Nestor mining area (NSS) also have As concentration with a range between 80 ppm and 104 ppm (Figure 5-27). As values in soils from Golden Snake Mine (GSSS) (5.4-13.4 ppm) and Bourke's Luck Mine (BLSS) (10.24-22.90 ppm) were also found to exceed the maximum allowable limit of 2 ppm of As in soils as specified by the South African National Standards. Concentrations of metals were recorded high close to mine area and values decrease further from the mining area (Figure 5-28)

#### *Lead (Pb)*

Soils from the Nestor mining area (NSS) exceeded the MAC for Pb lead by approximately 80 ppm. Pb values at Nestor mining area (NSS) range between 70 ppm and 120 ppm. Values of Pb exceeding MAC levels were also obtained in soils from Bonanza gold mining area (BSS). Pb was found to be at acceptable levels at Golden Snake Mine (GSSS) with values between 1.5-3.4 ppm (Figure 5-29). Pb was not detected in soil samples from Bourke's Luck mining area (BLSS).

### *Other PHEs*

The Cr contents in soils from Bonanza mining area (BSS) exceeded the permissible concentration of 80 ppm in soil according to the South African National Standards. Soils from Golden Snake mining area (GSSS) showed non-compliance in Cr content in all samples. Bonanza soils were also found to contain above MAC levels of nickel. Vanadium content in soils from Bonanza mining area (BSS) was also high with concentration varying between (5.76-55.2 ppm) compared to the other areas (Table 5-3).

Cu content in soils collected from Bonanza mining area and Golden Snake mining area were significant (10.4-108.72 ppm). Soils from Nestor mining area also have significant amount of Cu (5.6-17.1 ppm) in surrounding soils. Cu was not detected from Bourke's Luck mining area. Co contents were within MAC levels in all soils tested.

Distribution of arsenic in soil around the derelict and ownerless mining areas

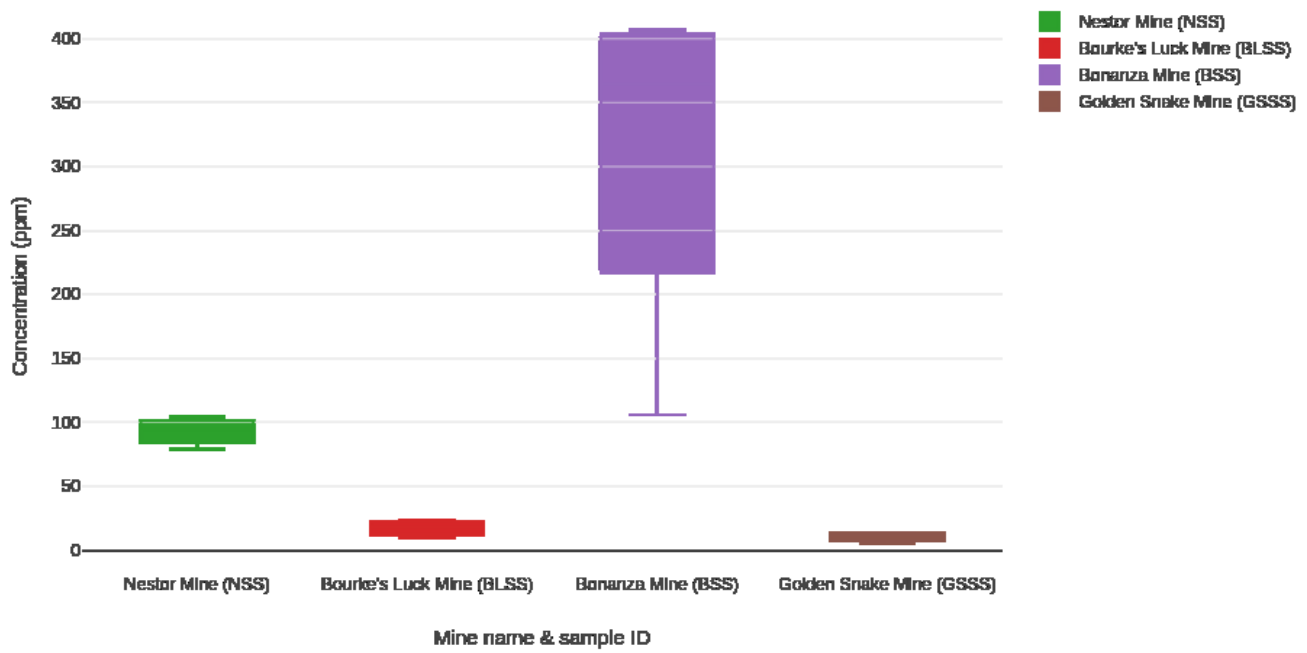


Figure 5-27 Box and Whisker showing the data distributions of arsenic in soils around the derelict and ownerless mines

Distribution of lead from Nestor mining area to the surrounding soil

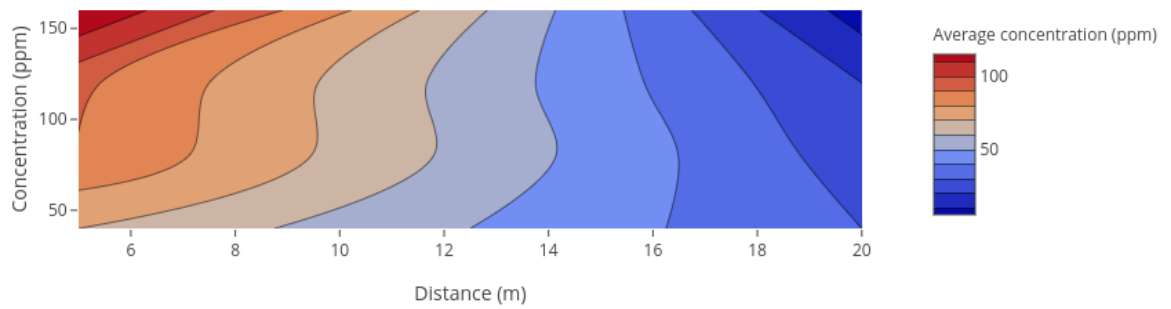
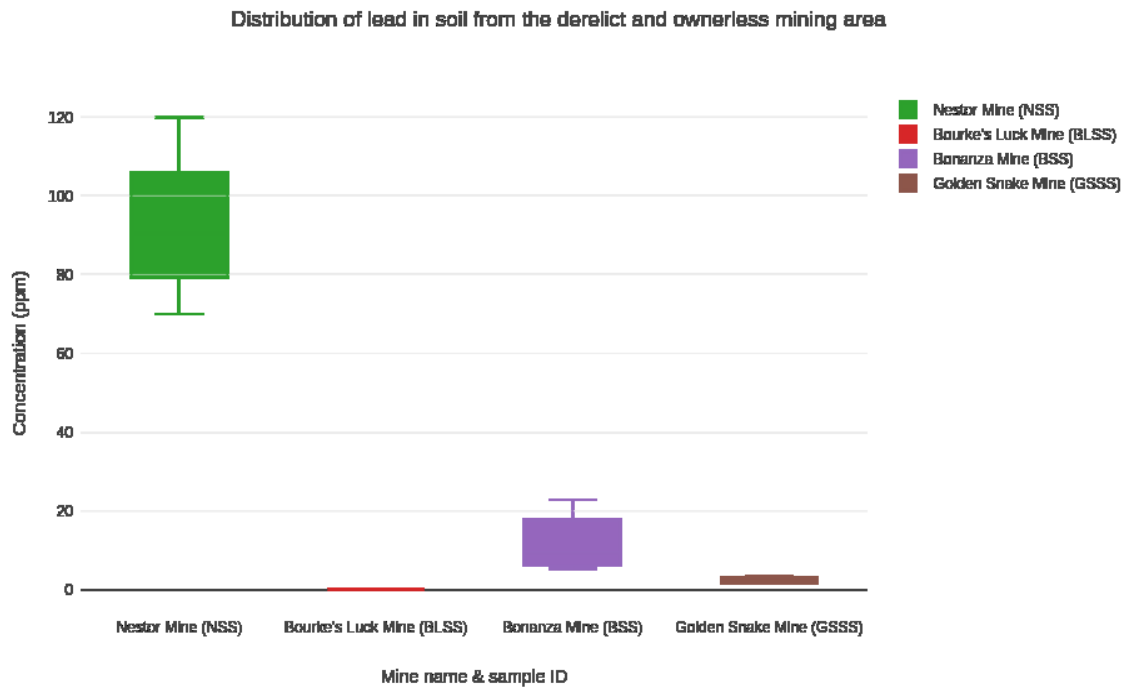


Figure 5-28 Distribution of Pb from Nestor mining area to the surrounding soils



**Figure 5-29** Box and Whisker diagram showing the data distributions of Pb in soils from the derelict and ownerless mines

**Table 5-3 Showing concentration of selected metals (ppm) in soil samples around the derelict and ownerless mines**

<b>Sample ID</b>	<b>As</b>	<b>Cr</b>	<b>Cu</b>	<b>Co</b>	<b>Pb</b>	<b>Ni</b>	<b>V</b>
<b>NSSO1</b>	89	13.1	17.1	ND	92.1	ND	ND
<b>NSSO2</b>	104	29.01	5.6	ND	120	ND	ND
<b>BLSSO1</b>	10.24	ND	ND	ND	ND	ND	ND
<b>BLSSO2</b>	22.02	5.1	ND	ND	ND	ND	ND
<b>BSSO1</b>	400.2	310.88	108.72	11.9	12.5	107	55.2
<b>BSSO2</b>	407	300.11	129.1	16.22	22.8	201.66	44.21
<b>BSSO3</b>	329.1	208.1	171.1	10.22	6.8	92	12.1
<b>BSSO4</b>	106	55.2	13.33	12.1	5.4	33	10.67
<b>BSSO5</b>	675.8	208.1	10.4	5.3	15.6	43.8	5.76
<b>BSSO6</b>	107	5.7	13.4	ND	ND	ND	ND
<b>GSSSO1</b>	5.4	120	12.8	11.01	1.54	22.1	1.23
<b>GSSSO2</b>	12.88	95.8	11.5	12.98	2.6	12.8	3.1
<b>WRC guidelines</b>	2	80	6.6	20	6.6	50	NS

*ND- not detected*

*NS-Not stipulated in the guidelines*

*WRC- Water Research Commission of South Africa*

## 5.2.2 Laboratory analyses

### 1.1.1.1 Concentration levels of selected traces and major elements

A total of 16 solid samples were sent to the Council for Geoscience laboratory for analyses of the concentration of trace and major elements.

#### *Arsenic (As)*

Highest values of As were recorded for samples from Bonanza Mine (BTD) (Figure 5-30). The values of As from Bonanza Mine varies between 560 and 1840 ppm. Bourke's Luck Mine samples (BLTD) also recorded high values of As with a range between 420 and 622 ppm (Figure 5-30). Tailings samples from Nestor Mine (NTD) also recorded high values of As which exceed the 2 ppm set by the South African

National Standards for agricultural soils. NTD recorded values between 220 and 582 ppm (Figure 5-30). High As values from the tailings dumps from these derelict mines are also articulated in the surrounding soils and water bodies. These values As exceed MAC of 2 ppm.

High values of As were also recorded in waste rock samples from the derelict and ownerless mines of the BGB. Waste rock samples from the Golden Snake Mine (GSW) recorded a high 260 ppm of As with Bonanza mine (BW) recording 230 ppm (Table 5-4). The lowest As values recorded were 5 ppm in waste rock samples from Nestor Mine(NW) and Bourke's Luck Mine (BLW) respectively. All collected tailings samples from all the derelict and ownerless mines have As values far-flung from the soil standards set by the South African National Standards.

#### *Lead (Pb)*

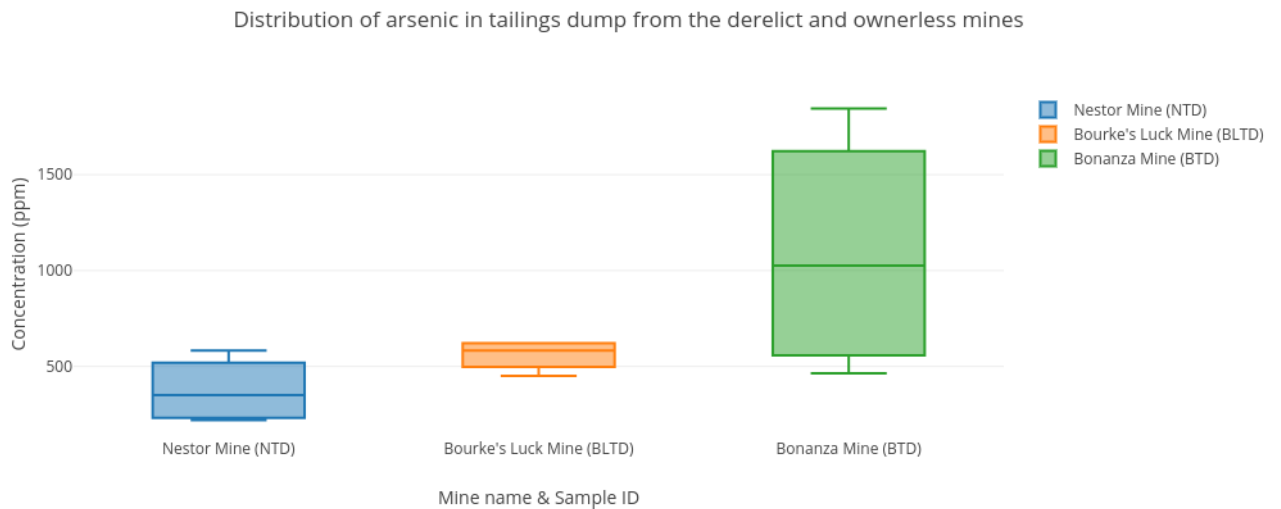
The range concentration of Pb in tailings dump from Nestor Mine (NW) of 98-288 ppm exceeds the MAC of 6.6 ppm set by the South African National Standards (Figure 5-31). It is noteworthy that these high values of Pb from Nestor Mine tailings are articulated to the surrounding soils. Tailings samples from Bourke's Luck and Bonanza also recorded higher ranges of Pb, 24-56 ppm and 30-55 ppm respectively (Figure 5-31).

#### *Other trace elements*

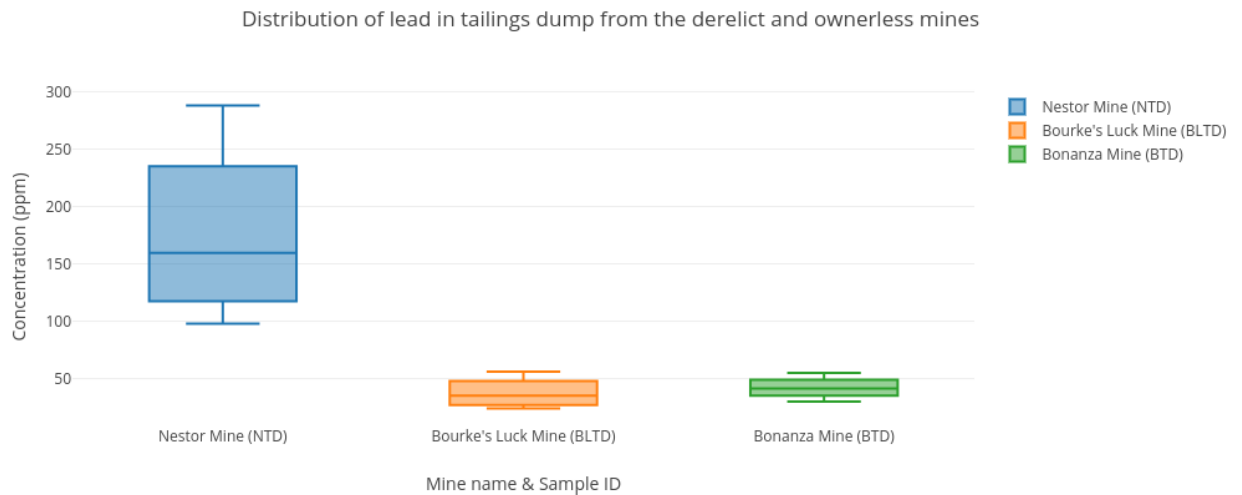
The concentrations of other metals (Cr, Cu, Co, Ni, V and Zn) were also observed to be elevated at in the tailings dump from the derelict and ownerless mines. Nestor Mine (MW) have Cr concentrations 290-1031 ppm. These values are about ten times above the regulated limits of Cr in South Africa. High contents of Cr and Cu were also detected from the waste rock sample collected from Golden snake gold mine (Table

5-4). Zn was only found to be high showing non-compliance with respect to the South African Standard of MAC, in tailings dumps from Bonanza gold mine.

Predominant oxides in the Nestor gold mine tailings dumps samples are  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{Al}_2\text{O}_3$  (Table 5-5). These major oxides varies from depth to depth:  $\text{SiO}_2$  varies between 77.34-89.99 wt. % with an average wt. % of 75;  $\text{Fe}_2\text{O}_3$  varies from 2.28–11.27 wt.%, and  $\text{Al}_2\text{O}_3$  varies from 1.89-6.28 wt. %. The waste rock sample collected from Nestor contained approximately 90 wt. % of  $\text{SiO}_2$  (Table 5-5). Bourke's Luck gold mine tailings samples are dominated by  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{CaO}$ , and  $\text{MgO}$ .  $\text{SiO}_2$  varies from 55.97-81.02 wt. %;  $\text{Al}_2\text{O}_3$  varies from 6.89-11.27 wt. %;  $\text{Fe}_2\text{O}_3$  varies from 4.81-16.43 wt. %;  $\text{CaO}$  varies from 1.01-5.02 wt. % and  $\text{MgO}$  varies from 0.09-3.44 wt. % (Table 5-5).



**Figure 5-30** Box and Whisker diagram showing the distribution of As in tailings dump from the derelict and ownerless mines



**Figure 5-31** Box and Whisker diagram showing the distribution of Pb in tailings dump from the derelict and ownerless mines

**Table 5-4** Showing concentration of selected metals (ppm) in waste rock and tailings dumps from the derelict and ownerless mines

Sample ID	As	Cr	Cu	Co	Pb	Ni	V	Zn
<b>NTD1</b>	220	71	33	1.7	288	11	20	8.6
<b>NTD2</b>	245	45	40	10	137	29	27	30
<b>NTD3</b>	455	67	99	15	182	19	40	23
<b>NTD4</b>	582	120	120	45	98	24	99	42
<b>NW</b>	52	81	7.7	4.8	<2	25	14	<3
<b>BLTD1</b>	545	136	15	30	24	68	250	18
<b>BLTD2</b>	620	68	56	150	40	73	77	17
<b>BLTD3</b>	622	150	85	210	30	221	69	34
<b>BLTD4</b>	420	130	177	170	56	73	188	41
<b>BLW</b>	5	23	<2	<1	<2	<2	<3	<3
<b>BTD1</b>	1845	1031	40	15	55	354	112	107
<b>BTD2</b>	650	980.00	23	150	43	230	184	68
<b>BTD3</b>	1400	913.00	98	180	30	185	104	58
<b>BTD4</b>	564	293.00	232	230	40	161	105	24
<b>BW</b>	230	320.00	21	80	26	81	90	31
<b>GSW</b>	260	1302.00	35	45	22	73	57	53
<b>WRC guidelines</b>	2	80	6.6	20	6.6	50	NS	46.5

Predominant oxides in the Bonanza gold mine tailings dumps samples are SiO<sub>2</sub>, MgO, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, CaO and K<sub>2</sub>O. SiO<sub>2</sub> varies from 59.03-71.65 wt. %; MgO varies

from 3.00-12.00 wt. %, Fe<sub>2</sub>O<sub>3</sub> varies from 3.87-10.45 wt. %; Al<sub>2</sub>O<sub>3</sub> varies from 3.65-10.4 wt. %; CaO varies from 2.89-5.28 wt. % and K<sub>2</sub>O varies from 1.66-3.12 wt. %. Waste rock sample from Bonanza is dominated by SiO<sub>2</sub>, MgO, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub> and CaO. Waste rock sample from Golden snake contains high content of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, MgO, CaO and Fe<sub>2</sub>O<sub>3</sub> (Table 5-5).

**Table 5-5 Concentration of selected major elements (wt %) of waste rock and tailings dump from the derelict and ownerless mines**

Sample ID	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MnO	MgO	CaO	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	Cr <sub>2</sub> O <sub>3</sub>
NTD1	89.89	0.17	3.20	2.82	0.006	0.02	0.43	0.89	0.031	0.013
NTD2	78.41	0.64	6.28	6.74	0.030	1.64	0.65	1.88	0.017	0.070
NTD3	80.21	0.34	4.67	5.30	0.040	0.14	2.08	1.65	0.050	0.014
NTD4	77.34	0.17	1.89	11.27	0.230	0.80	0.13	0.33	0.060	0.060
NW	90.96	0.07	2.90	3.18	0.104	<0.01	0.02	0.81	0.033	0.013
BLTD1	55.97	2.41	8.64	16.43	<0.001	0.09	1.01	2.75	0.051	0.023
BLTD2	61.99	0.56	11.27	4.81	0.034	0.25	5.02	1.36	0.050	0.010
BLTD3	74.44	1.89	7.82	6.01	0.250	3.44	2.30	1.87	0.040	0.050
BLTD4	81.02	0.45	6.89	8.50	0.110	2.78	4.45	2.44	0.060	0.010
BLW	74.71	<0.01	0.86	0.53	0.086	5.08	7.23	0.07	0.013	0.007
BTD1	71.65	0.43	3.65	10.45	0.130	3.00	4.00	2.31	0.03	0.05
BTD2	66.06	0.4	9.66	3.87	0.130	4.84	3.48	1.78	0.08	0.11
BTD3	60.96	10.4	10.4	4.87	0.170	12.00	4.19	1.66	0.06	0.10
BTD4	59.03	10.4	10.4	8.00	0.140	11.85	2.89	2.10	0.04	0.21
BW	69.34	0.63	7.6	6.45	0.013	14.80	5.28	3.12	0.05	0.15
GSW	60.82	0.12	9.45	2.56	0.08	5.50	5.21	2.20	0.07	0.23

#### 1.1.1.2 Mineralogical composition of tailings dump samples from the derelict and ownerless mines

The primary aim of determining the mineralogy of the tailings was to identify minerals associated with PHEs. Tailings dumps are characterised of two varieties of minerals. The primary minerals which were deposited during the formation of the rock, or ore and secondary minerals which refer to those that were formed during- or by alteration, precipitation, or dissolution of primary minerals.

### *Pyrite*

Pyrite values were found to be high in tailings and waste rock samples from Nestor Mine (NTD) with values ranging between 2.9-3.1 wt % (Table 5-6). These values are enough to trigger the formation of acid mine drainage in the presence of oxygen and water. Low values of pyrite were recorded in tailings samples from Bourke's Luck Mine (BLTD), Bonanza Mine (BTD) and Golden Snake Mine (GSM).

### *Other minerals*

Tailings dumps sample from Bourke's Luck Mine have high values of dolomite, mica, and plagioclase. These minerals are considered as buffer minerals for acid rock formation. Secondary minerals discovered are gypsum and goethite (Table 5-6). BTD also have high content of buffer minerals in the form of magnesite, dolomite and calcite. The major iron minerals in the Bonanza tailings samples are in the form of haematite.

**Table 5-6 Mineralogical composition (wt %) of tailings dump samples from the derelict and ownerless mines**

Sample ID	Quartz	Mica	Gypsum	Plagioclase	Amphibole	Talc	Kaolinite	Dolomite	Jarosite	Goethite	Haematite	Pyrite	Magnesite	Calcite
NTD1	70.21	11.3	1.9	3.5	ND	ND	2.11	ND	4.1	ND	ND	03.5	ND	ND
NTD2	68.99	9.02	2.1	3.11	ND	ND	<1	ND	<2	ND	ND	<3	ND	ND
NTD3	74.2	10.19	0.9	4.2	ND	ND	1.84	ND	2.03	ND	ND	2.89	ND	ND
NTD4	63.08	12.4	0.01	3.22	ND	ND	1.90	ND	1.10	ND	ND	3.1	ND	ND
BLTD1	58.14	12.02	8.99	3.00	ND	ND	1.11	23.78	ND	3.69	ND	ND	1.2	ND
BLTD2	52.3	11.98	6.09	2.13	ND	ND	0.09	19.84	ND	2.84	ND	0.03	0.89	ND
BLTD3	51.43	10.87	7.33	3.10	ND	ND	1.66	23.70	ND	3.12	ND	ND	0.88	ND
BLTD4	55.53	11.78	5.99	2.97	ND	ND	1.33	18.93	ND	3.11	ND	0.02	0.2	ND
BTD1	45.1	0.12	3.12	2.16	09.22	30.12	10.89	10.1	ND	ND	03.12	ND	12.1	3.91
BTD2	51.02	0.01	2.10	1.78	7.84	20.16	11.20	9.2	ND	ND	02.13	0.01	10.2	2.19
BTD3	52.1	ND	1.40	2.12	6.21	15.78	8.9	8.88	ND	ND	3.10	ND	11.01	2.10
BTD4	49.98	ND	1.20	1.12	5.23	19.01	09.2	9.08	ND	ND	2.10	ND	10.76	2.11

ND- not detected

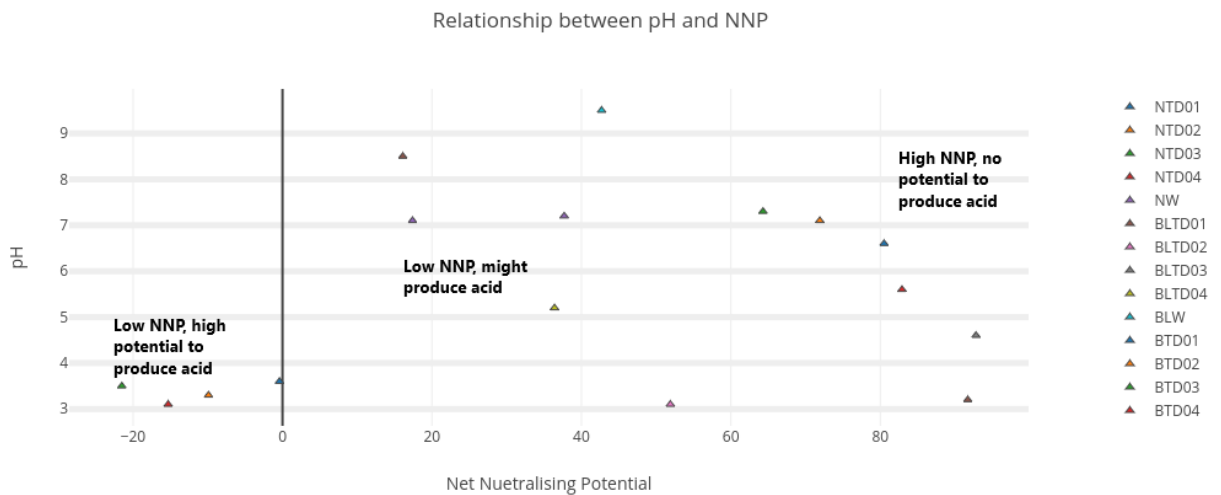
### 5.2.2.1 Acid base accounting

Table 5-7 shows the ABA results for all collected tailings dumps and waste rock samples from the study areas. Nestor Mine tailings samples have the potential to generate acid (Figure 5-32). All Nestor Mine tailings samples are characterised by high AP than NP ( $NNP=NP-AP < 0$ ), and their net potential ratio is less than 1 (Figure 5-33). The AP ranges from 16.3 kg  $CaCO_3$ /ton to 46.9 kg  $CaCO_3$ /ton, whereas NP ranges from 15.9 kg  $CaCO_3$ /ton to 31.6 kg  $CaCO_3$ /ton. Samples are characterised by low pH values and sulphur content which ranges between 0.52-1.5 %. Waste rock samples from Nestor Mine have  $NNP > 0$  and  $NPR < 1$ , therefore are likely to produce an alkaline drainage (Figure 5-33).

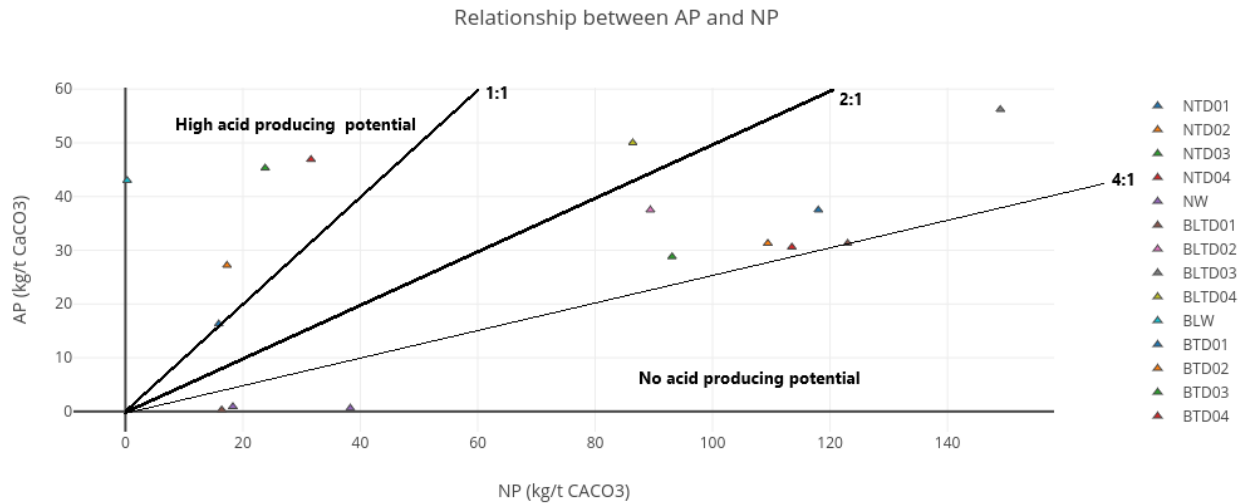
Tailings samples from Bourke's Luck Mine are characterised by high NP than AP ( $NNP=NP-AP > 0$ ), and their net potential ratio is greater than 2 ( $NPR > 2$ ) except for BLTD4 which has a NPR of 1.73 suggesting that it is likely to generate acid (Figure 5-33). The AP ranges from 31.3 kg  $CaCO_3$ /ton to 56.2 kg  $CaCO_3$ /ton, whereas NP

ranges from 86.4 kg CaCO<sub>3</sub>/ton to 149 kg CaCO<sub>3</sub>/ton. Samples have paste pH values which ranges from 3.1-5.2 (Figure 5-32). Samples contain high S content which ranges from 1-1.8 %. Waste rock samples from Bourke's Luck Mine have NNP <0 and NPR >2, therefore are likely to produce acid drainage (Figure 5-33).

Tailings samples from the Bonanza Mine are characterised by high NP than AP (NNP=NP-AP >0), and their net potential ratio is greater than 2 (NPR>2) (Figure 5-33). The AP of these samples ranges from 28.8 kg CaCO<sub>3</sub>/ton to 31.3 kg CaCO<sub>3</sub>/ton, whereas NP ranges from 93.1 kg CaCO<sub>3</sub>/ton to 113.5 kg CaCO<sub>3</sub>/ton. Samples from Bonanza Mine are characterised paste pH which ranges from 5.6-7.3 (Table 5-7).



**Figure 5-32 Scatter graph showing the relationship between pH and NNP of waste rock and tailings dump from the derelict and ownerless mines**



**Figure 5-33 Scatter graph showing the relationship between AP and NP of waste rock and tailings dump from the derelict and ownerless mines**

**Table 5-7 Acid-base accounting results of waste rock and tailings dump samples from the derelict and ownerless mines**

Sample Id	Paste pH	Fizz Test	% Reactive S	NP kg/t CaCO <sub>3</sub>	AP kg/t CaCO <sub>3</sub>	Net NP (NP-AP)	NPR (NP/AP)	Interpretation
NTD1	3.6	None	0.52	15.9	16.3	<0	0.98	Acid generating
NTD2	3.3	None	0.87	17.3	27.2	<0	0.63	Acid generating
NTD3	3.5	None	1.45	23.8	45.3	<0	0.53	Acid generating
NTD4	3.1	None	1.5	31.6	46.9	<0	0.67	Acid generating
NW	7.1	None	0.03	18.3	0.9	17.4	20.33	Acid neutralizing
BLTD1	3.2	Moderate	1	123	31.3	91.7	3.93	Acid neutralizing
BLTD2	3.1	Moderate	1.2	89.4	37.5	51.9	2.38	Acid neutralizing
BLTD3	4.6	Strong	1.8	149	56.2	92.8	2.65	Acid neutralizing
BLTD4	5.2	Moderate	1.6	86.4	50	36.4	1.73	Acid neutralizing
BLW	9.5	Weak	0.01	43	0.3	42.7	143.33	Acid neutralizing
BTD1	6.6	Moderate	1.2	118	37.5	80.5	3.15	Acid neutralizing
BTD2	7.1	Moderate	1	109.4	31.3	71.9	3.5	Acid neutralizing
BTD3	7.3	Moderate	0.92	93.1	28.8	64.3	3.23	Acid neutralizing
BTD4	5.6	Moderate	0.98	113.5	30.6	82.9	3.71	Acid neutralizing
BW	7.2	Weak	0.02	38.3	0.6	37.7	63.83	Acid neutralizing
GSW	8.5	Weak	0.01	16.4	0.3	16.1	54.67	Acid neutralizing

### 5.3 Risk assessment

The method for rating the identified hazards as described previously is presented here using modifications to the guidelines by Sares *et al.*, (1998) to achieve the aim of the study.

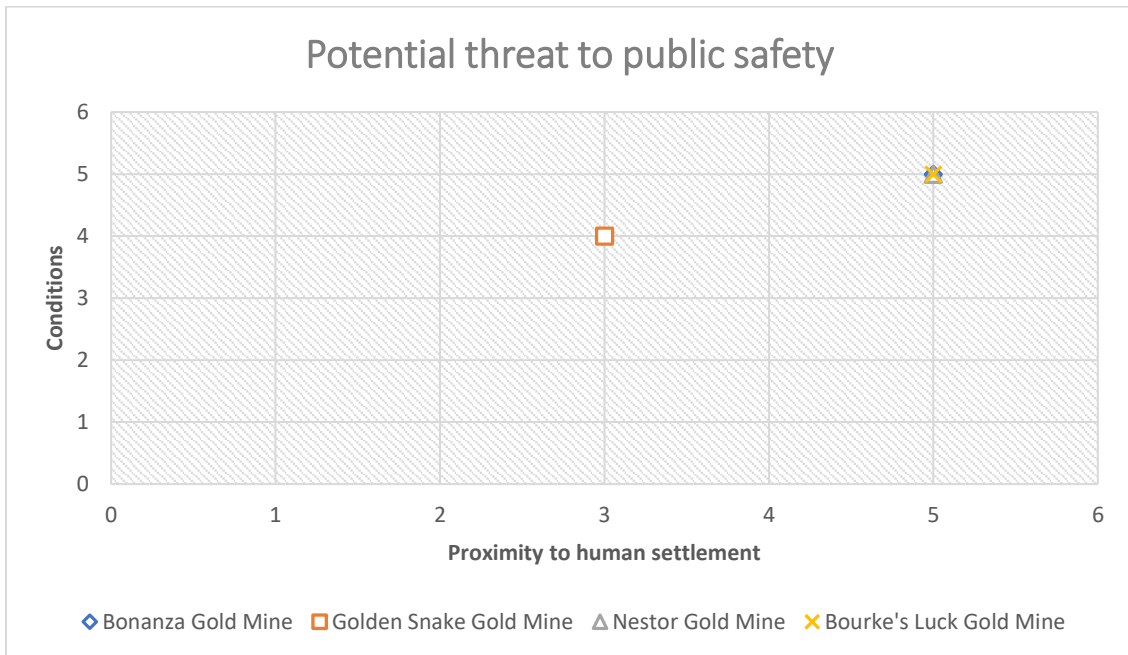
#### 5.3.1 Public safety

The existing conditions at Bonanza mine is of high risk a far as human and animal safety is concern. Bonanza mine is located very close to human settlement and children frequent the mine site on regular basis. Cattle headers also visit the site for greener pastures for their stock and for hunting. The presence of open vertical shafts some in shrubby environments poses a great risk of sudden-fall-in when walking around the site unaware. These existing conditions and proximity to settlement were rated very high risk (Figure 5-34).

Nestor mine also resemble same conditions existing at Bonanza mine. However, Nestor mine is further away from the settlement compared to Bonanza. Nestor mine is frequented by illegal miners and wood collectors who are aware of the existing shafts. These conditions and proximity to settlement were rated very high risk (Figure 5-34). However, justification was made that the conditions are well known to the local dwellers who frequent the area.

The Vertical shafts at Golden Snake were sealed during the field visit. Open horizontal shaft poses less risk of sudden-fall-in when compared to vertical shafts. The site is in a fenced area and only frequented by cattle headers and wood collectors. These conditions were rated high and proximity to settlement was rated moderate (Figure 5-34).

The open shafts at Bourke’s Luck pose less risk to human and animal safety when compared to all the visited sites. The shafts are horizontal and the mine site is not easily accessible. The area is not frequented by local people, only the game rangers with knowledge of the site conditions. There are existing conditions that can pose physical harm on site, hence the conditions and proximity were rated very high (Figure 5-34).



**Figure 5-34 Scatter graph showing the potential threat to public safety of derelict and ownerless mines**

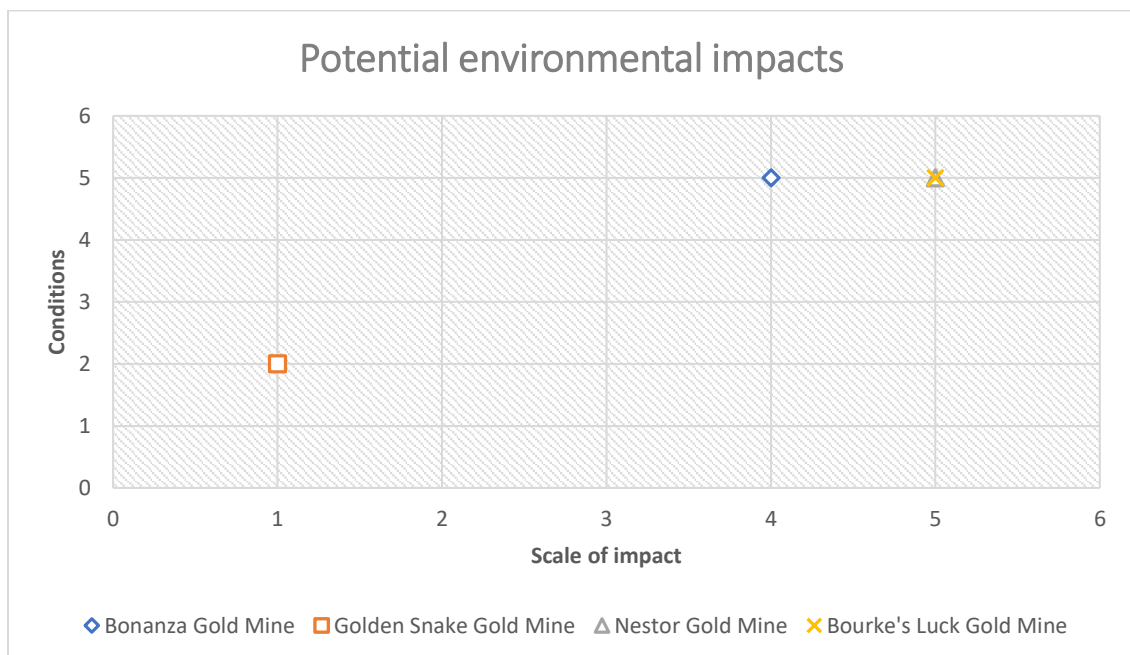
### 5.3.2 Environmental impacts

The major environmental concern associated with derelict mines from Transvaal Drakensberg gold field is water contamination. Tailings dumps from Bourke’s Luck mine contain high concentration of PHEs which are likely to contaminate Blyde River and surrounding environment. ABA tests suggest that waste materials from Bourke’s Luck are likely to generate alkaline drainage due to the presence of buffer minerals. However, PHEs such as Al, Zn, Ca, Mn, Mg, As, Fe and Pb are likely to be leached from this tailings dumps. Illegal miners present on site further pollute water during the

processing of gold bearing material. The conditions and scale of contamination were rated very high risk (Figure 5-35).

Tailings dumps from Nestor mine are considered a very high risk to the environment due to presence of acid generating substances with a range of 30 kg/t CaCo<sub>3</sub> (Figure 5-35). These tailings dumps also constitute high concentration of Ca, Mg, Pb, Fe and Mn and these PHEs are likely leached to deeper environments. Golden Snake mine waste rocks material consist of minerals which carry less potential to cause environmental damage. Acid mine drainage is not anticipated in the waste material from the Barberton Greenstone Belt. These conditions at Golden Snake mine were rated low and scale of environmental impact rated very low (Figure 5-35).

Conditions at Bonanza mine were rated very high and scale of impact were rated high (Figure 5-35). Evidence of erosion of the tailings material were noted and the geochemical analyses suggest the presence of PHEs. The tailings materials are characterised by buffer minerals and hence the scale of impact was rated high compared to the very high rating given to Bourke's Luck and Nestor mine.



**Figure 5-35 Scatter graph showing the potential environmental impact of the derelict and ownerless mines**

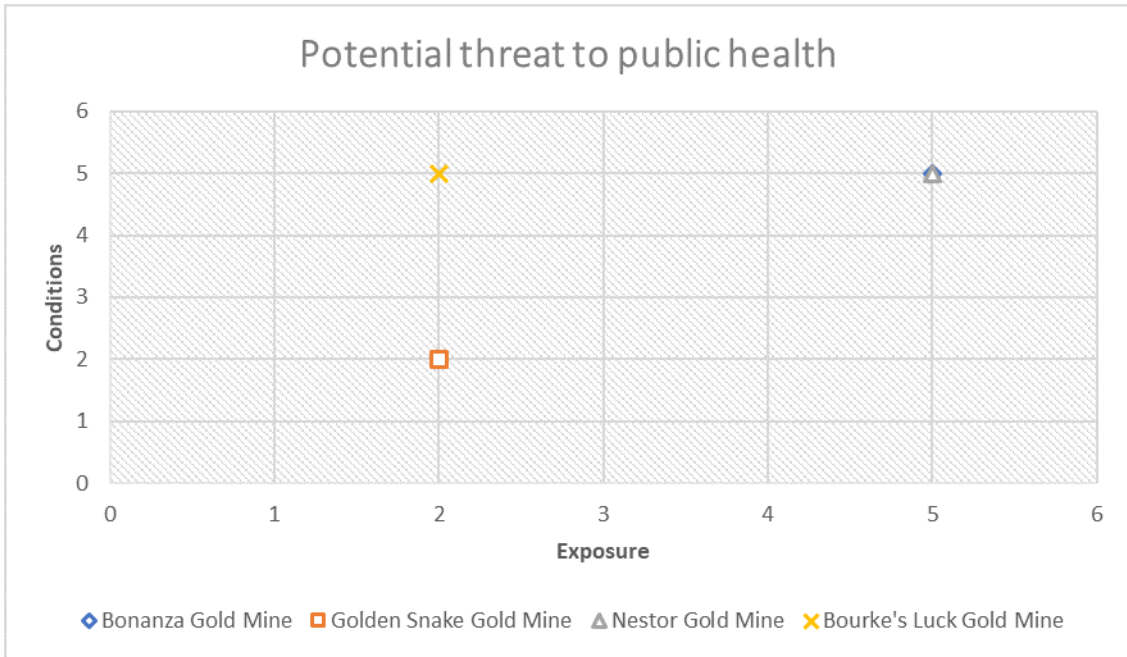
### 5.3.3 Public health

Derelict mines from the Barberton Greenstone Belt are considered an environmental threat and poses health and safety risks. The tailing dump at Bonanza gold mine can be considered a health hazard to the Sheba community. Some households are built on top of the eroded tailings dump and ingestion of tailings materials is high probably through inhalation of dust and direct ingestion of soils especially by children. Soils around the area contains high concentration of PHEs such as As and Pb (Table 5-3).

Contaminated soils are likely to cause skin related diseases and abdominal pain when ingested. Pb poisoning and arsenicosis amongst children are likely at Sheba community due to high concentration of both As and Pb in soils. These conditions and risk of exposure were rated very high (Figure 5-36).

Nestor mine also present a very high risk of exposure to the PHEs present in the tailings material. The proximity to human settlement also justifies the very high rating (Figure 5-36). Conditions at Bourke's Luck mine present a very high threat to human health. The mine is in a valley and not frequented by people, hence the risk of exposure was rated moderate (Figure 5-36).

Golden Snake mine present low threat to human frequenting the site. The risk of exposure to PHEs from the waste rocks material is very low (Figure 5-36)

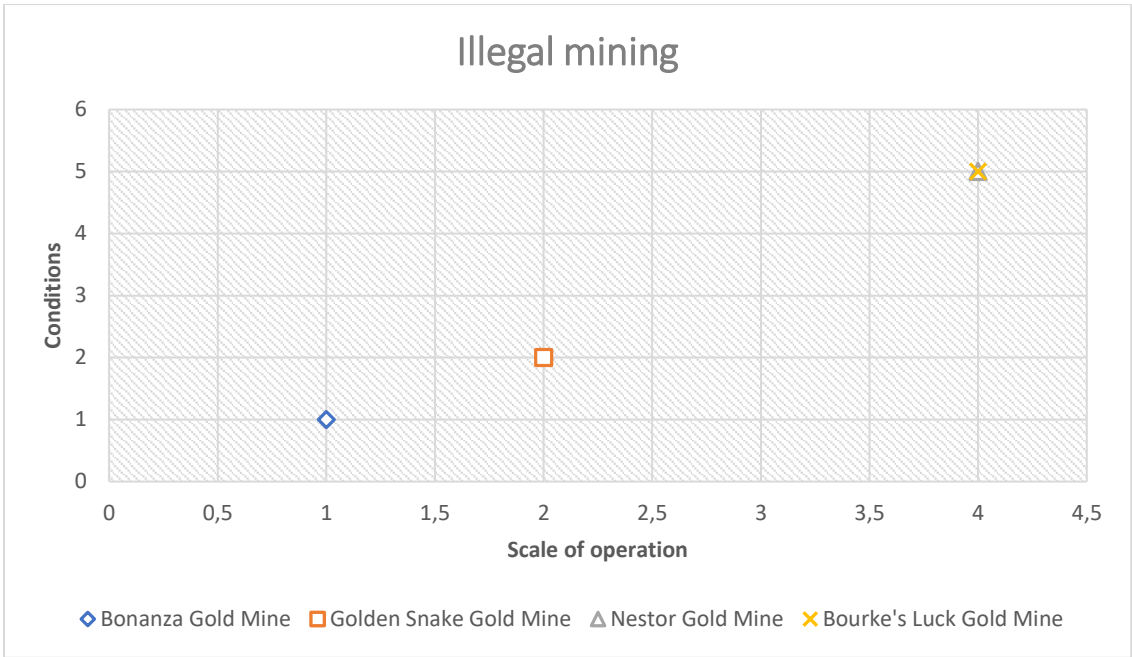


**Figure 5-36 Scatter graph showing the potential impact to public health of the derelict and ownerless mines**

#### 5.3.4 Illegal mining

Illegal mining was observed to be very high in the Transvaal Drakensberg gold field region at both Bourke’s Luck gold mine and Nestor gold mine (Figure 5-37). Illegal miners from this region acquire gold bearing material from underground and in old processing plants. The adequate water supply in the Transvaal Drakensberg area allows illegal miners to make use of sluice boxes and panning to process gold bearing material around mining areas. The scale of the operations is high as the mine attracts over 100 illegal miners. Gun wars are common in the area due to misunderstandings over territory amongst different ethnical origins.

Illegal mining in the Barberton Greenstone Belt area saw a decline due to issues of stability of the old workings. No evidence of illegal mining was observed at Bonanza mine (Figure 5-37). Golden Snake mine is vandalised for the scrap metals but no evidence of illegal mining was observed hence it was rated low (Figure 5-37)



**Figure 5-37 Scatter graph showing the extent of illegal mining in the derelict and ownerless mines**

## 6 CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

6.1.1 The comparison of environmental and physical risks posed between the derelict and ownerless mines of the Barberton Greenstone Belt and Transvaal Drakensberg gold field.

**Table 6-1 Summary of identified mine features from each derelict and ownerless mine**

Mine feature	Barberton Greenstone Belt		Transvaal Drakensbeg gold field	
	Bonanza	Golden Snake	Bourke's Luck	Nestor
<i>shaft</i>	5 shafts	3 open shafts	2 open shafts	3 shafts
<i>tailings dump</i>	3 tailing dumps		1 tailingdump	1 tailing dump
<i>waste rock</i>	1 waste rock dump	2 waste rock dum[ps	1 waste rock dump	1 waste rock dump
<i>processing plant</i>	1 huge plant	1 small plant	1 processing plant	1 small plant
<i>buldings</i>	several buldings	several buildings	several structures and buildings	3 buildings

Mine features identified from each mine include; shafts, waste rock dumps, tailings dump, processing plant and buildings (Table 6-1). From the field visits and assessment all the mines are near major rivers and human settlements (Appendix A).

#### *Water contamination*

Water pollution is most likely to occur due to erosion of waste materials containing PHEs from the mines and seepage through the tailings (Chapter 5.2). Mines from the TDGF present the worst cases of erosion of tailings dumps. The measurable erosion gullies support that fine materials from the tailings dumps are washed to nearby streams. The proximity of the derelict mines to major rivers was identified as a major environmental concern.

Yellowish stains and salt precipitates observed in tailings dumps from Nestor, Bourke's Luck and Bonanza suggest chemical weathering is recurring on the waste materials. Yellow stains are evidence of acid mine drainage which was detected to contribute to lowered stream water pH and introduced PHEs to the Blade River. Erosion gullies along the vertical profile of tailings dumps suggest that the by-product of chemical weathering eventually enters surrounding water system. Water pollution in the TDGF is exacerbated

by the presence of illegal miners who employ unsustainable mining methods known to contaminate surrounding agroecosystem. Illegal miners from this region use mercury to extract gold which is known to cause deleterious effects on aquatic ecosystems and persistent in any environment. Transvaal Drakensberg gold field receives more rainfall of 883 mm per year compared to 672 of the Barberton Greenstone Belt which further supports that more erosion and chemical weathering takes place there compared to Barberton Greenstone Belt area.

### *Soil contamination*

Contamination of surrounding soils can be attributed to wind and water erosion and seepage of waste material. Bourke's Luck mine is in a valley along the faulted Drakensberg Mountains and wind erosion is less likely to occur. Waste materials from Bonanza have been timelessly exposed to erosion by wind as a result soil contamination is extensive. Bonanza mine is very close to human settlement, and the exposed dumps not only impacting surrounding soil but are most likely to cause health problems due to the presence of PHEs (Table 5-4). Nestor mine is in a shrubby environment and erosion of fine tailings materials is less likely. However, PHEs further away from the tailings dumps were identified. This can be attributed to erosion by rain water.

#### 6.1.2 The potential for acid generation in the old mine tailings dump and waste rocks through on-site investigations, predictions and laboratory analyses.

Derelict mines from the Transvaal Drakensberg Goldfield are characterised by both potential acid-generating and non-acid generating mine residues. Nestor tailings dumps are characterised by the presence of pyrite as a primary acid producing mineral and jarosite as a secondary acid-generating mineral. Nestor mine poses a high risk for generating acid drainage. Acid generation in the region is exacerbated by the availability of water due to high rainfall. Gold in the Bourke's Luck mine is associated with sulphide mineralisation within dolomite. ABA results for Bourke's Luck tailings material supports the presence of buffer minerals within waste materials which reduces the risk of acid generation.

Derelict mines from the Barberton Greenstone Belt are characterised by potential non-acid generating mine residues. This can be attributed to high concentration of neutralising minerals compared to acid generating species. The presence of calcite and magnesite in tailings collected from Bonanza confirms the presence of considerable amount of buffer mineral species. There is an urgent need to conduct kinetic test to ascertain the rate of mineral weathering from both regions. This is the need to conduct stream sediment studies to determine the impacts of the mine residues from the derelict mines on surrounding streams.

### 6.1.3 The potential harmful elements (PHEs) from the derelict mines through water quality assessment at the mine settings and surrounding agroecosystems.

#### *Water*

Water collected from derelict and ownerless mines contained considerable amounts of  $\text{SO}_4^{2-}$ . Sulphate in water is considered laxative and is associated with abdominal concerns in animals (Rascher & Hobbs, 2008). Mine water from Nestor mine were more threatening due to its low pH and chemical content (Table 5-3). PHEs likely to be leached from Nestor dump include Pb, Ca, Mg, As, Fe, Zn, Cu, Mn and Co (Table 5-4). Water sample from the surrounding river (NRW) contains high concentration of Fe,  $\text{PO}_4^{2-}$  and  $\text{SO}_4^{2-}$  which exceeds the water quality standard set by DWAF.

Mine water from Bourke's Luck also contains high concentration of PHEs which exceeds the water quality guidelines set by DWAF (Table 5-3). High concentrations of Ca and Mg in water samples suggest the presence of calcite-dolomite rocks which are common in Malamani dolomites of the Transvaal Supergroup. The most concerning results in Bourke's Luck tailings is the high concentration of Fe which is likely to be leached. High concentration of Fe was detected from the water sample (BLRW) collected downstream of Blyde River (Table 5-2).

Mine water from Golden Snake also poses a major concern due to high concentration of Fe, Al, Mn, Zn, Cu, As and Cr which exceed the water quality guidelines as set by DWAF (Table 5-2). These PHEs are also likely to be leached from the waste rock dumps at Golden Snake. Tailings dumps from Bonanza mine are likely to leach considerable amounts of Mg, Ni, Ca, Fe and Pb to nearby Sheba River. High concentration of Fe was detected in water samples collected from Sheba River.

### *Soil*

Soils from Nestor mine contained high concentration of Pb, As and Cu which exceed the targeted standard concentration as specified in WRC Report 2000. Lead contamination becomes unsafe for children playing in contaminated fields. As is identified as a main concern in soils collected from Nestor mine. Other elements were below detection limits of the handheld XRF (Table 5-4). Bourke's Luck soil samples contained high concentration of As which exceeds the MAC (Table 5-3). Other elements were below the MAC and some were below detection limits of the handheld XRF (Table 5-3).

Soils from Bonanza mine contained alarming concentration of As, Cr, Ni, Pb and Cu (Table 5-3). These elements exceed the MAC by far. According to Rossner and Schalwyk (2000) higher concentration of some PHEs require mitigation measures to eliminate the risk to human, plants and animal. The pair documented the intervention values of some of PHEs as follows; As-55ppm, Cr-380ppm, Cu-380ppm, Ni-280ppm and Pb-580ppm. In this case an intervention to mitigate health to human, plants and animals associated with As at Bonanza which exceeds the intervention value is required.

6.1.4 The geological features and structures on each mine site that relate to potential environmental and health and safety concerns.

#### *Potential environmental impacts*

From the field observation and literature review a concrete conclusion can be drawn that the gold mineralisation in the Transvaal Drakensberg gold field contains high constituents of acid mine drainage compared to Barberton Greenstone Belt (Table 5-7). However some of the gold is hosted within buffer minerals of the Malmani Subgroup which tend to neutralise the acid drainage formed (Table 5-7). This case is evident in the sample tested from Bourke's Luck (Table 5-6). The presence of faults within the geological settings of the mines raises concerns over contamination of ground water. From the field observation no lining was done in both tailings and waste rock dumps observed at Nestor and Bourke's Luck and PHEs from these waste dumps are likely to be leached to deeper environments.

Gold mineralisation at Bonanza mine is associated with buffer minerals as a result alkaline drainage is formed during chemical weathering of tailings dumps (Table 5-6). PHEs within the formed drainage are likely to reach deeper environment due to the presence of faults in the area which include the Sheba Fault. Golden Snake mine falls within the Kromberg Fault between Msauli and Komati River. Basaltic rocks were identified on waste rock dumps which further literature study. Waste material from the waste rock dumps identified from Golden Snake are less subjected to chemical weathering which can be attributed to the large particle size of the waste rock material and the minimal amount of rainfall in the area.

#### *Potential safety and health concerns*

The presence of faults in all mines visited raises concern over safety of the open shafts and supports within mine workings. Under normal circumstances, mine support structures are subjected to intensive maintenance to insure safety thus maximizing support of the

overburden. Derelict mines are not maintained as a result support structures are subjected to corrosion in the case of steel supports and rotting in the case of timber support which jeopardises support of the old mine workings.

Lack of maintenance of old mine workings poses safety concerns to people living at vicinity of the mines. Overburden support in derelict mines is further jeopardised by illegal artisans who collect steel structure from the old workings. High level of illegal mining in the Transvaal Drakensberg gold field suggests that old mines are at risk of collapsing. Illegal miners not only scavenge steel scrap but also employ dangerous mining methods which undermine safety.

Bonanza mine is mostly frequented by local people from Sheba Village and are at high risk of falling into collapsing mine workings. Existing faults in the surrounding geology of Bonanza mine suggest the presence of weak zones which present risks of collapsing due to lack of maintenance of support structures. Illegal artisans collect steel support from Golden Snake mine and this has jeopardised support of the overburden. There is an urgent need to conduct seismic investigation to assess ground movement to ascertain the risk of collapsing.

## **6.2 Recommendations**

Due to the variability of the nature and geological conditions of each mine assessed in both the gold fields, measures and strategies of risk assess approach mine by mine should be implemented. These strategies should include factors already presented by the current report such as public health and safety and environmental considerations. Some similarities were identified in mine from the same gold field in instances such as geological features, level of illegal mining and erosion due to similar rainfall pattern. The current study serves as a background study which highlight the need for immediate assessment and rehabilitation for mines located in areas with adequate water supply which are a primary target for illegal miners.

The study also revealed that immediate assessment of all sites located close to human settlements and proper remedial actions are to be taken to reduce the public safety and health risks. Further studies which will ascertain the health concerns attached to each derelict mines must be undertaken as an assessment approach to improve decision making for rehabilitation. This must include assessment of radioactivity of soils and tailings dumps close to human settlement. There is an urgent need to relocate communities living in highly contaminated areas to meet the rights of all people as stated in the South African constitution.

The current study also stresses the need to further investigate the requirements to legalise small scale mining to curb illegal mining through assessment of the following key issues:

- Promulgate and implement legislations which will ensure safe working conditions amongst illegal miners.
- Promote the use of mining methods that will take into consideration the theme of sustainable development.
- Implement cartels which will ensure the constant pricing of commodities.
- Govern and register all small-scale mining activities as small business enterprise.

Furthermore, there is a need to evaluate the economic viability of some of the derelict and ownerless mines from these gold fields to reopen them which will help address environmental and safety issues. More funds need to be injected by the government towards re-mining of many tailings dumps in each gold field to one mega tailing dump as a rehabilitation approach. Re-mining of scattered tailings dumps throughout each gold field carries advantages listed as follows:

- Economically viable to manage one mega tailings dump than the scattered dumps throughout each gold field.
- Economically viable to synchronize exploitation and rehabilitation in mining.

Sealing of shafts must be done in all areas declared un economical for re-mining purposes. Proper sealing of shafts to deem illegal mining is required and this can also be achieved through continuous monitoring of such shafts. Flooding of old mine workings was also discovered as a major problem in derelict mines from Barberton Greenstone Belt and this requires constant monitoring to ensure that the water does not seep into surface water.

## BIBLIOGRAPHY

- Adam, K., Kourtis, A., Gazea, B., Kontopoulos, A. 1997. Evaluation of static tests used to predict the potential for acid drainage generation at sulphide mine sites. *Transaction Inst Min Metall, Sect A, Min Ind* 106:1–50
- Adler, R. and Rascher, J. 2007. A Strategy for the Management of Acid Mine Drainage From Gold Mines in Gauteng. Report CSIR/NRE/PW/ER/2007/0053/C (Pretoria: Council for Scientific and Industrial Research).
- Adriano DC. 1986. Trace elements in the terrestrial environment. Springer Verlag, New York, U.S.
- Akcil, A and Koldas, S. 2006. Acid Mine Drainage (AMD): causes, treatment and case studies. *Journal of Cleaner Production* 14:1139-1145.
- Anhaeusser, C.R. 1973. The evolution of the early Precambrian crust of southern Africa: *Philosophical Transactions of the Royal Society of London, A* 273, p. 359-388.
- Anhaeusser, C. R. 1976b. The nature and distribution of Archaean gold mineralization in southern Africa. *Minerals Science and Engineering*, 8 (1), 46-84.
- Anhaeusser, C. R. 1986b. The geological setting of chrysotile asbestos occurrences in Southern Africa, 359-375. In: Anhaeusser, C. R. and Maske, S. eds. *Mineral Deposits of Southern Africa*, I. Geological Society of South Africa, 1020 pp.
- Anhaeusser, C.R. 1976a. The geology of the Sheba Hills area of the Barberton Mountain Land, South Africa, with particular reference to the Eureka syncline. *Transactions of the Geological Society of South Africa*, 79, 253-280.
- Anhaeusser, C.R. 1976. Archean metallogeny in the southern Africa: *Economic Geology*. 71, p. 16-43.
- Anonymous. 1993. *South African Water Quality Guidelines, Domestic Use*. Department of Water Affairs and Forestry, Pretoria, 216 pp.
- Atkins, A.S., Pooley, F.D. 1982. The effects of bio-mechanisms on acidic mine drainage in coal mining. *International Journal of Mine Water* 1:31–44

- Atkins, A.S., Pooley, F.D. 1982. The effects of bio-mechanisms on acidic mine drainage in coal mining. *International Journal of Mine Water* 1:31–44
- Aubertin M. Bussi re B and Berbier L.R. 2002. Environnement et gestion des rejets miniers. CD-ROM, Presses internationales de Polytechnique.
- Auditor-general South Africa. 2009. Report of the Auditor-General to Parliament on a Performance Audit of the Minerals and Energy. Auditing to Build Public Confidence, October-2009.
- Ayuba, H.K. 2005. Environmental science. An introductory text. Apani publisher.
- Balkau, F. 1999. Abandoned Mine Sites: Problems, Issues and Options, UNEP Division of Technology, Industry and Economics: 5 p.
- Bell F.G., Donnelly L.J. 2006. Mining and Its Impact on the Environment. Oxon, England: Taylor and Francis Group.
- Bell, F.G., Bullock, S.E.T. 1996. The problem of acid mine drainage, with illustrative case history. *Environmental Engineering Geoscience*. 2, 369-392.
- Bell, F.G., Bullock, S.E.T., Halbich, T.F.J., Lindsay, P. 2001. Environmental impacts associated with abandoned mine in the Wibank Coalfield, South Africa. *International Journal of Coal Geology* 45 (2001) 195-216.
- Benzaazoua M., Bussi re B., Nicholson R. and Nernier L. 1998. Geochemical behavior of multi-layered cover made of desulphurized mine tailings. *Tailings and Mine Waste* 98, Fort Collins, Balkema Ed. : Rotterdam : 389-398.
- Bianca Botha, M. 2013. Mine collapse traps four. enca, 25 November. [online] Available at [www.enca.com](http://www.enca.com) [accessed 24 November 2014]
- Blowes, D.W., Jambor, J.L., Appleyard, E.C., Reardon, E.J., Cherry, J.A. 1992. Temporal observations of the geochemistry and mineralogy of a sulfide-rich mine-tailings impoundment, Heath Steele Mines, New Brunswick. *Explor. Mining Geol.* 1, 251–264.
- Boer, R.H., Meyer, F.M., Robb, L.J., Graney, J.R., and Vennemann, T.W. 1993. The nature of gold mineralization in the Sabie-Pilgrim’s Rest Gold Field, Eastern Transvaal,

South Africa: Information Circular, Economic Geology Research Unit, University of the Witwatersrand, Johannesburg, 262, 26pp.

- Bradshaw, A.D., Williamson, M.S., Johnson, M.S. 1982. Mine waste reclamation. *Min. J.* 299, 75-80.
- Briggs, P. and Meier, A. 2002. The determination of forty-two elements in Geological materials by Inductively Coupled Plasma-mass Spectrometry for NAWQA U.S. Geological Survey: 15 p.
- Brime, C. 1985. The accuracy of X-ray diffraction method for determining mineral mixtures: 538 p.
- Brown, J. 2007. Derelict mines to cost state R100bn. *Business Report*, 23 May 2007. p 22.
- Bulpin, T.V. 2002. *Lost Trails of the Transvaal*. Stephen Phillips (Pty) Ltd. ISBN 0636 0116X
- Bureau of Land Management (BLM). 2014. Abandoned mineral lands portal: Extent of problem. Bureau of Land Management, Washington, DC. <http://www.abandonedmines.gov/ep.html> (accessed May 19, 2014).
- Bussi re, B., Aubertin, M. and Chapuis, R.P. 2002. A laboratory set up to evaluate the hydraulic behavior of inclined capillary barriers. *International Conference on Physical Modelling in Geotechnics*, St.Jonh's, Newfoundland, 391-396.
- Canovas C.R., Olias M., Nieto J.M., Sarmiento A.M., Ceron, J.C. 2007. Hydrogeochemical characteristics of the Tinto and Odiel Rivers (SW Spain). Factors controlling metal contents. *Science Total Environment* 373:363–382
- Cartwright, A. P. 1961. *Valley of Gold*. Howard Timmins, Cape Town, 187 pp.
- Chadderton S. 2014. Hundreds of illegal miners feared trapped underground after suspected rockfall in Johannesburg, South Africa. *Mirror* 16 February.[online] Available online at [www.mirror.co.uk](http://www.mirror.co.uk) [accessed 24 November 2014]
- Chamber of Mines of South Africa. 2008. *Mining and Environmental Impact Guide*. Gauteng Department of Agriculture, Environment and Conservation. <http://www.bullion.org.za/Departments/Environment/Downloads/Impact%20Guide>

/GDACE%20Mining%20and%20Environmental%20Impact%20Guide.pdf  
(accessed 02.12.2012).

- Cloete, H. and Truter, J. 2001. Major and Trace element analysis by X-ray fluorescence spectrometry at the Council for Geoscience, Council for Geoscience, Pretoria p.
- Coasttech Research. 1994. Acid Rock Drainage Prediction Manual: A manual of chemical evaluation procedures for the prediction of acid generation from mine wastes. , Mining and Mineral Sciences Laboratories, Ottawa, Ontario: 123 p.
- Coelho P., Silva S., Roma-Torres J., Costa C., Henriques A., Teixeira J, Gomes M, and Mayan O. 2007. Health Impact of Living Near an Abandoned Mine-Case Study: Jales Mines. International Journal of Hygiene and Environmental Health; 210: 399-402.
- Coetzee, H. 2005. Method CGS-EGU-001: Calibration of mettler toledo MA130 ion meter equipped with a mettler toledo in lab 413 combination pH electrode for pH measurement, Council for Geoscience, Pretoria: 6 p.
- Coetzee, H. 2005. Progress in monitoring and management of ingress and decant of water in the Western Basin.
- Council for Scientific and Industrial Research. 2009. Acid Mine Drainage in South Africa.
- Curror, W. D. 1967. Golden Memories of Barberton. The Barberton and District Publicity Association, Barberton. 85 pp.
- Dallas, H.F., and Day J.A. 1993. The effect of water quality variables on riverine ecosystems: a review Water Research Commission Report TT61/93.
- Davenpoort, J. 2006. "Abandoned Mines: Government allocates R90 million for Rehabilitation of 8 000 Derelict Operations." Engineering News Volume, DOI:
- De Beer, J.H., Stettler, E.H., Du Plessis, J.G. and Blume, J. 1988. The deep structure of the Barberton Greenstone Belt: a geophysical study: South African Journal of Geology, 91, p. 184-197.

- De Ronde, C.E.J and De Wit, M.J. 1994. The tectonic history of the Barberton Greenstone Belt, South Africa: 450 million years of Archean crustal evolution, *Tectonics*, 13, p. 983-1005
- De Ronde, C.E.J, Spooner, E.T.C., De Wit, M.J. and Bray, C.J. 1992. Shear zone related Au-quartz deposits in the Barberton Greenstone Belt, South Africa: field and petrographic characteristics, fluid properties and light stable isotope geochemistry: *Economic Geology*, 87, p. 366-402.
- De Villiers, J. E. 1957. The mineralogy of the Barberton gold deposits. *Bulletin, Geological Survey of South Africa*, 24, 60 pp.
- Department of Mineral Resources. 2009. The National Strategy for the Management of Derelict and Ownerless Mines in South Africa.
- Department of Water Affairs. 2011. South African River Health Programme. DWAF: Pretoria.
- Dinelli E., Lucchhini F., Fabbri M., Cortecci G. 2001. Metal distribution and environmental problems related to sulphide oxidation in the Libiola copper mine area (Ligurian Apennines,(Italy). *Journal of Geochemical Exploration* 74:141–152
- Dreschler, B. 2001. Small scale mining and sustainable development within the SADC region: Mining Minerals and Sustainable Development. No. 84. England: SANTREN/ ITDG.
- Dreschler, B. 2001. Small scale mining and sustainable development within the SADC region: Mining Minerals and Sustainable Development. No. 84. England: SANTREN/ ITDG.
- Department of Water Affairs and Forestry. 1996. South African Water Quality Guidelines (second ed.), vol. 1, Domestic Use. CSIR Environmental Services.
- Eriksson, P.G and Clendenin, C.W. 1990. A review of the Transvaal Sequence, South Africa in *Memoir on the Phanerozoic Continental Sediments of Africa* (C.A Kogbe, E. Klitzch and J Lang, eds): Pergamon, Oxford.

- Eriksson, P.G and Clendenin, C.W. 1990. A review of the Transvaal Sequence, South Africa in Memoir on the Phanerozoic Continental Sediments of Africa (C.A Kogbe, E. Klitzch and J Lang, eds): Pergamon, Oxford.
- Food and Agriculture Organization, of the United Nations. 2004. Drought impact mitigation and prevention in the Limpopo River basin: a situation analysis. Rome: Food and Agriculture Organisation of the United Nations.
- Ghose M.K. 2002. Air Pollution Due to Opencast Coal Mining and the Characteristics of Air-Borne Dust-an Indian Scenario. *International Journal of Environmental Studies* 2002; 59(2): 211-228.
- Ghose, M.K. 2003. Promoting cleaner production in the Indian small scale mining industry. *Cleaner Production*. 2 (11): 167-174.
- Green, T., 1968. *The World of Gold: The History, the Lure, and the Power of Man's Most Precious Metal*. Simon and Schuster, New York, p.99.
- Hall, A. L. 1910. The geology of the Pilgrims Rest Gold Mining District. Memoir, Geological Survey of South Africa, 5, 158 pp.
- Heinrichs, T. 1980. Lithostratigraphische Untersuchungen in der Fig Tree Gruppe des Barberton Greenstone Belt zwischen Umsoli und Lomati (Südafrika). *Göttinger Arbeiten zur Geologie und Paläontologie*, 22, 118pp.
- Hobbs, P., Oelofse, Z.H.H., and Rascher, J. 2008. Management of environmental impacts from coal mining in the upper Olifants river catchment as a function of age and scale. CSIR natural resources & the environment, Pretoria, South Africa.
- Hobbs, PJ and Cobbing, JE. 2008. A hydrogeological assessment of acid mine drainage impacts in the West Rand Basin, Gauteng Province. Report No. CSIR/NRE/WR/ER/2007/0097/C CSIR THRIP: Pretoria, South Africa.
- Hofmann, A. 2005. The geochemistry of sedimentary rocks from the Fig Tree Group, Barberton Greenstone Belt: Implications for tectonic, hydrothermal and surface processes during mid-Archaean times. *Precambrian Research*, 143, 23-49.

- Kamo, S.L., Davis, D.W. 1994. Reassessment of Archean crustal development in the Barberton Mountain Land, South Africa, based on U–Pb dating. *Tectonics* 13, 167–192.
- Kavourides C., Pavloudakis F., Filios P. 2002. Environmental protection and land reclamation works in West Macedonia Lignite Centre in North Greece current practice and future perspectives. In: Ciccu R. (ed.) *SWEMP 2002: Proceedings of the 7 th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production, SWEMP 2002, 7-10 October 2002, Cagliari, Italy*. University of Cagliari.
- Kelly, M. 1988. *Mining and the Freshwater Environment* London: Elsevier Applied Science.
- Kibble A.J., Saunders P.J. 2001. Contaminated Land and the Link with Health. In: Hester R.E., Harrison R.M. (ed.) *Assessment and Reclamation of Contaminated Land*. Cambridge: Royal Society of Chemistry, Thomas Graham House; p65-84.
- King, T.V.V. 1995. Environmental considerations of active and abandoned mine lands: lessons from Summitville, Colorado United States Geological Survey Bulletin 2220.
- Klukanova A., Rapant S. 1999. Impact of Mining Activities upon the Environment of the Slovak Republic: Two Case Studies. *Journal of Geochemical Exploration* 1999; 66: 299–306.
- Komnitsas K., Modis K. 2006. Soil Risk Assessment of As and Zn Contamination in A Coal Mining Region Using Geostatistics. *Science of the Total Environment*; 371: 190–196.
- Lloyd, P.J. 2002. *Coal mining and the environment*. Energy research institute, University of Cape Town, Rondebosch 7701, South Africa.
- Lowe, D. R. and Byerly, G. R. 1999. Geologic evolution of the Barberton greenstone belt and vicinity. *Geologic Evolution of the Barberton Greenstone Belt, South Africa*. Special Paper, Geological Society of America, 329, 319 pp.
- Lowe, D.R. and Byerly, G. R. 1999. Stratigraphy of the west-central part of the Barberton Greenstone Belt, South Africa. In: Lowe, D.R. and Byerly, G.R. (eds.), *Geologic*

Evolution of the Barberton Greenstone Belt, South Africa. Special Paper, Geological Society of America, 329, 1-36.

- Mathusa K., Ogola, J., and Maas, K. 2012. Dispersion of Metals at Louis Moore Gold Tailings Dam, Limpopo Province. University of Venda, Thohoyandou.
- McCarthy TS. 2011. The impact of acid mine drainage in South Africa. South African Journal of Science.107(5/6), Art.#712, 7 pages. doi:10.4102/sajs.v107i5/6.712 December 5-11,1994.
- Meiring, P. 1976. Dynamite and Daisies - The Story of Barberton. Purnell, Cape Town, 177 pp.
- Mhlongo, S.E. and Amponsah-Dacosta, F. 2016. A review of problems and solutions of abandoned mines in South Africa. International Journal of Mining, Reclamation and Environment, vol. 30, no. 4. pp. 279–294.
- Miththapala, S. 2008. Coral reefs: International Union for Conservation of Nature: Ecosystems and Livelihoods Group. Coastal ecosystems series Vol. 1.
- Morin, K.A. and Hutt, N.M. 1997. Environmental Geochemistry of Minesite Drainage : Practical Theory and Case Studies. MDAG Publishing, Vancouver (Canada).
- Mpendazoe, F. M. T. 1996.Towards sustainable small scale gold mining in Tanzania.(Proceedings of the 1996 First World Mining Environment Congress held at Rotterdam in 1996).Balkema: Rotterdam.
- Mummey D.L., Stahl P.D. and Buyer J.S. 2002. Microbial Biomarkers as an Indicator of Ecosystem Recovery Following Surface Mine Reclamation. Applied Soil Ecology. 21: 251-259.
- Munnik.V., Hochmann, G., and Hlabane, M. 2009. The social and environmental consequences of coal mining South African case study. Environmental Monitoring Group.
- Naiker, K., Cukrowska E., McCarthy T.S. 2003. Acid mine drainage arising from gold mining activity in Johannesburg, South Africa, and environs. Environmental Pollution. 122:29–40.

- Ndalulilwa, K., Haidula, H and Leonard, R. 2011. Risk assessment of abandoned mine sites in Namibia. Czech Geological Survey.
- Nkosi M. 2014. Trapped South African miners refuse to leave pit. *BBC*, 24 November 2014
- Nordstrom, K.D., Alpers, C.N. 1999. Geochemistry of acid mine waters. In: Plumlee, G.S., Logsdon, M.J. (Eds.), *The Environmental Geochemistry of Mineral Deposits. Part A: Processes, Techniques, and Health Issues*, Rev. Econ. Geol., 6A, pp. 133–160.
- Oelofse, S & Turton, A. 2008. Mine water pollution – acid mine decant, effluent and treatment: A consideration of key emerging issues that may impact the state of the environment. Emerging Issues paper: Mine water pollution. Pretoria: Department of Environment and Tourism.
- Ogola, J.S. 2010. Dispersion of Heavy Metals and their potential impacts on the Environment: A case study of Gold Tailings Dam in Giyani Belt, Limpopo Province, South Africa. University of Venda, Thohoyandou.
- Olofin, E.A. 1989. Human response to the natural environment in the kano region. Kano and Some of Her Neighbours. ABU Press.
- Plumlee, G.S., Smith, K.S., Montour, M.R., Ficklin, W.H., Mosier, E.L. 1999. Geologic controls on the composition of natural waters and mine waters draining diverse mineral-deposit types. In: Filipek, L.H., Plumlee, G.S. (Eds.), *The Environmental Geochemistry of Mineral Deposits. Part B: Case Studies and Research Topics*. Society of Economic Geologists, Littleton, CO, pp. 373–432.
- Pretorius, D. A. 1965. Fragments of History. Post-Congress Excursion, Barberton Mountain Land. Economic Geology Research Unit, University of the Witwatersrand, Johannesburg, 57 pp.
- Renner, S., Rankin, M., Ponce, R., Griffin, B., Moraes, R., Dalheimer, M., Parot, M.E. 2009. Abandoned Mines – Attempts to face the unwanted legacy in Chile.
- Ricca, V.T., & Schultz, R.R. 1979. Acid mine drainage modelling of surface mining. In: Argall GO, Brawner CO Jr (eds) *Mine Drainage*, Proceedings of the first international mine drainage symposium, Miller-Freeman Publications, San Francisco, pp 651–670

- Ritcey GM. 1989. Tailings Management, Problems and Solutions in the Mining Industries. Elsevier.
- Rubio R.F., Del Olmo, A.G. 1995. Mining drainage and water supply under sustainable constraints. In: Hotchkiss WR, Downey JS, Gutentag ED, Moore JE (eds) Proceedings on water resources at risk, American Institute of Hydrology, Denver, 14–18 May, pp 23–32
- Sams J.I., Beer K.M. 2000. Effects of Coal-Mine Drainage on Stream Water Quality in the Allegheny and Monongahela River Basins-Sulfate Transport and Trends: Water-Resources Investigations. Lemoyne, Pennsylvania, Report 99-4208
- Schmidt-Eisenlohr, W.F. 1969. Report on geological reconnaissance in the NE Transvaal Report. Geological Survey. Council for Geoscience, Pretoria, 1970-0002 (unpubl.)
- Schouwstra, R.P. and De Villiers, JP.R. 1988. Gold mineralisation and associate wallrock alteration in main Reef Complex at Sheba Mine, South Africa: Transactions of the Institute of Mining and Metallurgy, 97B, p 158-170
- Sengupta M. 1993. Environmental Impacts of Mining Monitoring, Restoration, and Control. USA: Lewis Publishers.
- Sobek, A.A., Shuller, W.A., Freeman J.R., & Smith R.M. 1978. Field and laboratory methods applicable to overburdens and mine soils. EPA 600/2-78-054, U.S. Environmental Protection Agency, Cincinnati
- Song S., Min E.S., Kim M.H. and, Lee H.K. 1997. Pollution by Acid Mine Drainages from the Daeseong Coal Mine in Keumsan. Econ. Environ. 30(2): 105-116..
- SRK (Steffen, Robertson and Kristen). 1989. Guide technique préliminaire sur le drainage rocheux acide, BC AMD Task Force, Vol.1. Centre de Recherches Minérales, Québec.
- Steenkamp, N.C and Clark-Mostert, V. 2012. Impacts of Illegal Mining at Historic Gold Mine Locations, Giyani Greenstone Belt area, South Africa.
- Strode, S., Jaegle, L. and, Selin, N.E. 2009. Impact of mercury emissions from historic gold and silver mining: Global modelling. a Department of Atmospheric Sciences, University of Washington, Box 351640, Seattle, WA 98195, USA

- Tan, K. 2005. Soil sampling, Preparation, and Analysis, Tylor and Francis.
- Tian, L., Guo, H.F., Gao, X.T. and Li., Q.Y. 2009. Effects of Mercury Released from Gold Extraction by Amalgamation on Renal Function and Environment in Shanxi, China. *Bulletin of Environmental Contamination and Toxicology*. Volume 83, 1, pp 71-74.
- Tokalioglu, S., Kartal, S. and Birol, G. 2001. Application of a three-stage sequential extraction procedure for the determination of extractable metal contents in highway soils. *Journal of Chemistry (27)*: pp. 346.
- Tutu, H., McCarthy T.S., and, Cukrowska E. 2008. The chemical characteristics of acid mine drainage with particular reference to sources, distribution and remediation: The Witwatersrand Basin, South Africa, as a case study. *Application Geochem.* 23:3666–3684.
- United Nations Environmental Programme. 2001. Abandoned mine sites: Problems, Issues and Options: Discussion paper. 3rd Asia Pacific training Workshop on Hazardous Waste Management on Mining, Beijing, China, UNEP.
- United States Environmental Protection Agency. 2003. 446e Practices for the collection and Handling of Drinking water.
- Viljoen, R. P. and Viljoen, M. J. 1969. The relationship between mafic and ultramafic magma derived from the upper mantle and the ore deposits of the Barberton region. *Special Publication, Geological Society of South Africa*, 2, 221- 244.
- Ward, J. H. W. and Wilson, M. G. C. 1998. Gold outside the Witwatersrand Basin, 350-386. In: Wilson, M.G.C. and Anhaeusser, C. R., eds. *The Mineral Resources of South Africa. Handbook*, Council for Geosciences, 16, 740 pp.
- Water Research Commission. 2000. Quality of domestic water supplies. Volume 2: Sampling Guide. First Edition 2000 Water Reaserch Commission, (2000). Quality of domestic water supplies: Sampling guide, Water Research Commission: 28 p.
- Wilson, M.G.C, and Anhaeusser, C.R. 1998. *The Mineral Resource of South Africa: Handbook*, Council for Geoscience, 16, 740pp.
- World Information Service on Energy. 2007. Chronology of major tailings dam failures. Available online at: [www.wise-uranium.org/mdaf.html](http://www.wise-uranium.org/mdaf.html), accessed 6 March 2007.

- Wright, C.Y., Matooane, M., Oosthuizen, M.A., and Phala, N. 2014. Risk perceptions of dust and its impacts among communities living in a mining area of the Witwatersrand, South Africa. *Clean Air Journal*, Vol 24, No.1
- Zhao F., Cong Z., Sun H., Ren, D. 2007. The geochemistry of rare earth elements (REE) in acid mine drainage from the Sitai coal mine, Shanxi Province, North China. *International Journal of Coal Geology* 70:184–192.

**Appendix I Ranking results for Bonanza gold mine**

FIELD RANKING SHEET						
<b>Name of inspector</b>	Sibiya Bonginkosi	<b>Date</b>	02-Apr-15	<b>Mine name</b>	Golden Snake	<b>Coordinates</b> Lat: 25.715833 Lon: 31.1352768
SITE INFORMATION						
<b>Mine scale</b>	Small	<b>Com</b>	Gold	<b>Town &amp; Province</b>		Ngoneni, Mpumalanga
<b>Mine feature</b>	<b>Feature No.</b>	<b>Area (Size)</b>	<b>Coordinates</b>		<b>Comments</b>	
			<b>Lat</b>	<b>Lon</b>		
Tailings Dump 1	1	264 m X 140 m	25.695459	31.169092	Tailings vegetated on top, highly eroded on sides, surrounded by houses	
Tailings Dump 2	2	100 m X 30 m	25.703129	31.16421	Highly eroded tailings dump closed to Sheba River	
Tailings dump 3	3	105 m X 45 m	25.710365	31.147429	Highly eroded tailings dump along the road to Sheba mine	
Processing plant	4	100 m X 50 m	25.709782	31.145684	Old building close to human settlement, potential hub for criminals	
Shaft no 1	5	2.1 m X 1.5 m	25.701781	31.154212	Open shaft approximately 1.5 km from Sheba village, Access by cattle herders	
Shaft no 2	6	3 m X 3 m	25.710225	31.153112	Open shaft approximately 500 m from Sheba village	
Inclined Shaft 1	7	3 m X 3.5	25.710398	31.153048	Open shaft approximately 500 m from Sheba village	
Horizontal Shaft 1	8	3 m X 6 m	25.71026	31.153179	Open shaft approximately 500 m from Sheba village	
Horizontal shaft no 2	9	4 m X 5 m	25.710848	31.153832	Open shaft closed to Sheba river, potential hub for criminals	
Waste Rock dump	10	40 m X 40 m	25.711027	31.153551	Unstable waste rock dump close to Sheba River, evidence of erosion	
Old building	11	5 m X 5 m	25.710574	31.153069	old mine building in a bushy area, potential hub for criminals	
<b>Geological conditions</b>	Rock type present include Sandstones, greywacke, iron banded stones and quartz veins. well lithified geology with faulting in some areas					
<b>hydrological conditions</b>	Area is drained by a seasonal streams, undulating slopes gives the area a high drainage density, streams are characterised by steeper slopes					
<b>Factors</b>	<b>Criteria</b>	<b>Rating</b>	<b>Comments</b>			
<b>Public safety</b>	<i>Conditions</i>	5	5 open shafts the closest is 500 m from human settlement			
	<i>Proximity</i>	5	Closest open shaft is 500 m from human settlement, the furthest is 1.5 km			
	<i>State of hazard</i>	5	Cattle herders reported cases of cows falling into the open shafts			
	<i>Type of hazard</i>	5	Falling into the vertical shafts can result into death			
<b>Environmental</b>	<i>Conditions</i>	5	Higher content of As, Cr, Cu, Zn, Pb and Co. Evidence of erosion to surrounding stream and soil.			
	<i>Scale</i>	4	High As, Ni, Cr, Pb were detected from soils away from the tailings dump			
<b>Public health</b>	<i>Conditions</i>	5	Tailings dump contain high content of As, Pb, Ni, Cr, Zn, Cu which can have negative impacts on human health			
	<i>Proximity</i>	5	Tailings dump is surrounded by houses			
	<i>Exposure</i>	5	High risk of exposure during wind blown dust and the population exceeds 50 people			
<b>Illegal mining</b>	<i>Conditions</i>	1	No evidence of illegal mining, min workings are reported to be filled with water			
	<i>Proximity</i>	1	No evidence of illegal mining, min workings are reported to be filled with water			
	<i>Size of operation</i>	1	No evidence of illegal mining, min workings are reported to be filled with water			
<b>Public opinion</b>	Open shafts are a major concern for public safety, exposed tailings dumps creates a dust environment during windy conditions					
<b>Overall site priority rating</b>	VERY HIGH- Urgent attention to seal the shafts at 500 m from human settlement. Rehabilitation of the eroded tailings is required					

**Appendix II Ranking results for Golden Snake gold mine**

FIELD RANKING SHEET							
<b>Name of inspector</b>	Sibiya Bonginkosi	<b>Date</b>	02-Apr-15		<b>Mine name</b>	Golden Snake	<b>Coordinates</b>
							Lat: 26.03197
							Lon: 31.04005
SITE INFORMATION							
<b>Mine scale</b>	Small	<b>Com</b>	Gold		<b>Town &amp; Province</b>	Ngoneni, Mpumalanga	
<b>Mine feature</b>	<b>Feature No</b>	<b>Area (Size)</b>	<b>Coordinates</b>		<b>Comments</b>		
			<b>Lat</b>	<b>Lon</b>			
Processing plant	1	100 m X 50 m	-26.025679°	31.038483	Old processing plant that requires demolishing		
Shaft no 1	2	2.1 m X 1.5 m	26.024929°	31.038768	Sealed shaft with steel might fall prey to illegal artisans approximately 8 km from Ngoneni		
Shaft no 2	3	3 m X 3 m	-26.026946°	31.038518	Sealed shaft with steel might fall prey to illegal artisans approximately 8 km from Ngoneni		
Horizontal Shaft 1	4	3 m X 6 m	26.026932°	31.038196	Open shaft used by illegal artisans to collect steel from the old mine workings		
Waste Rock dump	5	160 m X 40 m	-26.028200°	31.04045	Stable dump with no evidence of erosion		
Old building	6	5 m X 5 m	-26.025228°	31.038928	Old mine building is a potential hub for criminals		
<b>Geological conditions</b>	The area is characterised by thick soil profile and no outcrops were identified						
<b>hydrological conditions</b>	Area is drained by Komati Catchment, no evidence of erosion of waste rock dumps was identified on site						
<b>Factors</b>	<b>Criteria</b>	<b>Rating</b>	<b>Comments</b>				
<b>Public safety</b>	<i>Conditions</i>	4	2 sealed shaft with steel and this might fall prey to illegal artisanal miners. Open shaft used by illegal miners to access old mine workings				
	<i>Proximity</i>	3	Site is accessed by a gravel road in an access controlled area				
	<i>State of hazard</i>	5	Falling into the open shafts can result into death				
	<i>Type of hazard</i>	5	Faling into the vertical shafts can result into death				
<b>Environmental</b>	<i>Conditions</i>	2	small waste rock dumps with no evidence of oxidation. Lab result shows potential to buffer acid				
	<i>Scale</i>	1	No impact identified				
<b>Public health</b>	<i>Conditions</i>	2	Small waste rock dump, no evidence of erosion, potential elements to be leached are Ca, Mg, As. ABA results suggest the materials are Non-PAG				
	<i>Proximity</i>	4	Site is located within 8 km from Ngoneni				
	<i>Exposure</i>	2	Area is access controlled, only cattle herders and adventures access the site				
<b>Illegal mining</b>	<i>Conditions</i>	2	Local artisans collect steel from the old mine workings				
	<i>Proximity</i>	3	Site is located within 8 km from Ngoneni				
	<i>Size of operation</i>	2	Local artisans collect steel from the old mine workings				
<b>Public opinion</b>	Site is in an access controlled area, no cases of death were reported since the mine closed. No windblown dust originates from the mine.						
<b>Overall site priority rating</b>	MODERATE- Site is in an access controlled area, strenghtening of security services to combart illegal scavenging of steel is required						

**Appendix III Ranking results for Nestor gold mine**

FIELD RANKING SHEET						
<b>Name of inspector</b>	Sibiya Bonginkosi	<b>Date</b>	06-Apr-15	<b>Mine name</b>	Nestor	<b>Coordinates</b> Lat: 25.07419 Lon: 30.79941
SITE INFORMATION						
<b>Mine scale</b>	Large	<b>Com</b>	Gold	<b>Town &amp; Province</b>		Sabie, Mpumalanga
<b>Mine feature</b>	<b>Feature No</b>	<b>Area (Size)</b>	<b>Coordinates</b>		<b>Comments</b>	
			<b>Lat</b>	<b>Lon</b>		
Processing plant	1	80 m X 70 m	-25.073827°	30.7999	Old processing plant that requires demolishing	
Shaft no 1	2	1.5 m X 1.5 m	-25.077543°	30.794326	Open shaft in a shrubby area suuden fall when moving around the site might occur	
Shaft no 2	3	1.5 m X 2 m	-25.074472°	30.800711	Open shaft in a shrubby area suuden fall when moving around the site might occur	
Horizontal shaft no 1	4	2.5 m X 3 m	-25.074005°	30.801141	Sealed shaft with waste material to prevent illegal miners from accessing old mine workings	
Tailings dump	5	380 m X 100 m	25.076080°	30.797677	Heavily eroded tailings dump, evidence of oxidation, presence of salts, low pH drainage	
Waste Rock dump	6	160 m X 40 m	25.074809°	30.798731	Evidence of oxidation in Waste rock material	
Old building	7	30 m X 20 m	-25.073466°	30.800238	Old mine building is a potential hub for criminals	
<b>Geological conditions</b>	The area is charecterised by dense vegetation and outcrops were not idebtified on site					
<b>hydrological conditions</b>	Area is drained by Sabie Catchment, Tailings dump is highly eroded suggesting strong rains during summer					
<b>Factors</b>	<b>Criteria</b>	<b>Rating</b>	<b>Comments</b>			
<b>Public safety</b>	<i>Conditions</i>	5	2 open vertical shafts which can result into immediate threat to adventurers moving on site.			
	<i>Proximity</i>	5	Site is located approximately less than 1 km from Simile Village and is located along R 532 from Sabie to Pilgrim's Rest			
	<i>State of hazard</i>	5	Falling into the open shafts can result into death			
	<i>Type of hazard</i>	5	Faling into the vertical shafts can result into death			
<b>Environmental</b>	<i>Conditions</i>	5	Heavily eroded dumps, evidence of oxidation, evidence of salts, low pH drainage from the dump, PHE include As, Pb, Cr, Co, Cu			
	<i>Scale</i>	5	Surrounding soils contained high content of PHE present in tailings dump, high arsenic content in stream water			
<b>Public health</b>	<i>Conditions</i>	5	Tailings dump can be a source of PHE such as As which can cause health problem to local people, other metals are leached to streams			
	<i>Proximity</i>	5	Site is located within 1 km radius from Simile			
	<i>Exposure</i>	5	Area is accessible. Site is located in a higher elevation as to Simile village as a result PHE leached from the site impact downsteam users			
<b>Illegal mining</b>	<i>Conditions</i>	5	Strong point of artisanal mining in the Transvaal Drakensberg gold field			
	<i>Proximity</i>	5	Site is located within 1 km radius from Simile			
	<i>Size of operation</i>	4	More than 3 ethnic groups are reported to mine illegal on this site. Approximately over 50 illegal miners mine underground			
<b>Public opinion</b>	Site is close to human settlement, contamination of Sabie River, intervantion to curb illegal mining which endanger the lives of local community					
<b>Overall site priority rating</b>	VERY HIGH- Immediate attention to curb acid mine drainage which impact Sabie River required, Seal open shaft to curb illegal mining, Demolish old buildings					

**Appendix IV Ranking results for Bourke's Luck gold mine**

FIELD RANKING SHEET							
<b>Name of inspector</b>	Sibiya Bonginkosi	<b>Date</b>	07-Apr-15	<b>Mine name</b>	Bourke's Luck	<b>Coordinates</b>	Lat: 24.66646 Lon: 30.81766
SITE INFORMATION							
<b>Mine scale</b>	Large	<b>Com</b>	Gold	<b>Town &amp; Province</b>		Bourke's Luck, Mpumalanga	
<b>Mine feature</b>	<b>Feature No</b>	<b>Area (Size)</b>	<b>Coordinates</b>		<b>Comments</b>		
			<b>Lat</b>	<b>Lon</b>			
Processing plant	1	80 m X 70 m	-24.666507°	30.817326	Old processing plant that requires demolishing		
Shaft no 1	2	1.5 m X 1.5 m	-24.666682°	30.816898	Open shaft used by illegal miners to access underground workings		
Shaft no 2	3	1.5 m X 2 m	-24.666427°	30.817631	Open shaft used by illegal miners to access underground workings		
Tailings dump	5	380 m X 100 m	-24.666917°	30.817594	Heavily eroded tailings dump, evidence of oxidation, presence of salts, low pH drainage		
Waste Rock dump	6	160 m X 40 m	-24.667585°	30.81727	Evidence of oxidation in Waste rock material		
<b>Geological conditions</b>		Area is dominated by dolomitic rocks and iron stones. Faults are dominant in most of the outcrops					
<b>hydrological conditions</b>		Area is drained by Oliphants Catchment, Tailings dump is highly eroded suggesting strong rains during summer					
<b>Factors</b>	<b>Criteria</b>	<b>Rating</b>	<b>Comments</b>				
<b>Public safety</b>	<i>Conditions</i>	5	2 open shafts used by illegal miners to access old workings are visible enough to not to pose immediate physical threat				
	<i>Proximity</i>	5	Site is located approxiamtely 500 m from the Bourke's Luck Potholes Residence				
	<i>State of hazard</i>	5	Falling into the open shafts can result into death				
	<i>Type of hazard</i>	5	Faling into the vertical shafts can result into death				
<b>Environmental</b>	<i>Conditions</i>	5	Heavily eroded dumps, evidence of oxidation, evidence of salts, low pH drainage from the dump, PHE include As, Pb, Cr, Co, Cu				
	<i>Scale</i>	5	High content of PHE present in stream water, heavily eroded dump suggest they are washed down to the nearby dam				
<b>Public health</b>	<i>Conditions</i>	5	Tailings dump can be a source of PHE such as As which can cause health problem to local people, other metals are leached to streams				
	<i>Proximity</i>	5	Site is located within 500 m radius from Bourke's Luck Potholes Residence				
	<i>Exposure</i>	2	Area is access contolled, however the PHE from this mine are carried downstream				
<b>Illegal mining</b>	<i>Conditions</i>	5	Strong point of artisanal mining in the Transvaal Drakensberg gold field. Miners uses heavy machinery to pump water and mercury to process				
	<i>Proximity</i>	5	Site is located within 500 km radius from Bourke's Luck Potholes Residence, reported cases of theft attributed to illegal mining				
	<i>Size of operation</i>	4	More than 3 ethnic groups are reported to mine illegal on this site. Approximately over 100 illegal miners mine underground & surface				
<b>Public opinion</b>		Site is close to human settlement, illegal miners threatens lives of local people, waste material from the mine pollute the Blyde River					
<b>Overall site priority rating</b>		VERY HIGH- Immediate attention to curb acid mine drainage which impact Blyde River required, Seal open shaft to curb illegal mining					



