UNIVERSITY OF VENDA

ASSESSMENT AND MANAGEMENT OF ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS OF SMALL-SCALE GOLD MINING AT GIYANI GREENSTONE BELT

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A Dissertation Submitted to the Department of Geography and Geo-Information Sciences, School of Environmental Sciences, University of Venda in Fulfilment of the Requirements for Master Degree in Environmental Sciences

August 2017

DECLARATION

I, **Magodi Rofhiwa,** hereby declare that the dissertation for the Master of Environmental Sciences in Geography degree at the University of Venda, hereby submitted by me, has not been submitted previously for a degree at this or any university. That it is my own work in design and execution and that all reference material contained therein has been duly acknowledged.

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ACKNOWLEDGEMENTS

I would like to thank God for being my guide and providing me with the strength, ability and health I needed to complete this study. He was my pillar of strength and my daily dose of encouragement. Much gratitude father, you are indeed the mighty warrior who is unequalled in battle.

My most sincere gratitude to my supervisor Dr. F Amponsah-Dacosta for the assistance and guidance he provided academically and personally. He did not only provide technical assistance but also provided encouragement when I had no will to go on. I would like to highly acknowledge the critical eye, expertise and support which I got from my co-supervisor and mentor Mr. Sphiwe Emmanuel Mhlongo. He has proven most competent repeatedly through the years. His support, guidance and assistance were phenomenal.

The National Research Funding (NRF) made the conduction of the study most efficient by providing more than adequate financial support. The NRF made everything to be possible through the financial support which was used in various stages of this study. I feel honoured to have had the support of an institution as reputable as the NRF.

I cannot forget to appreciate the assistance of Mr Ramatsitsi Khuliso, Mudau Thifhatelwi, Brilliant Tivavone, Sikhwari Thendo, Nembilwi Ndamulelo, Glen Pindihama, Ntsako Bright Rekhotho, Bvindi Abundance and Rabelani Mbedzi during data collection and laboratory analysis in laboratory. They played a huge role in ensuring validity and reliability of the field and laboratory analyses data.

This study would not have been possible without the emotional and financial support of my family, especially my aunty Stella Muthevhuli and My mother Tshililo Magodi. Their support enabled me to conduct this study in the most efficient of ways. I would also like to appreciate the support of my classmates, who became as much a pillar to me as I was to them. I want to give my sincere appreciation to my friend and colleague Mr Vincent Chauke, this journey was worth it because of you.

ABSTRACT

Artisanal and small-scale gold mining (ASGM) has devastating impacts on different parts of the environment and is a source of environmental degradation and contamination. ASGM degrades water resources, contaminate soil, sediments and water and lead to serious land degradation problems. ASGM activities are also associated with socio-economic issues such as child labour, prostitution and health and safety concerns. Insufficient understanding of the environmental and social problems of ASGM in Giyani Greenstone Belt has led to lack of mitigation strategies to reduce such problems.

The main aim of this research was to assess and manage the environmental and socio-economic impacts of ASGM in Giyani Greenstone Belt. Remote sensing and GIS and Normalised Differential Vegetation Index were used to assess the effects of mining activities on vegetation cover. Assessment of the effects of ASGM on water, sediments and soil quality involved collection of samples in order to establish their physical and chemical properties. The concentration of toxic and trace metals were determined using Atomic Absorption Spectrometer (AAS) and X-ray Fluorescence (XRF) instruments. The pH meter was used to determine the pH level of the collected samples. Questionnaires, interviews and SPSS were used to assess socio-economic impacts of ASGM.

The study culminated in devolvement of NDVI maps and this was used to assess the effects of ASGM on vegetation cover. Results showed that the mining activities in the area had caused extensive environmental degradation due to serious removal of vegetation cover in the site. ASGM had serious effects on soil, water and sediments quality such as environmental contamination by toxic and trace elements. Soil samples were found with high concentration of As, Cr, Cu, Ni, Pb and Zn as compared to the recommended South African Soil Quality and WHO threshold values for plants. It was found that Klein Letaba had high concentration of Ba, La, V, and Ce above the World Soil Averages for plants. Sediments were heavily contaminated with Cr, Ni, Pb, Zn, As and Ba as compared to the recommended standards prescribed by US EPA and WHO. The pH of water, soil and sediments samples collected from both mining sites were found to be strongly alkaline which affects the plants growth as well as aquatic flora and fauna. Socio-economic issues such as child labour, injuries, educational problems, health and safety issues, police disturbance, creation of jobs and income generation were identified at mine sites.

ASGM had serious effect on vegetation cover through environmental degradation. ASGM also had serious environmental contamination by toxic and trace elements. ASGM had both positive and negative socio-economic issues at mining site which include employment opportunities, income generation, occupational health and safety, police disturbance and arrests and the use of child labour. Mine site rehabilitation is recommended in this study to reduce environmental degradation. The remediation of contaminated area by concentrated toxic and trace elements should be applied at both mining sites. ASGM should be legalised to enhance positive aspects of the mining such as increase in income generation and creation of more employment opportunities. However, there should be enforcement of mining policies to reduce social and environmental problems.

Keywords: *Artisanal and small-scale mining, environmental and socio-economic impacts, mitigation strategies, mine site rehabilitation, sustainable resources management*

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LIST OF ABBREVIATIONS

AAS:	Atomic Absorption spectrometer
ASGM:	Artisanal and small-scale gold mining
DMR:	Department of Mineral Resources
DPMR:	Diamond and precious Metal Regulator
DMR:	Department of Mineral Resources
DME	Department of Mineral and Energy
DPMR:	Diamond and precious Metal Regulator
DWAF:	Department of Water Affairs and Forestry
EC:	Electrical Conductivity
EIA:	Environmental Impact Assessment
GGB:	Giyani Greenstone Belt
GIS	Geographical Information system
MPRDA:	Mineral and Petroleum Resources and Development Act
NDVI:	Normalised Difference Vegetation Index
NIR:	Near Infra-red Reflectance
ppm:	Parts per Million
pH:	Potential of Hydrogen
RED:	Red reflectance value
SPSS:	Statistical Package for Social Science
SQG:	Sediments Quality Guidelines
SAHRC:	South African Human Rights Commission
USEPA:	United States Environmental Protection Agency
WHO:	World Health Organisation
WRC:	World Research Commission

CHAPTER ONE: INTRODUCTION

1.1 Background to the Research Problem

The term artisanal and small-scale gold mining (ASGM) covers a broad spectrum of activities which makes it difficult to define (Phiri, 2011). According to Hilson (2002), artisanal and small-scale mining can be defined as an informal and formal activity that is carried out using low technology or minimal machinery. Such mining activities encompass individuals, small and medium group of miners who extract minerals resources using mercury and other chemicals (WRC, 2004). Small-scale miners are generally unskilled and uneducated people who depend on mining activities for living. In addition, most of the populations of small-scale miners are poverty-stricken and live in the rural areas (Hoedoafia, 2014). According to Hentschel (2002), small-scale mining may be practiced seasonally, part-time or full time in some areas. These activities are characterized by lack of safety measures and health care (Kitula, 2006).

In artisanal and small-scale mining there are informal and formal mining activities. Individuals enter into small-scale mining because of various factors. These factors were described by Arah (2014) as push (i.e. drought and floods) and pull (i.e. employment and income generation) factors. Artisanal and small-scale operators are generally migratory. They move from one site to the other searching for easy ways to extract minerals. In Africa it is estimated that more than 8 million people are involve in small-scale mining and these in turn support about 45 million dependents (Hentschel, 2002).

According to the Hilson (2002), small-scale mining plays an important role in poverty alleviation and rural development through the employment and income opportunity. More especially in developing countries, many people depend on artisanal and small-scale mining for living. However, such mining activities are as well a source of environmental degradation and contamination. They pose problems on the ecological system (Phiri *et al*., 2015). Furthermore, the number of small-scale miners is increasing because of few economic opportunities and increasing of a marketable item produced to satisfy wants or needs (Obiri *et al.,* 2015). However, the more the number of small-scale miners increases, the more the environment problems associated with small-scale-scale mining increase.

Small-scale mining has devastating impacts on different parts of the environment. They degrade water resources, contaminate the soil and lead to serious land degradation problems. In addition, they are associated with a serious noise and dust pollution problems (Phiri *et al*., 2015). Small-scale miners use mercury in the extraction and processing of gold (Arah, 2015). Hence, some of the mineral extraction chemicals such as mercury and cyanide take long to be lowered to environmentally acceptable levels (Obiri et *al.,* 2015). Consequently, there is a need to assess the nature and extent the environmental impacts of small-scale mining activities in areas where these practices are being undertaken.

According to Kessey and Arko (2013), small-scale mining has negative effect on environment because the miners do not give the environment the attention it deserves. That is, eliciting the change and action needed to mitigate its harmful effects. Small-scale miners dig the soil where gold is identified and mix the soil with water to form slurry (Amankwah, 2013). Hence, such soil contains toxic chemicals that can be harmful to flora and fauna. Moreover, such chemicals can affect the quality of water and soil. Consequently, the small-scale gold mining industry is getting more destructive as second largest source of pollution after agriculture in Africa (Twerefou, 2009).

In addition, artisanal and small-scale mining activities are associated with socio-economic issues such as child labour and health and safety concerns. As such, the majority of children would not go to school while undertaking mining activities for little or no pay (Arko, 2014). Due to inappropriate technology, miners get to be exposed to serious safety and health risks. Mercury can be harmful to their health through skin contact and eating plants or drinking water contaminated with high concentration of mercury. Dust pollution and toxic elements from artisanal and small-scale mining activities can poison miners and cause life-long health problems as well as allergic reactions and other immediate problems (Hoedoafia, 2014).

This research focuses on assessment of environmental and socio-economic impacts of artisanal and small-scale gold mining activities at selected sites in the Giyani Greenstone Belt. There is currently, insufficient understanding of socio-economic and environmental/ecological problems of small-scale gold mining in the Giyani Greenstone Belt and these have led to lack of mitigation strategies to reduce the impacts. There is therefore a need for this study to be conducted as in order to come up with strategies for managing the ecological and social impacts. In addition, this will make artisanal and small-scale mining to more efficient, productive and prosperous. This will also help to eliminate negative impacts such as child labour, educational effects and health and safety concerns.

1.2 Objectives of the Research

The main aim of this research was to assess the environmental and socio-economic impacts of artisanal and small scale gold mining activities in the Giyani Greenstone Belt and to come up with action plan for enhancing the positive aspects of the operations and mitigate the adverse effects. The specific objectives of this research were:

- To assess the effects of Artisanal and Small-scale Gold Mining (ASGM) on vegetation cover in the study area,
- To determine the effects of the artisanal and small-scale mining on soil and water quality in study area,
- To identify and assess socio-economic impacts which are associated with artisanal and small-scale gold mining activities, and
- To develop management strategies for addressing the overlapping issues of ASGM and mitigating the adverse impacts of the artisanal gold mining operations on the environment.

1.3 Research Questions

- What are the effects of artisanal and small-scale gold mining on vegetation cover in the Giyani Greenstone Belt?
- What are the impacts of artisanal and small-scale gold mining on water and soil quality?
- What are the socio-economic issues of artisanal and small-scale gold mining?
- What are the management strategies for addressing the overlapping issues of ASGM and mitigating the adverse impacts of the artisanal gold mining operations on the environment?

1.4 Justification of the Research

The main aim of this research was to assess the environmental and socio-economic impacts of artisanal and small-scale mining at Giyani Greenstone Belt. This will have several benefits to both the environment and the communities around the selected sites. The assessment of the environmental impact will establish in-depth knowledge of the nature and extent of ecological problems caused by artisanal and small-scale mining in the study area. The established knowledge about the nature and extent of the environmental problems will be used in the development of the rehabilitation strategies for the mine sites. The developed rehabilitation strategies will serve as a framework or guideline for the selection of appropriate rehabilitation strategies at other artisanal and small-scale gold mining sites in the country.

The assessment of the environmental impacts will have positive impacts to the host and/or neighbouring communities, policy makers and the state as it will inform the formulation of mitigation strategies to reduce these environmental impacts. This research will provide a step towards good land management practices that are crucial in sustainable resources (i.e. water, land, aquatic flora and fauna) management.

One of the objectives of this research was to assess the socio-economic issues of artisanal and small-scale mining in Giyani Greenstone Belt. This will assist in identifying the negative impacts and developing strategies to eliminate the negative socio-economic impacts such as child labour, educational effects and health and safety issues of the operations. In general, this research will come-up with action plan for enhancing the positive aspects of the operations and mitigate the adverse effects. The impacts of artisanal and small-scale gold mining in the Giyani Greenstone Belt are not well known. Therefore, this research will assist the host community as it will raise the social problems in the mine site and recommend strategies to avoid such problems.

1.5 Description of the Study Area

This section describes the selected study area in terms of the geographical location, climatic condition, land use, pedology, topographic relief, drainage pattern and vegetation covers.

1.5.1 Geographical location of the study area

The Giyani Greenstone Belt is found in the Limpopo Province of South Africa. The selected sites in Giyani Greenstone Belt namely Louis Moore and Klein Letaba are the abandoned gold mining sites. The nearest towns to both Louis Moore and Klein Letaba gold mines are Giyani town and Thohoyandou town as shown in Figure 1.1.

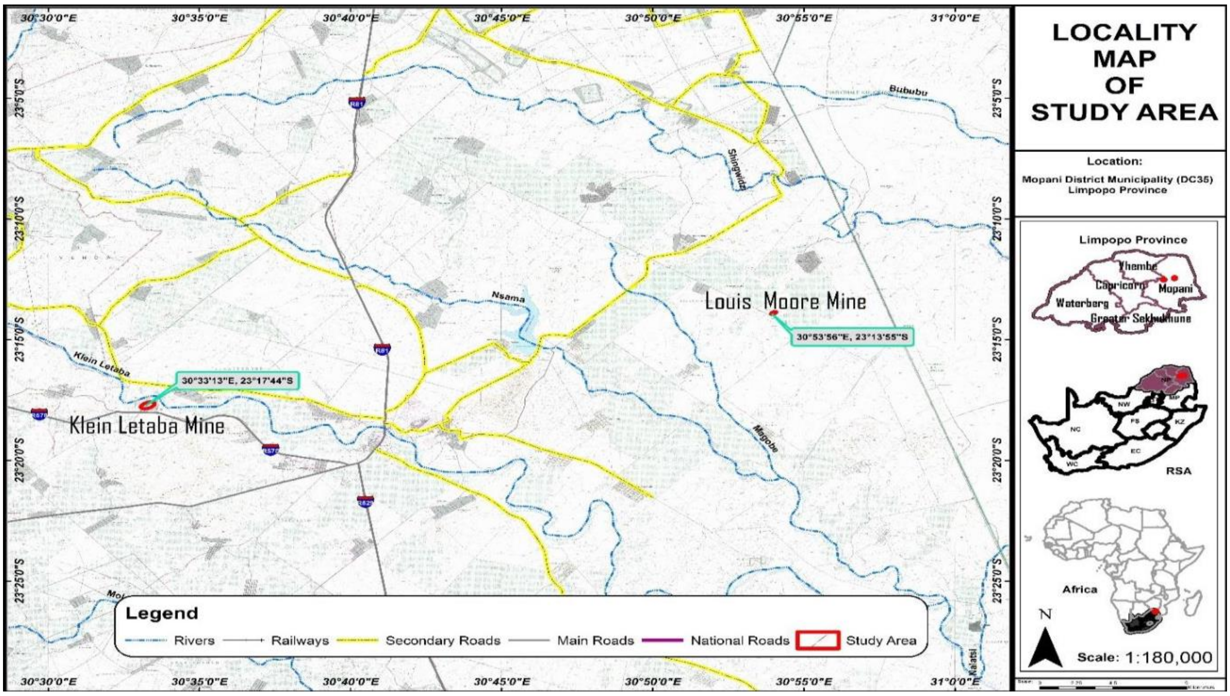

Figure 1.1: The geographical location of the study area

The Louis Moore Mine is situated in Mavalane Village found approximately 14km northeast of Giyani Town and 72km from Thohoyandou town. On the other hand, the Klein Letaba Mine is also within GGB in Mapuve Village which is approximately 13km northwest of Giyani Town and 87km from Thohoyandou Town at the co-ordinates of 23º 13' 55" S (latitude) and 30º 33' 13"E (longitude).

1.5.2 Climate of the area

The area is very dry and warm, with a low annual precipitation. The annual minimum temperatures in the study area ranges from 14°C to 17°C while the maximum is between 28°C and 30°C. The maximum temperature is experienced in January while the minimum temperature is recorded in July (Chauke, 2011). Climate is categorised into two seasons; namely, wet and cool dry season. During warm wet (i.e. from December to February) temperatures are warm, ranging from 16°C to 25 °C. However, cool during dry season (i.e. from May to August) the temperatures ranges from 18°C to 25°C. Winters in Giyani are mild during the day and cold during the nights. The rainfall season is between September and March while the winter season is from April to August. The annual precipitation varies from less than 450mm in low-lying plains to more than 2300mm in the mountainous areas (Chauke, 2011).

1.5.4 Topography and drainage pattern

The study area is approximately 150 meters above the main sea level. Most of the basins consist of the relatively undulating terrain separated by ranges of steep sided hills and mountainous. The Ntsami River, which flows north-eastward, has deep gorges through the hills and mountain ranges, which resulted in spectacular landscape units. The surrounding areas also consist of the valley and the presence of such valleys around the mine disturbs the flatness of the area making it undulating.

The rivers are seasonal and the area is dominated by Mopani veld. The Ntsami and Rivati rivers flow on the eastern side of the study area. The Ntsami and Rivati rivers are situated in low rainfall areas and record peak flow during wet summer times only. In the south-southwest parts of the study area including Ntsami and Letaba sub-catchments are characterized by poor drainage, therefore they are considered endorheic (Chauke, 2011).

1.5.6 Pedology of the study area

Soil formation across the study area reflects the strong influence of the underlying rocks which are mainly climatic features and biological activity. The west and south are dominated by moderately deep sandy. Sandy clay loam is another soil type which is dominant. In the north and east, soil is reddish. This reddish coloured soil play a significant role in agricultural activities along the Ntsami River (Chauke, 2011). The colour of the soil ranges from reddish to brownish (Rembuluwani, 2011).

1.5.7 Land use and vegetation cover

The area around and within Giyani Greenstone Belt is widely used for settlement. Very little subsistence farming is practiced in the area. Settlements occupy a large amount of the land in the study area. There is also land reserved for grazing. Around the study area subsistence agriculture is being practised. The area is also used for mining activities more especially small-scale mining. The tailings dam covers a large area around the two selected abandoned mines.

The study area falls within Mopani woodland. The vegetation in the study area is classified under the lowveld mopaniveld savannahs, characterised by mixture of trees, shrubs and grasses (Rutherford *et al.,* 2006; Makhado *et al.,* 2009). In the study area, *Colophospermun Mopani* occurs in abundance together with many other trees species such as *Acacia species, Commiphora species, Cassine aethlopica, Terminalia sericea, Diopsyros mespiliformis, Combretum api culatum, Sclerocarya bi rea, Dichrostachys cinerea and Dalbergia melanoxylon* (Makhado *et al.,* 2009).

1.6 Operational Definitions

An easy understanding of the work presented in this dissertation depends on clear an understanding of some terms and concepts as they are used in the research. Therefore, this section presents the definitions of the key terms and concepts that form part of this dissertation as follows:

- *Artisanal and Small-scale mining (ASM):* is an informal or formal activities which is carried out using low technology or minimal machinery, such mining activities encompass individuals, small and medium group of miners who extract minerals resources using mercury and other chemicals (Phiri, 2011).

- *Environmental impact*: Is any change in the state of any component of the environment whether adverse or beneficial of the environment such as water, air and natural resources, flora, fauna and that which results or partially results from projects or departments (Singo, 2011).

- *Economic impacts:* is the effect that an event, policy change or market trend will have on economic factors such as interest rate or employment. However, in this study economic impact referred to the effect that artisanal and small scale mining will have on economic factors such as income generation or unemployment (Hoedoafia, 2014).

- *Social impacts:* is the effect of an artisanal and small-scale mining operation on the social fabric of the community and well-being of individuals and families (Hentschel *et al.,* 2003).

- *Sustainable resources management:* refers to the management of natural resources such as land, water, soil, plants and animals with a particular focus on how management affects the quality of life for both present and future generation.

- *Mitigation strategies:* is a process taken to reduce or eliminate long-term risk of artisanal and small-scale gold mining to people and property from hazards and their impacts.

- *Mine site rehabilitation:* is important to environmental sustainability which involves returning the land to its natural state post mining.

1.7 Organisation of the dissertation

This dissertation is arranged into six chapters. Chapter One introduces the geographical as well as the environmental and socio-economic aspects that led to the identification of the problem. The chapter expounds on the problem setting, further breaking it down into objectives, which link to address the main aim of the study. The background section involves an overview of the environmental and socio-economic impacts of artisanal and small-scale gold mining. This also consists of background to research problem, aim and objectives, research questions and description of the study area, as well as a justification of the study.

Chapter Two presents the synthesis of the literature relevant to the main aim and specific objectives of this research. The chapter reviews the available literature on artisanal and small scale gold mining in relation to environmental and socio-economic impacts.

Chapter Three presents description of the methods, tools and procedures employed during data acquisition aspect of this research. This chapter also introduces the research design that focuses on type of design, sampling design, ethical considerations, reliability and validity. The theoretical concepts are broken down into themes based on the objective.

Chapter Four is earmarked for the presentation and interpretation of the environmental and socio-economic impacts of artisanal and small-scale gold mining in Giyani Greenstone Belt. This chapter analysed and presents the physical degradation of ASGM on the environment. In addition, the effects of ASGM on vegetation cover, soil and water quality are also presented. In summary, it presents and discusses the results of the research.

Chapter Five presents and interpret the management strategies of the environmental and socio-economic impacts of the artisanal and small-scale mining. The management strategies were also addressed in a form of conceptual model or framework. Chapter Six is earmarked for presentation of the summary, conclusion and recommendations of the study.

CHAPTER TWO: LITERATURE REVIEW

This chapter presents a review of previously published material relating to small-scale mining and associated environmental impacts. It also shows the gap in knowledge that this research aims to fill and discuss small-scale gold mining operations and their associated problems. In addition, the chapter provides overview of management strategies used to address the overlapping issues of artisanal and small-scale mining and part of overlapping issues.

2.1 Regional Geology and History of Mining

The Giyani Greenstone Belt (GGB) also known as Sutherland Greenstone Belt is mainly recognised by its gold mineralisation. As shown in Figure 2.1, Louis Moore and Klein Letaba Mines are part of the Giyani Greenstone Belt. According to Steenkamp and Clark-mostert (2012) the belt is almost surrounded completely by the migmatitic gneiss. These gneisses occur mainly at the north and south of the belt. The central part of the Giyani Greenstone Belt comprise of succession of ultramafic schists consisted of trmolite (Davis *et al.,* 2012). Massive and pillowed hornblende-bearing amphibolite represents the mafic rocks in the belt. Rhyolite which are fine grained rock consisting dominantly of quartz and microcline with minor plagioclase and muscovite (Rembuluwani *et al.*, 2014).

Metasedimetary rocks are minor in the GGB. These include rocks such as quartz-biotite schists and quartz-muscovite-garnet (Davis *et al.,* 2012). The ultramafic rock and micaceous quartzile are available but in the far north-eastern part of the belt. Serpentinite body was reported by Pretorius *et al*. (1988) to be only found along the east part of the belt within the surrounding gneisses. According to Rembuluwani *et al*. (2014), the Giyani Greenstone Belt is a shallow feature and allochthonous. In the northern part there are scattered outcrops that suggest the occurrence of a succession dominated by mafic and ultramafic rocks.

In 1870, Button and Sutherland discovered the Murchison and Sutherland Greenstone Belt (now known as Giyani Greenstone Belt) goldfields. After the discovery of the GGB, mines such as Louis Moore, Ellerton, Tombstone and Birthday were opened (Steenkamp and Clark-mostert, 2012). In 1886, the gold rush started in the Giyani Greenstone Belt. The area where the gold rush started was declared as the public digging area by the Zuid-Afrikaansche Republick (Davis *et al*., 2012. The Anglo-Boer second War interrupted mining and after the war, rich goldfields of the Witwatersrand had surpassed the smaller deposits of the Eastern Transvaal (Steenkamp and Clark-mostert, 2012). At the New Union Mine, gold mineralization was discovered in 1934.

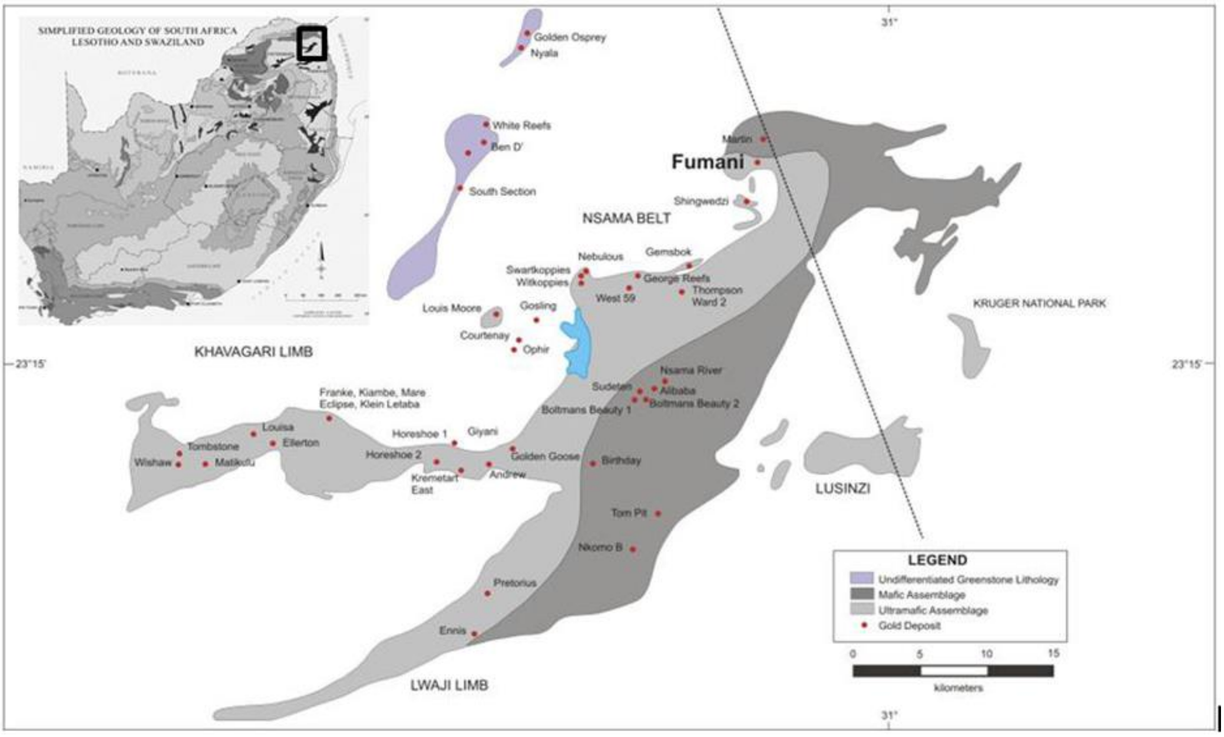

Figure 2.1: Geological map of Giyani Greenstone Belt (Steenkamp and Clark-mostert, 2012)

2.2 Issues of Artisanal and Small-Scale Mining

The definitions of artisanal small-scale mining (ASM) vary and there is no exact definition (Phiri, 2011). According to Macdonald *et al.* (2014), artisanal and small-scale gold mining (ASGM) can be considered to be subsistence mining carried out by individuals or small collectives using rudimentary technologies for both extraction and processing of the mined out ores. The operations of ASGM can be formal or informal but both of them have the devasting effects on the environment (Hoedoafia, 2014).

Formal mining refers to the legal artisanal and small-scale mining. In this type of artisanal and small-scale mining, miners have their claims registered in accordance with the provisions of mines and mineral laws (Hentschel *et al.,* 2003). Informal small-scale mining refer to those mines that are not registered in accordance to the relevant department in the country or region. In this type of artisanal and small-scale mining, miners operate without legal mining titles (Dreschler, 2001). According to Spitz and Trudinger (2008), artisanal mining as the small-scale mining operations; can be defined as the extraction carried out using manual methods by the individuals or group of family. Artisanal miners frequently use toxic materials in their attempts to recover metals and gems (Kessey and Arko, 2013). For example, artisanal and small-scale gold mining is one of the important sources of toxic chemicals (especially mercury) release into the environment.

In general, there is a thin line between artisanal and small-scale mining. According to World Business Council for Sustainable Development (2003), small-scale mining is particularly widespread in some developing countries of Africa, Asia and Latin America. They have serious negative effect on environment mainly due to the fact that miners do not give the environmental protection the attention it deserves (Kessey and Arko, 2013). That is, eliciting the change and action needed to mitigate its harmful effects. As a result, small-scale gold mining industry is getting more destructive as second largest source of pollution after agriculture in Africa (Twerefou, 2009).

Artisanal and small-scale gold mining contribute in the alleviation of poverty through the creation of employment opportunities. This type of mining can be a source of cash income on seasonal basis, very often to women (Owusu and Dwomoh, 2012). Most of the people get involved in artisanal and small-scale mining due to the fact that they need to improve their standard of living, generate income, unemployment reasons, poverty, and economic crisis. However, in many countries (especially in Africa, Asia and Latin America), ASM has been one of the major contributors to poverty alleviation (World Business Council for Sustainable Development, 2003).

Besides the fact that ASM contribute in poverty alleviation and improve the standard of living in developing countries, they are also a source of environmental contamination and degradation (Hentschel *et al*., 2003). Artisanal and small-scale gold mining affect the environment in different ways which include water resources degradation, contamination of soil and water, land degradation, noise and dust pollution (Phiri *et al*., 2015). Small-scale miners use mercury and/or cyanide in the extraction and processing of gold (Arah, 2015). These mineral extraction chemicals such are known to take long to be lowered to environmentally acceptable levels in soils (Dreschler, 2001).

ASM is also associated with serious socio-economic concerns. Some of the socio-economic issues of ASM operations include prostitution, spread of diseases (more especially HIV and AIDS) and social ills like drugs and alcohol abuse and creation of violent society (Obiri *et al.,* 2015). In artisanal and small-scale mining; working conditions are not the most favourable in many countries. This is serious in the case of illegal mining because there are no specific regulations regarding health and safety issues in artisanal and small-scale mines (Nyambe and Amunkete, 2009). However, due to the ignorant of miners even the regulations regarding the safety and health, might be there but not followed.

Health and safety has been one of the serious problems confronting small-scale miners. According to Hentschel *et al*. (2003), health and safety risks such as exposure to dust (silicosis), exposure to toxic chemicals (such as mercury and cyanide), noise effects and vibration, problems of heat and lack of oxygen and effects of over-exertion, not enough work space and not suitable mining equipment and machinery are of concern and they are associated with most small scale mining operations.

2.3 Regulatory Framework

In South Africa, the policy and legislative framework relevant to artisanal and small-scale mining (ASM) can be considered from two perspectives. The first perspective relates to the regulation of the mining sector which covers aspects such as mining rights and the attendant obligations relating to utilisation of the rights (Mutemeri and Petersen, 2002). Also related to administration of the mining sector are policies and laws about beneficiation and marketing of minerals. The other policies and legislative provisions are concerned with the artisanal and small-scale mining operations as business entities (Mutemeri *et al.,* 2010).

In terms of mining laws and regulations, artisanal and small-scale mining is regulated through the Mineral and Petroleum Resources and Development Act (MPRDA) of 2002 (Hentschel *et al.* 2003). The nature of artisanal and small-scale mining activities is often the basis for what is allowable in the licensing of small scale mining activities. For example, in the Mineral and Petroleum Resources and Development Act (MPRDA) of 2002, even though there is no specific mention of the term small-scale mining, a mining permit whose provisions are in keeping with what is generally accepted as small-scale activities is provided for (Department of Mineral and Energy of South Africa, 1998).

According to Hentschel *et al.,* 2003, in the Department of Mineral Resources (DMR) there is a Directorate for Small-scale Mining, which is charged with implementation of government policy with regards to supporting development of the artisanal and small-scale mining sector. On the other hand, Mine Health and Safety Act of 1996 of South Africa govern the aspects of health and safety in mining (DMR, 1998). Environmental aspects are governed by the National Environmental Management Act of 1998, the Mining and Mineral Act of 1991, Environmental Impact of Assessment (EIA) guidelines of 1997, the Environmental Conservation Act of 1986 and the aide-memoire requirements of 1992 (South African Human Rights Commission (SAHRC, 1998).

In South Africa, all the small-scale mining operations applying for mining licence are now forced to pay a deposit for environmental rehabilitation (Mutemeri *et al.,* 2010). The issue of labour relations in mining are governed by the Labour Relation Act of 1995, the basic conditions of Employment Act of 1997, the Employment Equity Act of 1998 and the Skills Development Act of 1998 (Mutemeri and Petersen, 2002). In terms of skills development, the Skills Development Act of 1998 sets out the framework for developing a coordinated approach to skills development in the Republic of South Africa (Hentschel *et al.,* 2003; Mutemeri *et al.,* 2010). Such act was developed in order to improve the productivity in the workplace, promote self-employment and encouraging employers to use the workplace as an active learning environment and to provide opportunities for new entrants to the labour market to gain work experience.

In terms of the beneficiation of mining in South Africa, there are several pieces of legislation supporting the beneficiation and value adding of minerals. Therefore, the Mineral and Petroleum Resources and Development Act (MPRDA) of 2002 provides for the promotion of beneficiation (Mutemeri *et al.,* 2010). While the Directorate for Beneficiation Promotion, the State Diamond Trader (SDT) and Diamonds and Precious Metal Regulator (DPMR) supports the implementation of government policy on beneficiation (South African Human Rights Commission (SAHRC, 1998).

The Diamond Amendment Act 29 of 2005 provides for the establishment a State Diamond Trader and the Diamond Regulator. The acquisition, smelting, refining, beneficiation, use and selling of precious metals is provided by the Precious Metals Act 37 of 2005 provides (SAHRC, 1998). The beneficiation and refining is licensed through the Diamonds and Precious Metal Regulator (Hentschel *et al.,* 2003). The aim of the Diamonds and precious Metal Regulator is to promote the beneficiation of South African diamonds and precious metals as well as to ensure equitable access.

2.4 Artisanal and Small-Scale Gold Mining and Processing Methods

Artisanal and small-scale miners use amalgamation process in the extraction of gold, this include the use of mercury. According to Dreschler (2001) mercury is used because of its ability to bind to gold to form an alloy which helps separate the precious metal from rock, sand and other material. Amalgam is then heated often in a shovel or metal pan over an open fire to vaporize the mercury, leaving behind only the gold (Kessey and Arko, 2013). Amalgamation is carried out in different ways, including whole-ore and heavy mineral concentrate amalgamation.

The artisanal and small-scale miners also process the gold through sluicing methods (Phiri *et al.,* 2015). Sluices use water to wash ore or alluvium down a series of angled platforms (Obiri *et al.,* 2015). As water washes sediment down a sluice, gold particles sink and are captured by material covering the bottom of the sluice, often carpets (Obiri *et al*., 2010). Sluices are usually inclined at 5 to 15 degree angle (Phiri, 2011). As moving water travels down a sluice, it generates greater force and keeps gold particles from sinking easily. However, most gold is captured at the beginning of the sluice (Dreschler, 2001).

Artisanal and small-scale mining uses the different methods to process gold. They can use the shaking table methods. Shaking tables are elevated tables tilted to one side with raised ridges running horizontally down their length (Hentschel *et al.,* 2003). Mineral feed (crushed ore or sediment) and water are released at one end of the table. The water washes the feed down the table. As the material is washed down the table, specialized grooves trap gold and direct it to collection points on the side of the table as lighter minerals are washed away (Obiri *et al*., 2010). During this process, the table is continually shaken by a motor to agitate the material and aid in the separation of gold particles (Arah, 2015).

2.5 Environmental Problems of Artisanal and Small-Scale Gold Mining

Small-scale mining activities pose serious problems on the environment and on the surrounding communities. It has been found out that such mining also pose enormous problems on the miners (Armah *et al.* 2013). The environmental impacts associated with ASM are discussed in the following sections.

2.5.1 Habitat degradation and loss of biodiversity

Habitat degradation is a decline in the state of specific types of habitat. According to Oblokuteye (2010), habitat degradation includes the destruction of the natural landscape and alteration of the hydrologic function. Small-scale mining has the effects on the habitat structure and function by disturbing the processes that create, connect and maintain habitat (Mathada, 2014). Artisanal small scale gold miners are responsible for the clearing of extensive habitat areas for fuel and infrastructural development in areas where those mines are located (Phiri *et al.,* 2015).
In the process of artisanal and small-scale gold mining, land is cleared and clear- cutting of trees takes place for mining space (Abdulgafar and Ishola, 2014). This clear-cutting of habitats disrupts local ecosystems, and causes animals to flee the area or perish. The loss of habitat results from the removal of vegetation to get a space for small-scale mining operations (Obiri *et*

al., 2015). However, the loss of habitat has effects on the wildlife and it is also one way or another affect the ecological system (Oblokuteye, 2010).

2.5.2 Mercury pollution

Mercury pollution is the principal environmental problem caused by small-scale mining activities through gold processing and extraction (Dreschler, 2001). Mercury can pollute the fresh vegetables and wild vegetation that may be consumed by human as well as animals. In addition, rivers and other water bodies that serve as a source of drinking water for surrounding communities may be contaminated by mercury (Obiri *et al*., 2010). Moreover, the pollution of mercury can disrupt aquatic flora and fauna (Phiri, 2011).

During the process of gold extraction by amalgamation, mercury is released to nearby water bodies from such process. As such during the burning of amalgam, soil and water can be contaminated (Dreschler, 2001). Mercury pollution also evaporates from the soil to the atmosphere thus leading to air pollution (Tarras-Wahlber, 2000). The high concentration of mercury into water bodies (i.e. rivers and lakes) can be transported downstream and spread over a huge area as shown in Figure 2.2. In sediments, mercury can change into methyl mercury which may be absorbed by aquatic animals (Kessey and Arko, 2013). According to Abdulgafar and Ishola (2014), the use of toxic chemicals which are used in artisanal and small-scale gold mining makes their way into the soil and the water which disrupt the local wildlife by poisoning their sources of food and water.

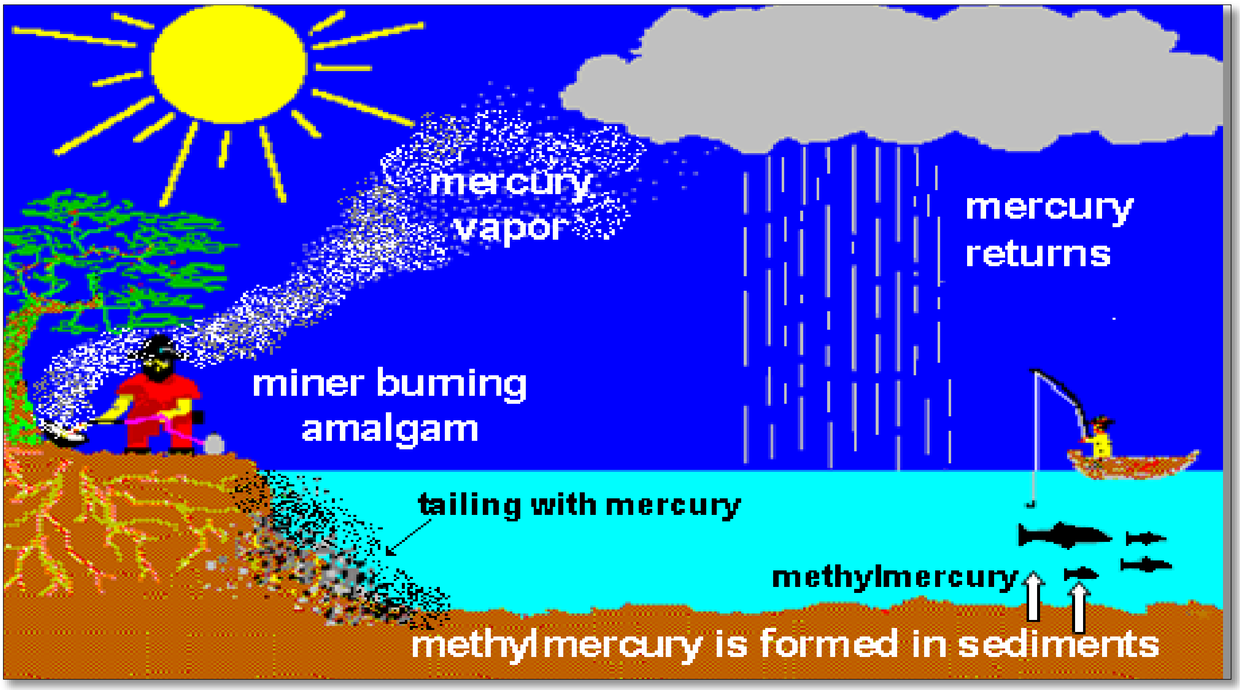

Figure 2.2: Amalgamation process contaminating the environment (Phiri, 2011).

2.5.3 Degradation of water resources

Water quality can be defined as the conditions of the water including chemical, physical and biological characteristics. Artisanal and small-scale mining can have effects on the quality of the water in the water bodies. According to Roussel *et al*. (2000), artisanal small-scale mining and the tailings dams act as a source of environmental contamination, including water contamination. It affects fresh water through heavy use of water in the processing ore (Hammond *et al.,* 2013)

Small-scale gold mining affects water quality in many ways including chemicals contamination. It may release arsenic and other toxic chemicals which may be harmful to the environment including water quality (Dreschler, 2001). Toxic elements pollution occurs when elements such as arsenic, cobalt, copper, cadmium, lead, silver and zinc contained in excavated rock or exposed in an underground mine come in contact with water (United States Environmental Protection Agency, 2007). Furthermore, the small-scale mining can also affect the water quality through acid mine drainage. Acid mine drainage is the outflow of acidic water from metal mines (Spitz and Tridinger, 2009). Department of Mineral and Energy (2000) defined acid mine drainage as the natural process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water.

Mines including artisanal and small-scale mining are sources of the acid mine drainage which is one of the environmental concerns (Spitz and Trudunger, 2008). Acid mine drainage is one of the most serious mining threats on both surface and ground water resources (Chauke, 2011). It may affect water supplies including both surface and groundwater used for domestic purposes (Spitz and Tridinger, 2009). Acid mine drainage severely degrades water quality and can kill aquatic life and make water virtually unusable (Hammond *et al.,* 2013).

2.5.4 Problems of dust and noise Pollution

Mine dust has enormous effects on the human health and the environment (Spitz and Tridinger, 2009). Dust from the artisanal and small-scale mining operations may spread over the surroundings more especially during dry weather (Kitula, 2006). This dust may be harmful for flora and fauna since they might be containing toxic chemicals. The dust and fumes from artisanal small-scale gold mining generated by blasting are quickly diluted and dispersed as most operations are shallow workings (Al-Hassan and Amoako, 2014). Air pollution resulting from artisanal and small-scale gold mining related activities comes from the generation of dust and emission of mine gases especially during drilling, blasting, grinding and crushing of ore (Dreschler, 2001).

Dust from artisanal and small-scale gold mining activities may also end up in nearby water bodies, in addition, when the dust smothers leaf surfaces, vegetation can be damaged by the blocking of the leaf stomata, hence inhibiting gas exchange in plants and reducing photosynthesis rate (Mathada, 2014). According to Dreschler (2001), the widespread use of pestle and mortar generates fine quartz dust, which is inhaled by those involved (mostly women) in the process. In surface operations, dust and emissions are diluted by the wind. However, due to the confined nature of small scale underground mining activities, dust generated in the stopes accumulates and serves as a potential health threat to the miners (Kitula, 2005).

2.5.5 Land degradation

According to Bansah and Bekili (2015), land degradation is the reduction in the capacity of the land to provide ecosystem goods and services. Despite the contributions of the artisanal and small scale gold mining sector to the economy, its negative effects especially on degradation of environment cannot be overemphasised (Kitula, 2006). A common indicator of land degradation is chiefly soil erosion among the reduction in vegetation cover and changes in vegetation composition (Al-Hassan and Amoako, 2014). Artisanal and small-scale miners degrade the land as they need space to carry out their mining operations which also leads to removal of the topsoil and increases the water erosion in the area (Oblokuteye, 2010). This lead to excavation of land which can result in killing of animals because they can fall in such pits while running, however, it is also dangerous to human beings.

Surface artisanal and small-scale mining method often results in the removal of large quantities of topsoil, leaving the land bare and susceptible to erosion (Bansah and Bekili, 2015). Considerable areas of land and vegetation in many mining communities are cleared to accommodate surface mining activities (Kitula, 2006). Abandoned artisanal and small-scale mining pits without proper reclamation also lead to further degradation of the landscape (Shoko, 2005). The set of problems caused by the land degradation include soil erosion, siltation, and soil compaction, destruction of ecosystems and loss of biodiversity (Nwango, 2010). This threatens the economic and physical survival which leads to household and national food insecurity in many developing countries (Armah *et al.* 2013).

2.6 Socio-economic Concerns of Artisanal Gold Mining

This section provides the common socio-economic impacts associated with the artisanal and small-scale gold mining adopted from various related studies. These socio-economic impacts include the increasing of employment opportunities, improvement in local income and economy, occupational health and safety as well as the use of child labour.

2.6.1 Increased employment opportunities

Artisanal and small-scale gold mining generates employment for people who have few alternatives to earn a similar level of income (Bhebhe, 2015). In developing countries, artisanal and small-scale mining has several benefits including employment and revenue (Hilson, 2003). These miners are involved in the extraction and processing of minerals because they can generate income (Kitula, 2006). Artisanal and small-scale mining operations employ and support millions of people which in turns contribute in poverty alleviation (Hilson, 2002). Artisanal and small-scale mining has become integral to the economies of many mining countries in the developing world because of its significant contribution to world mineral extraction (Hoedoafia *et al.,* 2014). According to Hentschel *et al*. (2003) more than 12 million people are involved in artisanal small-scale mining in the world. This employment is really contributing in the rural development, poverty alleviation and income generation.

2.6.2 Improvements in local income and economy

According to Wilson *et al.,* (2015), artisanal and small-scale gold mining activities have contributed significantly to gross domestic product (GDP) in developing countries, thus, making these activities a significant source of income and employment for miners and their dependents. Artisanal and small-scale gold mining contribute to the local income and economy through foreign exchange and revenues (Tom Dery *et al.,* 2012). For instance in Ghana there was an increase of 63% of gold production with its export revenue increasing about 173 million dollars (Arah, 2014). One of the major contribution of the formal artisanal and small-scale gold mining to the local income and economy of developing countries include the payments of royalties, revenue taxes and company taxes on wages and salaries (Amankwah and Anim-sackey, 2004).

2.6.3 Occupational health and safety

In artisanal and small-scale mining working conditions are not the most favourable in several countries. The conditions are even more deplorable in illegal mining because there are no specific regulations regarding health and safety in artisanal and small-scale mines (Nyambe and Amunkete, 2009). Health and safety has been one of the serious most problems for the small-scale miners, more especially illegal miners. According to Hentschel *et al.* (2003), there are five major health and safety risks of artisanal and small-scale mining and these are exposure to dust (silicosis), exposure to toxic chemicals (such as mercury and cyanide), noise effects and vibration, problems of heat and lack of oxygen and effects of over-exertion due to lack of enough work space and use of unsuitable mining equipment and machinery).

According to Jennings (1999), there are some causes of accidents that may result in serious and life-time injuries in small-scale mining and these may be attributed to lack of ventilation; lack of knowledge, misuse of explosives; lack of training, rock falls and poorly maintained equipment. Working conditions that are inappropriate result in more accidents in small-scale mining than in medium and large scale mining (Tarras-Wahlberg *et al.,* 2000). According to Hoedoafia *et al*. (2014), this is not always the case due to the nature of small-scale mining; the accident may also be low due to low mechanization compared to large scale mining.

2.6.4 Use of child labour in ASGM

Child labour refers to the employment of children in any work that deprives children of their childhood. However, child labour is widespread in much of the small-scale mining because of the poverty (Hilson, 2003). Children are involved in artisanal and small-scale mining for little or no pay (Hoedoafia *et al.,* 2014). Artisanal and small-scale mining have several negative effects on children such as health effects, detriment of their growth and not going to school (Phiri *et al.,* 2013). According to Jennings (1999), most of the child labour in artisanal and small-scale can be categorised among the worst forms of child labour in terms of the ILO Convention (No. 182). There is need for employers and organisations to help artisanal and small scale mining to become more efficient, productive, prosperous and eliminate child labour.

According to Nyambe and Amunkete (2009) both boys and girls between the ages of 6 to 17 are involved in the artisanal and small-scale mining operations. These children are involved in each process of artisanal and small-scale mining, processing and selling of products (Nyambe and Amunkete, 2009). According to Hilson (2002), the use of child labour is not legal, even if it is formal type of artisanal and small-scale miming. The majority of the children that are involved in artisanal and small-scale gold mining are illiterate as they spend lot of time at mining sites and not at school. Most artisanal and small-scale mining activities in developing countries involve young children who are either working with other members of their family or others who just go there to sustain their own livelihoods like the orphans (Tarras-Wahlberg *et al.,* 2000). In addition, this factor leads to many children dropping out of school and others failing to attend school completely from childhood.

2.7 Management of impacts of artisanal and small-Scale gold mining

The artisanal and small-scale gold mining has enormous impacts on the environment and communities such as environmental degradation and contamination, the issue of child labour, occupational health and safety. Therefore, there is a need for the mitigation measures of the impacts of ASGM to eliminate such impacts on the environment and surrounding communities. This section provides the strategies that can be used in improving and managing the artisanal and small-scale gold mining operations which include the following: Policies governing ASM, environmental education and awareness, access to mining skills, training, equipment and machinery; and easing the registration process for ASM.

2.7.1 Policies governing ASM

A policy is a course or principle of action adopted or proposed by an organization or individual. Currently, in many developing countries where artisanal and small-scale mining operations are taking place, there are no clear policies governing artisanal and small-scale mining operations (Hilson, 2003). This increases the long-term effects on mining on the environment as there is no effective policy governing miners to mine while considering environmental sustainably and management. However, most of the governments in developing countries are ignorant of the informal artisanal and small-scale mining. According to Kessey and Arko (2013), it is necessary to have an effective policy aimed at mainstreaming disaster risk reduction in all artisanal small scale gold mining activities. It is very important for the governments to come up with rules and regulations that will guide prevention and mitigatory plans in artisanal gold mining activities (Phiri *et al*., 2015). The majority of populations involved in artisanal and small-scale gold mining activities are ignorant of negative effects of their activities (Hoedoafia *et al.,* 2014) but mainly focus on the positive impacts of such activities.

2.7.2 Environmental education and awareness

Environmental education and awareness of the surrounding communities on artisanal and small-scale gold mining activities is one of the major management strategies to reduce the impacts of such activities (Kitula, 2006). This is important as it provides information of the long-term effects of artisanal and small-scale mining operations that can be harmful to the health and ecological aspects. In order to be able to reduce and manage the impacts of artisanal and small-scale mining activities, population involved in such activities should be given education about the risks and impacts of mining on the environment (Arah, 2014). In addition, they should be given information of the toxic chemicals that they use to extract gold such as cyanide and mercury (Hilson, 2003). In order to reduce unnecessary removal of natural resources, there is a need to educate people involve in artisanal and small-scale mining about the importance of natural resources and environmental sustainability (Kessey and Arko, 2013).

2.7.3 Access to mining skills and training

Lack of skills on is the main challenge facing artisanal and small-scale mining sector (Hinton, 2005). The state should provide the mining skills and training to the populations involved in artisanal and small-scale mining since this has notable of reducing the environmental and health problems while improving mining production (Arah, 2014). Each and every mining activity including the artisanal and small-scale mining requires a skill in order to be more fruitful. The management skills and training are very much important as they encourage mining activities to be conducted by taking into consideration environmental management and sustainability (Hoedoafia *et al.,* 2014). Thus, the local governments in developing countries and departments such as Department of Mineral and Resources in South Africa should consider provision of training and management skills for artisanal small scale miners in order to reduce the long-term effects and associated disaster risks.

2.7.4 Access to mining equipment and machinery

Lack of appropriate mining equipment and machinery are key challenges that artisanal and small-scale miners are facing (Twerefou, 2009). The reason why artisanal and small-scale mining are classified as small-scale sectors is because of the equipment and machinery they use (Kessey and Arko, 2013). According to Hoedoafia *et al*. (2014), if the artisanal and small-scale miners are helped or assisted with appropriate machinery and other mining equipment, they can be encouraged to form cooperatives and mine sustainably and create formal employment. In addition, if small-scale miners are able to mine sustainably, long-term effects on the environment and health may also be reduced.

The governments in developing countries, where there are artisanal and small-scale mining operations, need to create investor confidence (Phiri *et al*., 2015). This will enable investors to come and mine thus creating employment for local communities. This will be a positive drive in managing the issue of lack employment, access to finance and credits while encouraging environmental management (Arah, 2014). Poor equipment, machinery or technologies in general pose a serious problem to people involved in mining activities (Amankwah and Anim-sackily, 2004). The lack of appropriate equipment and machinery in artisanal and small-scale gold mining means that the work will be undertaken manually, thus resulting in fatalities (Armah *et al.,* 2013). According to Hilson (2002), the use of appropriate machinery and technologies reduce the injuries and health problems due to proper occupational safety standards.

2.7.5 Easing the registration process for ASGM

Artisanal and small-scale gold mining are facing a serious challenge of operating illegally in many developing countries (Obiri *et al.,* 2015). Illegal mining refers to operating without an applicable or appropriate legal framework (Macdonald *et al.,* 2014). Illegal mining can both increase resilience by providing an economic livelihood activity and increase vulnerability as it removes the protections and opportunities provided by the government (Obiri *et al.,* 2010). According to Mensah *et al,* (2015), government should remove and consider the amendment of the difficulties and process of registration regulations such as registration fee for illegal artisanal and small-scale mining as majority of illegal mining cannot afford to pay. This may enable more people involved in ASGM to register and obtain mining permit thereby reducing the high rates of environmental impacts associated with illegal mining activities while enhancing the positive aspects of mining. The informal artisanal and small-scale gold are motivated merely by a livelihood and survival intentions which makes them to pay no respect to environmental sustainability (Mensah *et al.,* 2015).

CHAPTER THREE: RESEARCH METHODOLOGY

This chapter presents the methods used in order to achieve the objectives of this research. It gives ideas on the kind of data needed and the specific methods employed in the collection and analysis of such data. Site characterisation was conducted in the study area with the aim of establishing the nature and sequence of artisanal and small-scale gold mining activities. Research design for this study was both qualitative and quantitative. Remote sensing was used to detect and analyse the effects of artisanal mining on vegetation cover. Research instruments such as interviews and questionnaires were used in the collection of data to quantify the socio-economic impacts of artisanal and small-scale gold mining operations in the study area. The flow of the methods and procedures followed in the collection and analysis of data to fulfil the objectives of this research are shown in Figure 3.1.

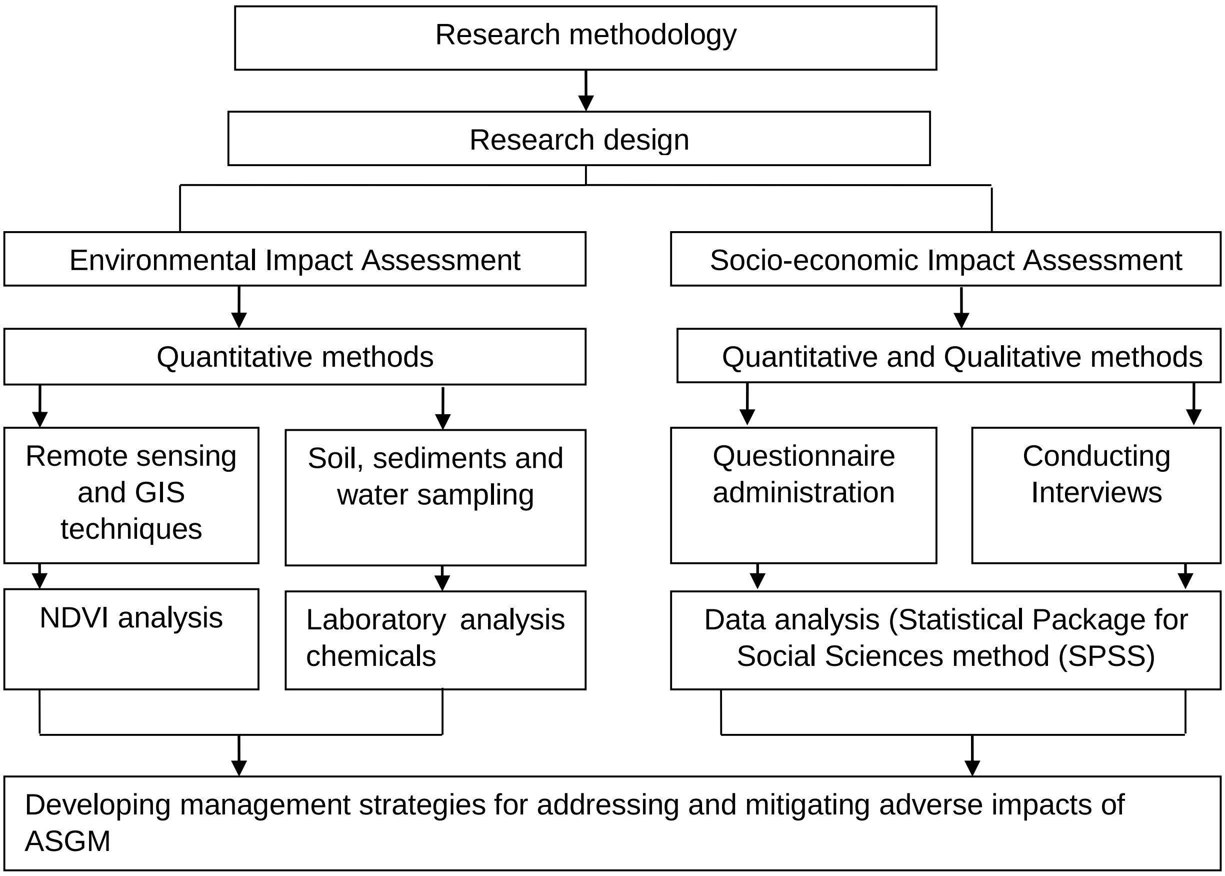

Figure 3.1: The flow chart of the methods and procedures followed in this research

3.1. Research Design

Research design is a structure or plan of the research which provides glue that holds a project together, groups or samples, observations or measures, programmes or treatments and other aspects of the methodology (Creswell, 2009). There are two types of research designs, namely; qualitative and quantitative. Qualitative research design is basically a descriptive approach that involves documentation of the response, observing behaviour or even studying written documents (Gwimbi and Dirwai, 2003). On this, ideas and/or information are found from people being studied.

On the other hand, quantitative research design is an explorative non experimental, descriptive structure which involves quantifying relationships between variables (Madyise, 2013). The design deals with figures and quantities. It involves precise measurements and statistical analysis of data using computer packages. A good research design is expected to ensure that there is maximum control over factors that affect adversely the reliability and validity of research results (Gwimbi and Dirwai, 2003). In this research, both qualitative and quantitative methods were used in order to acquire reliable and valid data and results. This research adopted both qualitative and quantitative approaches in order to cover both environmental and socio-economic issues. Quantitative approach was used to assess the environmental impacts of small- scale mining operations while qualitative approach was used to assess the socio-economic impacts of small-scale mining. This research adopted both qualitative and quantitative approaches.

3.2 Site Characterisation and Description of ASGM

Site characterisations and analysis of the artisanal and small-scale gold mining was conducted in the study area with the aim of establishing the nature and the sequence of the gold artisanal small-scale gold mining in the study area. Mine site characterisation in this research included two stages of characterisation namely; initial or reconnaissance and detailed characterisation or investigation. Initial characterisation was done in order to familiarise one with the conditions of the study area. Initial characterisation enables this research to determine the type of the artisanal and small-scale gold mining activities taking place, which is surface mining. In the detailed characterisation, the sampling of environment was done to assess the environmental impacts in the study area. This included sampling of the water, soil and sediments.

The detailed investigation entailed determination of physical environmental impacts (i.e. land degradation and loss of vegetation) through field observation. Through the determination of environmental impacts, digital camera was used to take pictures at the mining site in order to supplement the data of observation. This included pictures of the degraded environment. Data on environmental contamination and degradation was collected through detailed site characterisation. Site characterisation was carried out to determine the artisanal and small-scale gold mining activities in the study area. This included determination of the socio-economic issues of ASGM taking place in the study area. In addition, the methods undertaken to process ore as well as the tools used in the process were determined through characterisation and description.

3.3 Determination of Effects of ASGM on Vegetation Cover

The removal of vegetal cover by artisanal and small-scale mining activities results to adverse environmental effect such as loss of vegetation and soil erosion (Tom-Dery *et al.,* 2012). Therefore, it was important that the effects of small-scale mining on vegetation cover in selected parts of the Giyani Greenstone Belt are determined. This was to help in developing and recommending management strategies to address/mitigate the impacts of small-scale mining activities on vegetation cover. This section provides the method and techniques used to quantify the effects of artisanal and small-scale mining on vegetation cover in the two studied sites of artisanal and small-scale mining operations in Giyani Greenstone Belt.

Remote sensing technique was used to establish the effects of artisanal and small-scale mining operations on vegetation cover in the selected sites in the Giyani Greenstone Belt. Remotely sensed data was used to provide a basic overview of the study area. In order to achieve this, Landsat satellite imageries obtained from the United States Geological Survey (USGS) earth explorer were used as input data to the GIS software (Arc GIS 10.2). Landsat images from 1990, 1995, 2010, and 2015 were used to estimate the effects of ASGM on vegetation cover through different years of mining operations in the study area and comparison was made so as to establish the variation of land degradation with time.

The selection of these years was based on the fact that ASGM is known to have started in 1995 in the study area and became more common around the year 2010. The year 2015 was selected to provide the current situations of the effect of ASGM on vegetation cover in the area. Large-scale mining activities in Giyani Greenstone Belts were closed in the 1990s (Steenkamp and Clark-mostert, 2012). The reason for using satellite images collected before and after the period of large scale mining activities in the selected area ceased was to allow the comparison of the state of vegetation cover before small-scale mining and after. It was assumed that after five years the artisanal and small-scale gold mining in the study area started. Because summer (Dec, Jan, and Feb) is a rainy season in most places in South Africa including the Limpopo Province, satellite images acquired in winter (Jun, Jul, and Aug) were used to avoid the effects of high cloud cover. The specification of the satellite data used in this research is presented in Table 3.1.

Table 3.1: The specification of the satellite data used in this research

Data	Year acquired
Landsat 5 TM	1995
Landsat 7 ETM_SLC	2010
Landsat 8 TIRS_OLI	2015

3.3.1 Determination of the NDVI

Normalized Difference Vegetation Index (NDVI) was used as tool to analyse the effects of ASGM on the vegetation cover in the study area. It was used as a representation for the level of degradation in studied sites. According to Tucker *et al*. (2005), the NDVI is an index derived from reflectance measurements in the red and infrared portions of the electromagnetic energy spectrum. A series of NDVI composite of the study area were produced using the image analysis window in Arc Map. The NDVI of the images was calculated from the red (0.55 – 0.68µm) and near infrared (NIR, 0.73 -1.1µm) bands using the Equation 3.1:

$$\mathbf{NDVI} = \frac{(\mathbf{NIR}-\mathbf{RED})}{(\mathbf{NIR}+\mathbf{RED})} \qquad (3.1)$$

Where: RED is the Red reflectance value and NIR is the near infra-red reflectance value.

The Normalised Difference Vegetation Index (NDVI) gives a measure of the vegetative cover on the land surface over a wide area (Musa *et al.,* 2011). Dense vegetation shows up very strongly in the images and areas with little or no vegetation are also clearly identified (Meera *et al.,* 2015; Nicholson and Farra, 1994). It can also be used to identify areas of surface water and ice (Williams, 2006). Vegetation differs from other surface features due to the fact that it tends to absorb strongly the red wavelengths of the visible rays of the electromagnetic energy (i.e. sunlight) and reflect in the near-infrared wavelengths (Myneni *et al.,* 1995). Landsat satellites measure the intensity of the reflection from the Earth's surface in these wavelengths (Jury, 1997). The NDVI is therefore a measure of the difference in reflectance between these wavelengths ranges (Chikoore, 2005). It takes values between -1 and 1, with values 0.5 indicating dense vegetation and values <0 indicating no vegetation (Wang *et al.,* 2003). The information presented in Table 3.2 was used to analyse the data based on the NDVI values for various cover types.

It is worth mentioning that there is no any other land use activity or expansion of settlement in the selected small-scale gold mining sites and its surroundings. Therefore, the use of NDVI to determine the vegetation cover, allowed that all the areas of index values less than 0 (<0) be considered to be an indication of degradation of the environment by small-scale mining. In the cases where the index value was indicating dense vegetation, it was concluded that the mining activities had has little or no effects on vegetation cover. In Table 3.2, NDVI is the Normalised Difference Vegetation Index. NIR is the Near Infra-red Reflectance value. RED is the Red reflectance value.

Table 3.2: NDVI values for various cover types (from Julien *et al.,* 2009)

COVER TYPE	RED	NIR	NDVI
Dense vegetation	0.1	0.5	0.7
Dry Bare soil	0.269	0.283	0.025
Clouds	0.227	0.228	0.002
snow and ice	0.375	0.342	-0.046
Water	0.022	0.013	-0.257

Note:

3.4 Toxic Metals analysis on soil, sediments and water quality

Toxic elements from mining are major environmental problems and are of concern to artisanal and small-scale gold mining. In view of this, it was necessary that the level of such elements in soils and water bodies found near the ASGM site in the study area are determined. According to Rico (2007), toxic elements that are commonly found in contaminated area are arsenic (As), nickel (Ni), copper (Cu), cobalt (Co), cadmium (Cd), manganese (Mn), chromium (Cr), lead (Pb) and zinc (Zn). In this research such elements were analysed to determine these concentration levels with the purpose of determining the extent these chemicals exceed the permissible levels in the different part of the environment. The following sections are earmarked for the presentation of the methods used to sample and determine the level of toxic elements in soils, sediments and water around the ASGM sites in the study area.

3.4.1 Sample collection procedures

In order to be able to assess the impacts of ASGM on soil and sediments, samples of soil and sediments were collected. Artisanal and small-scale gold miners dig and create sluicing site randomly in the mining site and along the river banks. Therefore, soil samples were collected randomly at the sluicing site and digging areas. Sediments were collected along the river randomly were the concentration of gold is taking place. A shovel was used to extract the desired soil and sediments samples. In each sluicing and digging site, soil samples of approximately 2kg was collected and labelled according to the site the sample was collected for example soil samples from Louis Moore and Klein Letaba mining sites were respectively labelled LMSS-1 and KLSS-1. The sample tags were placed in the plastic bags with the samples. On the other hand, the sediments samples were labelled as LMRSS (Louis Moore site) and KLRS (Klein Letaba site). Both the soil and sediment samples were collected at the depth of 50cm.

In order to be able to assess the impacts of artisanal and small-scale gold mining on water, water samples were collected randomly along the nearby rivers. Mining sites where sluicing table were built, were targeted as water sampling sites. Prior to taking the samples, the sample bottles were rinsed with deionized water to decontaminate them. The decontaminated water bottles were kept closed until the time of collecting the samples. During the sampling, the bottle lid was held carefully to avoid touching of the inside part the screw cap as such leading to contamination of the sample. In each point of the mine where processing of gold was identified, one litre of water samples was collected. The bottle was then labelled according to the site the sample was collected and the type of the sample. For example, water sample one (WS1). All the collected samples (water, soil and sediments) were taken to the laboratory for the analysis of different chemical properties (i.e. toxic and trace elements analysis as well as pH and EC determination.

3.4.2 Laboratory analysis of samples

The preparation of soil and sediments samples included splitting of the samples to a sample size. Every soil and sediments samples were divided into half using a Humboldt riffle splitter. One half was to be analysed and the remaining half was kept as a duplicate for future references. The use of splitter also assisted in mixing the sample to produce a homogeneous sample of the soil. The fraction of soil samples that were to be milled for analysis were dried for 2 hours at a temperature of 110°C using a bench vacate mounted oven (See Figure 3.2a). Dry samples were then allowed to cool and milled using Retsch RS 200 milling machine to reduce the soil particles size.

Samples were milled for 5 minutes at 700 rpm to 80% particle size or <75µm. This level of fineness of the samples was done to ensure homogeneity and liberation of mineral grains in the samples. The milled samples were then weighed in a 250ml beaker and nitric acid and hydrochloric acid added. The beaker with the sample was then placed on a hot plate set of 40^{o}C for 2 hour for digestion. The digested solutions were carefully transferred into a 100ml volumetric flask and filled to the mark with Deionized water. In addition, the solutions in the volumetric flasks were vigorously mixed by shaking the flasks in order to homogenize the sample for analysis using Atomic Absorption Spectrometry (AAS) instrument. The concentration of toxic elements measurements was determined from working curve after calibrating the instruments with standard of known concentration.

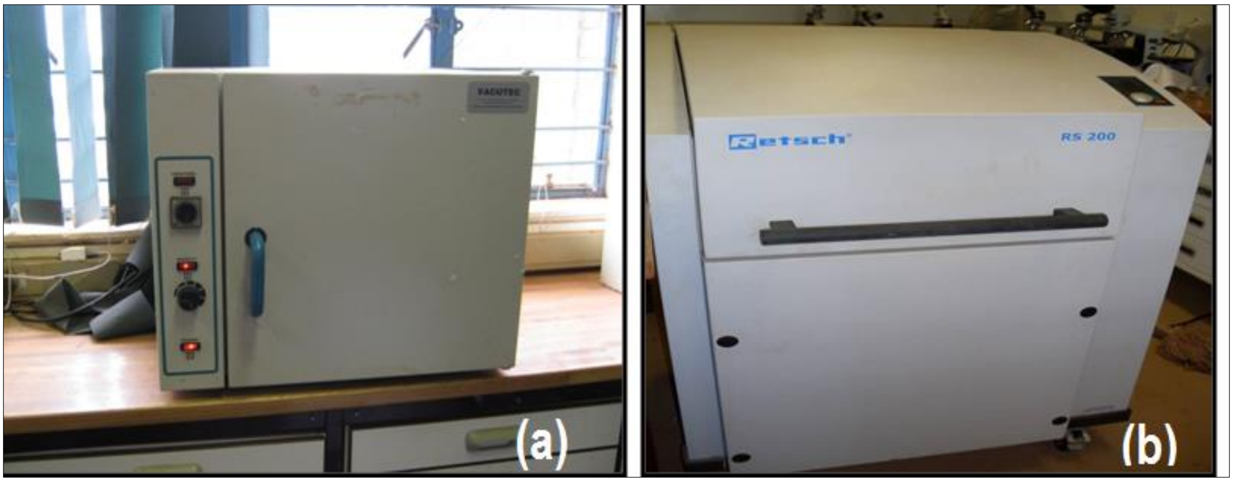

Figure 3.2: Photograph (a) bench vacate mounted oven and photograph (b) Retsch RS 200 grinding mill machine.

3.4.3 Toxic elements analysis

The determination of toxic elements concentration in soil, sediments and water was done using the Atomic Absorption Spectrometer (AAS) shown in Figure 3.3. The ASS is a common technique for quantitative determination of chemicals or toxic elements in soil and water. This technique requires a liquid sample to be aspirated, aerosolized, and mixed with combustible gases. This is carried out by the absorption of optical light (radiation) by free atoms in the gaseous state to determine chemical elements in a sample (Garcia and Baez, 2012). The atomic absorption spectrometer in particular is designed to operate with either the flame or with the graphite furnace, this is the ASS instrument used in this research with a flame atomic absorption spectrometer.

The atomic absorption spectrometer block consists of a radiation or light source which is necessary to emit the sharp characteristic spectrum of the element. A light beam from a lamp whose cathode is made of the element being determined was passed through the flame into a monochronometer and detector. The analysis also involved the introducing the water sample to the instrument aspirator where it was aspirated to flame in the form of aerosol. The beam of ultraviolet light at a specific wavelength focused to the flame prior to the sample aspiration. The machine detected the toxic elements that existed in samples (digested soil samples and water samples) by measuring the change in intensity of each metal under assessment. A computer software was used to convert the measured change in intensity into the absorbance that was subsequently presented in parts per million (ppm).

Figure 3.3: An illustration of the AAS instrument used in the analysis of toxic metals in soils and

water samples.

3.3.4 Trace elements analysis

In order to analyse trace metals in soils and sediments samples, the process sample preparation was carried out. This process included air-drying and milling of the samples to fine powder of 75µm size. The concentration of trace elements in soil and sediments samples was measured by the X-ray fluorescence (XRF) spectrometry on the pellets prepared from the powdered sample. Pressed pellets were prepared by pressing loose powders filled in a ring or cup using a set of cylinder dies and press machine. The cylinder die (i.e. female die) was filled with the powder sample and the male cylinder die was placed above and pressure was applied to form a pressed pellet. Prior to the determination of the trace elements, 5g of the dried and milled sample was mixed with the binding agent (i.e. Bauxite powder) and the mixture was pulverized in a Retsch RS 200 milling machine for 2 minutes. This was followed by pressing the powder into 25mm thick pellets.

The pressing was carried out using the hydraulic press at a pressure of 20 tons. The cellulose was used as a binder in a proportion 1:10 by weight and to reduce absorption of the target materials. The sample pallets were taken into the XRF for analysis of trace elements. The analysis of major and trace elements in soil/sediments by XRF was made possible by the behaviour of atoms when they interact with radiation. When these materials become excited with high-energy, short wavelength radiation, they also became ionized. The excited sample in turn emits X-rays along a spectrum of wavelengths characteristics of the types of atoms present in the sample. By counting the number of photons of emitted energy from a sample, the elements present may be identified and quantified. An illustration of the XRF instrument used for major and trace element analysis in this research is shown in Figure 3.4.

Figure 3.4: An illustration of the XRF instrument used for trace element analysis

3.4.5 Determination of pH and conductivity of samples

Soil, sediments and water samples were analysed for pH and corresponding electrical conductivity (EC). The samples pH was determined using a pH meter their readings were recordedThe samples from the field were manually homogenized through the use of stainless spoon and bucket. The stainless riffle splitter was used to split and reduce the homogenized samples to a fraction less than 50g. The content of one bin of the splitter was placed aside while the other content was passed through the chutes of the splitter until the required size of the sample was obtained.

The slurry was prepared by adding 20ml of deinozered water to the 20g scoop of samples in the beaker. Each sample was vigorously stirred for 10minutes with a glass stirring rod and let to stand for 25 minutes. The pH meter model was calibrated with buffer solution of pH and then immersed in the 200ml beaker with samples and readings were taken when the meter stops fluctuating. The pH of the soil and its corresponding electrical conductivity (EC) was then recorded from the pH meter and the electric conductivity meter. The pH of water samples collected from the river along the artisanal and small-scale gold mining site was measured by immersing the pH rod in 40ml in water for a minute. Prior to that, the water sample was vigorously stirred and let to stand for at least 60 minutes.

3.5 Assessment of Socio-economic Impact of ASGM

This section provides the method and techniques used to assess the socio-economic impacts associated with the artisanal and small-scale mining of both Louis Moore and Klein Letaba Gold Mines. This method includes the sampling of the population in order to determine the population where the data will be collected from. It also includes the instruments used in data collection (such as interviews and questionnaires), reliability and validity of data, data analysis and presentation.

3.5.1 Sampling of the population

Before distributing the questionnaires and conducting interviews, selection of respondents was necessary. Sampling is a process of choosing elements which are the basic unit from which data and information was collected to represent the entire population (Mugera, 2013). According to Creswell (2009), population is a collection of all individual items or points under investigation. Due to inadequate time and willingness of the respondents to participate in the study, one hundred households were considered in all three villages where the mining activities are taking place.

Two options of sampling considered were probability and non-probability. Probability methods require a sample frame which includes a comprehensive list of the population of interest (Madyise, 2003). Probability methods rely on random selection in a variety of ways from the sample frame of the population. According to Rubin (2005), probability methods permit the use of higher level statistical techniques which require random selection. However, non-probability methods are available even when there is no sample frame. They are generally less complicated to undertake. They may minimize the preparation costs of a survey, and be employed when you are actually unsure of the population of interest (Mugera, 2013). Convenience and purposive sampling designs were used in the sampling of the community. This study adopted purposive sampling method to select respondents. Purposive sampling method uses the research's judgement in selecting the respondents (Rubin, 2005). It was used to select the affected communities by small-scale mining activities. Convenience sampling allowed the researcher to select respondents who were readily available and willing to take part in the study

3.5.2 Instruments for data collection

Interviews

In order to identify and assess the impacts of socio-economic activities of artisanal and small-scale mining activities, qualitative and quantitative approach was used. Qualitative approach was adopted through the use of interviews. The qualitative aspect of the study employed semi-structured interviews to collect the primary data. Semi-structured interviews are credited as appropriate to the collection of data on a topic that lacks previous studies on that study area (Kitula, 2006). As such no one had conducted the study on a topic related to this present research in Giyani Greenstone Belt.

Semi-structured Interviews were used to collect primary data on the artisanal and small-scale mining operation and perception of the local community. Primary data is the first hand information collected from the respondents, which included the socio-economic characteristics of respondents such as employment, educational level, health and age structure and soliciting information on what respondents believed are the effects of the artisanal and small-scale gold mining on quality of life of communities (Hoedoafia, 2014). The study focused only on three mines in Giyani greenstone belt (GGB), namely; Louis Moore, New Union and Klein Letaba gold mines. Therefore, only three communities which are host communities of these mines were considered for interviews. These communities are Mavalani village around Louis Moore gold mine and Mapuve around Klein Letaba mine.

Interviews were directed to the artisanal and small-scale miners and the host community members. As it was used by Mathada (2014), this activity is also guided by the philosophy and methodology of Participatory Rural Approach (PRA) that is used to describe a growing family of approaches and methods to enable local people to share, enhance and analyse their knowledge of life and conditions, to plan and to act (Chambers, 1994). Participatory Rural Approach (RRA) is an extractive research methodology consisting of systematic, semi-structured activities conducted on-site with the aim of quickly and efficiently acquiring new information about rural life and rural resources (Kitula, 2006).

With the objective of identifying and assessing the socio-economic impacts associated with the artisanal and small-scale mining in Giyani Greenstone Belt (GGB), target groups were selected for the interviews. These included artisanal and small-scale miners and selected individuals from nearby communities. Here, predetermined set of open ended and yet flexible questions which allow the interviewer to diverge from the guide to pursue other details with respect to the study were used. The aim of the selection was particularly to give a broad view of the artisanal and small scale gold mining.

Questionnaires

Quantitative aspect of the study employed the distribution of the questionnaires to the community members and the small-scale gold miners. Quantitative methods are explorative and descriptive structure which involves quantifying relationships between variables (Hoedoafia, 2014). A questionnaire which consisted of both closed and open ended questions following literature review and reference was made to the problem identified and objectives set. A well-designed questionnaire should meet objectives of enquiry, fit between contents and research problem (Gwimbi and Dirwai, 2003). It was developed to solicit information from key informants on their views concerning artisanal and small-scale gold mining and the socio-economic impacts. It was used and administered to the villagers in the affected areas of Giyani Greenstone Belt.

A questionnaire survey was chosen because it allows participants to give their views anonymously reducing bias (Mertens and McLaunghlin, 2004). Some of the advantages of administering a questionnaire are that it is easy to test validity and reliability (Creswell, 2009). It is flexible and may be applied to many different populations within a short time. Same questions are repeated to get valid and reliable answers with minimal resources. Through questionnaires data is quickly collected and used for many purposes.

The questionnaire was administered to determine a variety of aspects from respondents which included beliefs, thoughts and knowledge about artisanal and small-scale gold mining in their areas. During this study, the researcher visited sampled households to explain the benefits of research and importance of their participation and involvement. A questionnaire was introduced prior to answering in the presence of an interpreter who translated questions from English to Tsonga for illiterate respondents.
The questionnaire was administered through a drop and pick survey. On distributing questionnaires, the researcher repeated benefits and importance of answering questions truthfully while assuring participants anonymity and confidentiality (Mugera, 2013). The questionnaire had open and close ended questions comprising of four parts. Information paragraph at the top was to introduce researcher, purpose and title of research.

3.5.3 Reliability and validity

According to Gwimbi and Dirwai (2003) a good research design should be valid and be able to produce reliable results. Reliability is referred to as the repeatability and consistency of the findings. A reliable measure does not fluctuate randomly and is used to discover relationships between variables. In this research, quantitative and qualitative designs were chosen to deduce impacts of artisanal and small-scale gold mining on the environment and socio-economic activities. Validity is the ability of an instrument to measure a concept under study and to be able to measure it accurately so that any observed differences are true and not the result of random or constant errors (Polit and Beck, 2008). Instrument validity determines whether an instrument accurately measures that which it is supposed to measure. This study ensured the reliability of data by using both qualitative and quantitative approach. To ensure such reliability, field work were done and pictures were also used to supplement the data.

In this study, content validity was done by doing a thorough related literature search on which the contents of questionnaire and interview guides were based. As it was done by Hoedoafia (2003), the questionnaires pre-tested randomly to ten (10) households before administering them to ensure validity and reliability of data gathered. There are two types of validity which are external and internal validity. External validity is when results obtained in a study can be generalised to other people and settings.

Generalisation is made considering degree of confidence in sample findings in relation to population and whether similar findings can be obtained at other times and places. When researcher meets most of the respondents for the first time to explain the aim of study, the relationship will be formal and therefore the effect was minimal (Madyise, 2003). As such, this will be important because if respondents are familiar with researcher, they may not provide true information and results will be biased (Creswell, 2009). In this study, external validity was influenced by the sampling methods used that is convenience and purposive sampling, therefore findings cannot be generalised to other settings.

3.5.4 Data analysis and presentation

Data analysis is the systematic organization and synthesis of research data (Polit and Beck, 2008). Data analysis thus entails categorizing, manipulating, ordering and summarizing the data and describing them in a meaningful way. Data obtained from the questionnaires and the interviews were analysed with the statistical package for social sciences (SPPS) version 21.0. Spread sheet was one of the aspects of SPSS used in this research. Microsoft excel was used as a tool to prepare and make some graphs for data analysis. The data collected was presented in the form of tables, images, graphs and charts. Using Statistical Package for Social Sciences (SPSS), frequency distribution and cross tabulation were used to analyse the data.

Frequency distributions included creating of a frequency table as a way of summarising and organizing the data. This was done by recording every possible score of the respondents as a column of numbers and the frequency of occurrence of each score. The table showed the number of frequency with their percentages. The information confined in the frequency table was converted into a form of graphs. On the other hand, cross tabulation were merely data tables that presented the results of the entire group of respondents (i.e. population involve and not involve in ASGM activities) as well as results from sub-groups of such respondents. Cross tabulations were used to examine connections within the data that were not being deceptive when analysing total survey responses. Every response item on the questionnaire was carefully entered as a numbered code under the question header in the SPSS when the entire survey questionnaires were collected. Going through each questionnaire after entering data was made for accuracy as well as referring back to the aims of the study.

CHAPTER FOUR: ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS OF ASGM

This chapter describes the processes of Artisanal and Small-scale Gold Mining (ASGM) in selected parts of Giyani Greenstone Belt namely; Louis Moore Gold Mine and Klein Letaba gold Mine. This chapter mainly present and describes the environmental impacts of ASGM including environmental degradation and contamination. It also presents and discusses the socio-economic issues of the artisanal and small-scale gold mining. The site description and observation including the mining activities taking place in the study area are also presented and discussed in this chapter.

4.1 Site Description and Observation of ASGM

In the Giyani Greenstone Belt (*i.e.* Louis Moore and Klein Letaba mining sites), artisanal and small-scale gold miners carry out mining activities around the mining sites mainly focusing on materials close to the tailings dumps, mine shafts and old processing plants. A stretch of land of length approximately 834m and 720m is affected by artisanal and small-scale gold mining operations in Louis Moore and Klein Letaba mining sites respectively. Artisanal and small-scale gold miners degrade land and remove the vegetation cover to create space for carrying out mining activities. The miners randomly dig shallow pits as they collect soils deemed to be containing gold and searching for easy ways to extract minerals around the mining sites. This digging of soils is carried out using rudimentary equipment (i.e. pick and shovel) while the collected soils are put in bags (*i.e.* 25kg bag size) and sold to people who have the capacity to process the gold then some of the materials are transported to the nearby river where sluicing is carried out to separate gold from waste material.

Through site characterization, it was observed that artisanal and small-scale gold miners do not collect the tailings materials and waste rocks for gold processing; they rather dig and collect the gravel around and/or close to the tailings dumps. Figure 4.1 illustrates the digging and collection of soil deemed to be containing gold close to the tailing dam. The digging and collection of soils around the old processing infrastructures and closed mine shafts increase the risk of physical injuries. This is due to the fact that the old structures might fall and cause injuries to miners and animals that grazing around the area. The digging and collection of the soils for gold processing in the mining sites lead to cutting and uprooting of trees that have grown on the site for many years. In generally, the process of soil and sediments collection around the mine site lead to degradation through the removal of topsoil which increase soil erosion around the mining area as depicted in Figure 4.1. In addition, the digging and collection of soils lead to the loss of biodiversity and destruction of habitats.

In the process of mining, artisanal and small-scale gold miners leave the excavations unfilled as they move from one site to the other searching for minerals. This puts the animals (*i.e.* cattle) that feed around the mining sites at risk of falling into unfilled excavations (See Figure 4.2). The average depth of such unfilled pits was found to be 2.9m and the average width was up to be 12m. The rivers (Klein Letaba River and Ntsami River) are used as washing sites for soils deemed to be containing gold by artisanal and small-scale gold miners. As shown in Figure 4.3, the miners dig out washing sites along the river bank to dam water and build sluicing table. Sluicing tables are used as a method of processing gold in the study area. When water in dammed area is finished, the area becomes abandoned and the washing operation is then moved to another location.

Figure 4.1: Land degradation and uprooting of trees close to tailings dump as a results of ASGM activities

Figure 4.2: Unfilled excavation with soils collected in bags around where cattle graze

This process has created heaps of material along the river banks and these have a potential to affect the water flow in the river. The top of the sluicing tables are covered with a towel that can collect the fine free gold particles. The towel is then washed in a bucket or dish to collect the fines. Once a sufficient volume of fines had been collected the material is panned and a concentrate collected. The washing of the soils containing gold on sluice tables along the river might lead to the degradation of surface water resources. The effects on water quality can have effect to health on people and animals (*i.e.* through consumption or getting in contact with the water).

Figure 4.3: Sluicing table and discharge of polluted water to river.

4.2 Effects of ASGM on vegetation cover

This section presents the effects of artisanal and small-scale gold mining on vegetation cover and discusses the Normalized Differential Vegetation Index (NDVI) Maps developed to help in the assessment of the continuous of vegetation cover in the study area. Results showed that the mining activities in the study area had caused extensive environmental degradation due to serious removal of vegetation cover.

4.2.1 Effects of ASGM on Vegetation Cover at Klein Letaba Mine

The NDVI Map generated from Landsat 5 TM of 1995, reveals the vegetation index of the study area for the period of 1995. The increasing of NDVI positive values indicate increasing greenness vegetation cover while negative NDVI values indicates non-vegetated features such as barren rock, sand, tailings dam, built-up area, snow and bare lands (Pettorelli, 2013). In 1995 the NDVI values of Klein Letaba Mine were found to be ranging from 0.1 to 0.5. as shown in Figure 4.4a, the non-vegetated surfaces (i.e. bare soil and tailings dam) had the NDVI values that ranged from of 0.3 to 0.4 while the vegetated surfaces had the values ranging from 0.4 to 0.5. According to Defries and Townshed (2007), the NDVI values of approximately 0.4 to 0.5 correspond to areas of dense vegetation cover.

During the year 1995, the study area was densely vegetated as revealed by the positive NDVI values ranging from 0.4 to 0.5. This supports that the artisanal and small-scale gold mining activities at this time had very low or no effect on vegetation cover. It might as well support that the artisanal miners had not invaded the area during this period. Hence, the area had significantly high vegetation coverage, thus, indicating low environmental degradation. The majority of the dense vegetation is also shown by the red colour in Figure 4.4a. The red colour in NDVI map corresponds to the dense vegetation and green colour correspond to non-vegetated area (Bradley and Mustard, 2004). However majority of green colour in the Klein Letaba is the tailings dam.

In 2010, the NDVI values of the study area ranged from -0.0 to 0.3 as shown in Figure 4.4b. Such NDVI values (*i.e.* 0.1 or less) correspond to areas of non-vegetated cover such as barren rock, sand, tailings dam and snow (Defries and Townshend, 2007; Gondwe and Jury, 1997). However, in the study area, features such as the tailings dumps, and bare soils were covered within a range of -0.0 to 0.1 of NDVI values which correspond to areas of no vegetation cover. This indicating that there was an increase in the loss of vegetation cover or increase of non-vegetated land in the study area compared to the vegetation cover in 1995. Tailings dam plays a huge role in non-vegetated area around the mining site. It was discovered that artisanal and small-scale gold mining in the Giyani Greenstone Belt (GGB) become more common in the year 2010 in this area leading to decrease in vegetation coverage in the site. The evidence of how the artisanal and small scale gold miners affect or destroy the vegetation cover in the study area is shown in Figure 4.4b. These indicate that the ASGM dig out and uproot trees that grow around the area for many years.

The sparsely vegetation cover ranged were found with the NDVI value ranging from 0.1 to 0.3. Such NDVI values was described by Pettorelli (2013), to be corresponding to the sparsely vegetation. In 2010, Klein Letaba Mine site constituted of sparsely vegetated with small patches of greener vegetation compared to the year 1995. Consequently, this suggests that the artisanal and small-scale gold mining in the site contributed to the loss of vegetation cover in the area.

In 2015, further changes on vegetation cover were observed in the NDVI map of the year 2015. The NDVI map showed that the non-vegetated areas were increasingly spreading throughout the study area. Such an increase in non-vegetated land led to a decrease in vegetation coverage in the study area. Non-vegetated features were found to be ranging from -0.2 to 0.2. Sparse vegetation (shrubs and grassland) correspond to the NDVI values of 0.1 to 0.3 (EImore *et al.,* 2000; Defries and Townshend, 2007).

The Klein Letaba Mine transect of its surrounding had spares natural vegetation covers characterised by the NDVI value that range from 0.1 to 0.2. The study area during this period was mostly covered with scattered grasses and shrubs. With reference to Figure 4.4c, the greener and forest vegetation covered a range of 0.2 to 0.4 denoted by red colour along the margins area. This indicated that vegetation coverage was well developed away from the mining area while environmental degradation was increasing toward the centre or close to the artisanal and small-scale mining site (*i.e.* in the vicinity of abandoned Klein Letaba mining site).

During the year 2015, there was intensive artisanal and small scale gold mining in Klein Letaba mine. Thus, the NDVI values showed an increase in environmental degradation (loss of vegetation) compared to year 1995 and 2010. There was a complete clearing-out of vegetation in the year 2015. In Klein Letaba mine, it was found that in 1995 there was significant vegetation coverage; however, as time goes on to the year 2010 there was a loss of vegetation in the area.

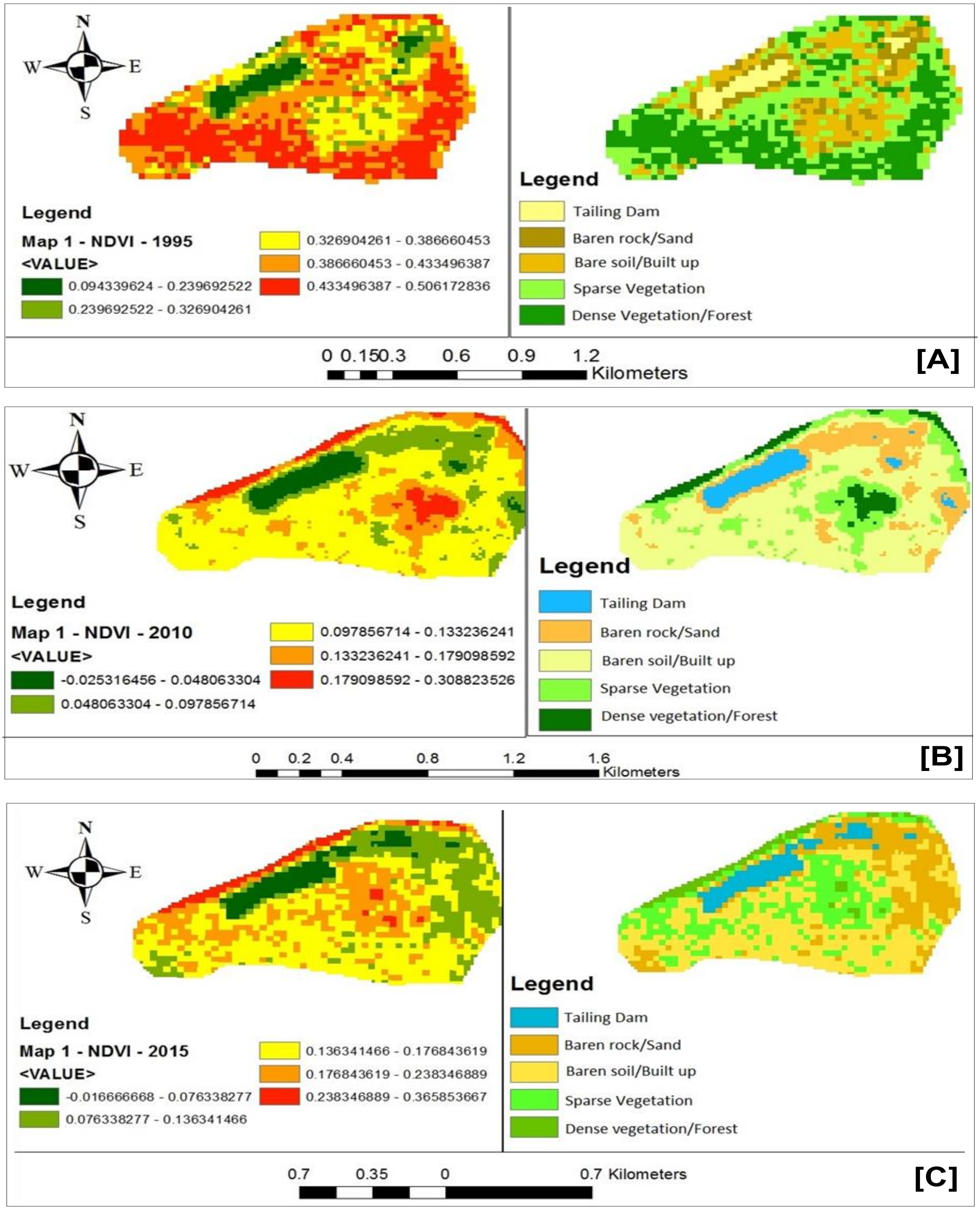

Figure 4.4: The NDVI maps of the Klein Letaba Mine

4.2.2 Effects of ASGM on Vegetation Cover at Louis Moore Mine

The NDVI values calculated from the 1995 image around Louis Moore Mine ranged from 0.2 to 0.5. According to Wanga *et al.,* (2003), such NDVI values suggested that an area was densely vegetated with section of sparse vegetation. However, in Louis Moore Mine the vegetation coverage was presented by the NDVI value that ranged from 0.4 to 0.5 showing a densely vegetated area or a significant level of vegetation coverage in the area during the year 1995 (See Figure 4.5a). The NDVI map shows an increase of forested vegetation across the study area at a range of 0.4 to 0.5. The non-vegetated area of the mine had an NDVI of 0.2 to 0.4. These values indicated substantial level of greenness in the study area for this period (Meera *et al*., 2015; Musa *et al.,* 2011).

The NDVI map calculated from satellite image showed that in the area there was no or low environmental degradation (Figure 4.5a) .This is indicated by red colour on the map. Such colour corresponds to the dense vegetation cover (Elmore *et al.,* 2000; Defries and Townshend, 2007). In addition, there are portions of green towards the centre of the study area. This represents areas of non-vegetated. According to Defries and Townshend, (2007), the green colour in the NDVI map indicates non-vegetated area. In the area of the abandoned Louis Moore Mine, the green colour covered the area occupied by large volume tailing dump.

A dramatic negative change in the vegetation cover was identified from 2010 images of Louis Moore. This is because of the fact that the NDVI map showed a decrease in vegetation coverage in the area with vegetation covering a range of 0.1 to 0.2 NDVI values as shown Figure 4.5b. Forested area also decreased in the year 2010, from a range of 0.4 to 0.5 in 1995 to a range of 0.1 to 0.2. Sparse vegetation also showed a decrease from a range of 0.39 to 0.42 in 1995 to a range of 0.12 to 0.14 in 2010 (See Figure 4.5b). This showed that artisanal and small-scale mining activities had a negative impact on the environment (especially on vegetation cover). However, this has been identified by the spread of mined patches across the study area. As compared to 1995, there was an increase of sparse vegetation (shrubs and grassland) and this is indicated by the yellow colour in the Figure 4.5b. According to Wang *et al.* (2003); Elmore *et al.* (2000), the yellow colour with the NDVI values of approximately 0.2 – 0.4 correspond to sparse vegetation.

The NDVI map of the area around Louis Moore Mine showed a continuous loss of vegetation in the year 2015 compared with the state of vegetation cover in the year 1995 and 2010. An increase in the level of artisanal and small scale gold mining activities in the area was also observed, thus, resulting to a serious uprooting of trees. The vegetation coverage ranged from 0.2 to 0.3; with a slight increase in sparse vegetation which covers a range of 0.1 to 0.2 as compared to 0.12 to 0.14 of 2010. Forested vegetation during year 2015 covered a NDVI value range of 0.2 to 0.3 which is still in a disturbed condition. This is identified by the scattered patches of forest in the mining site as shown in Figure 4.5c. The NDVI map shown Figure 4.5c indicated that there is little red colour which corresponds to areas of dense vegetation. The comparison of the 2015 and 2010 maps show that in 2015 there was an increase in vegetation loss in the area (*i.e.* Louis Moore site of artisanal and small-scale mining operations).

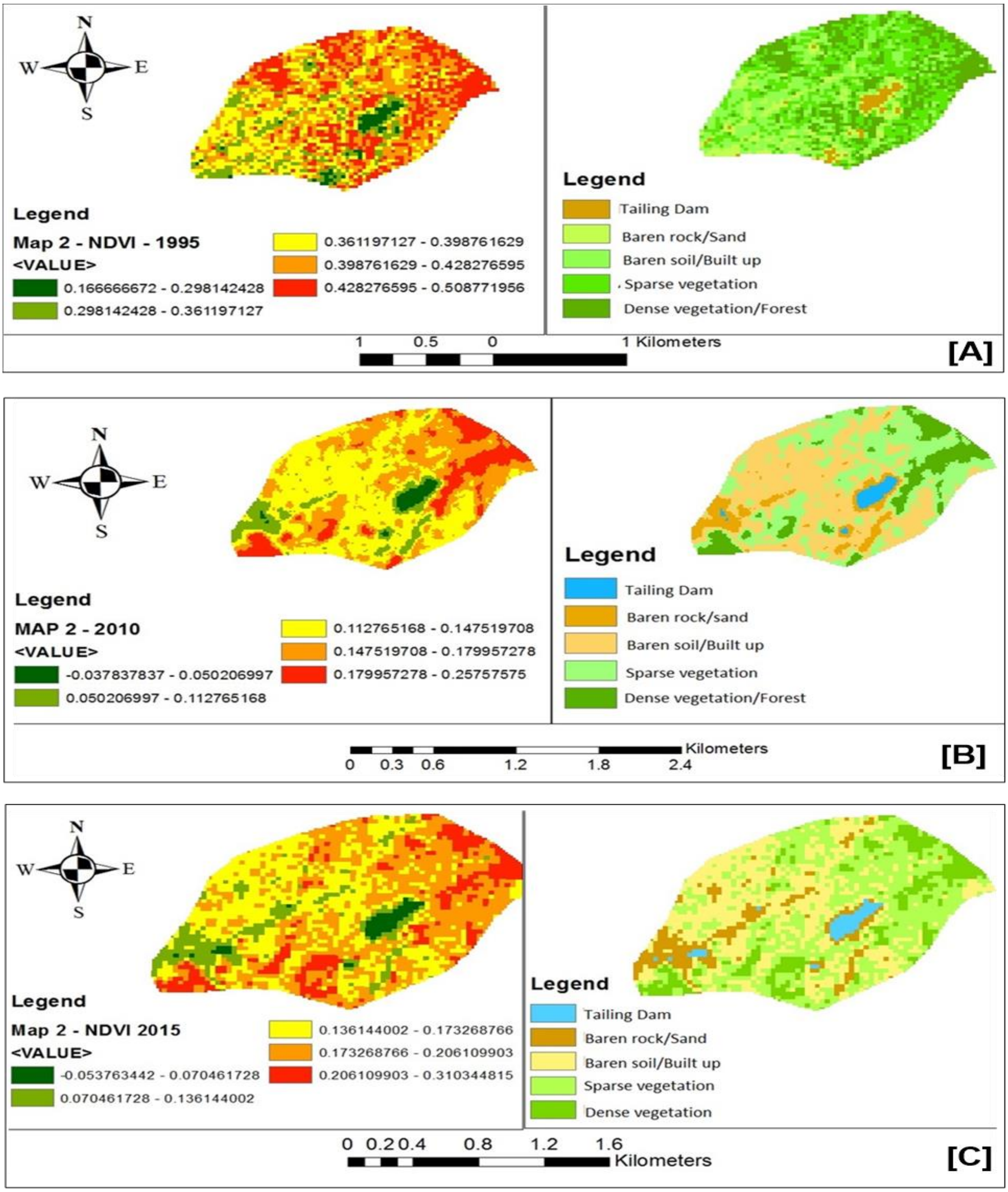

Figure 4.5: The NDVI maps of Louis Moore Mine

4.3 Results of Analysis of soil samples

This section presents the results of a concentration of toxic and trace metals and pH values as well as the corresponding electrical conductivity in soil samples. The results showed that mining activities in the study area had extensive environmental contamination due to serious release of toxic and trace elements into the soil.

4.3.1 Concentration of toxic elements in soil

The concentrations of As around the artisanal and small-scale gold mining areas was recorded to be ranged between the 3.20 to 14.20 ppm and 8 to 856.6 ppm in Louis Moore mine and Klein Letaba mine respectively. The average concentrations of As was found to be 6.72 ppm (in Louis Moore) and 352.78 ppm (in Klein Letaba). In both sites the recorded As levels were found to be exceeding the South African Soil Quality and World Health Organisation (WHO) Standards of 1 ppm and 2 ppm respectively. This gave an indication of contamination of soil by concentration of As around mining sites. According to Chibuike and Obiora (2014), the soils with the concentration of As above 1 ppm indicates the polluted soils or contamination of the soil. Soil contaminated with the As has the effects on plants and present serious health risk such as the chronic and acute poisoning (Nazir *et al.* 2015). In addition, toxicity of As in soil results in the reduction of the plant growth and fruit leaf as well as decrease in the leaf fresh weight (Chibuike and Obiora, 2014).

The other toxic element found to be above the standard recommended by South African Soil Quality and World Health Organisation was Cr. The average concentration of Cr was found to be 330.9 ppm and 542.1 ppm in Louis Moore and Klein Letaba respectively. These concentrations were found to be above both the recommended level of 80 ppm (SASQ) and 1.30 ppm (WHO). The average concentration of Cr in Louis Moore was above the South African Quality and WHO standards by about 250.9 ppm and 329.6 ppm while at Klein Letaba was above the South African Quality and WHO standards by 462.1 ppm and 540.8 ppm respectively. According to these standards, the obtained Cr concentration indicates that contamination is also an issue in the study area. According to Nazir *et al.* (2015), the high contamination of Cr on soil has a negative effect on the activities of protease, urease, alkaline phosphatase and arylsulfatase. The uptake of higher concentration of Cr by plants and subsequent accumulation along the food chain is a potential threat to animal and human health (Singh and Kalamdhad, 2011).

Cd concentrations were found to be between 0.00 to 0.10 ppm and 0 to 0.1 ppm in Louis Moore and Klein Letaba mines respectively. The average concentration of Cd was recorded to be 0.02 ppm at Louis Moore site and 0.06 ppm at Klein Letaba site. According to South African Soil Quality Standard, the measured average concentrations of Cd around the ASGM site in the study area indicate no contamination of the soil quality as it is below the permissible levels. However, such average concentration of Cd was found to be above the WHO recommended level of 0.02 ppm, thus, indicating slightly contamination according to World Health Organisation standard.

The relatively low concentration (10.02 ppm) of Co was recorded around the artisanal and small-scale mining site in Louis Moore. The average concentration of Co was found to be within the South African Soil Quality Standard of 20 ppm. According to Saha and Hossain (2012), the concentrations of toxic elements on soil below any permissible standards are the indication of the unpolluted or uncontaminated on the environment (i.e. soil, water and sediments). This is the evidence that in Louis Moore site there is no contamination of Co on soil. However, the average concentrations of Co at Klein Letaba was found to be 21.94 ppm which is above the South African Soil Quality Standard of 20 ppm, thus, showing a slight contamination of soil in this part of the study area.

The Cu concentration was found to be ranging between 15.90 to 26.90 ppm and 86.2 to 61.9 ppm at Louis Moore and Klein Letaba mining sites respectively. The results shown in Figure 4.6 indicate that the average concentration of Cu in both mining sites was recorded above the permissible South African Soil Quality Standard and WHO of 6.6 ppm and 10 ppm respectively. The average concentrations of Cu were recorded above South African standard and WHO standard by 10.4 and 7ppm respectively in Louis Moore. According to Wauna and Okieimen (2011), high concentration of Cu in soils and plants poses a serious threat to the survival of animals that feed on such contaminated plants. This may also have a serious effect on human health through the consumption of animals that feed on such contaminated plants.

The Ni concentration around the artisanal and small-scale gold mining area ranged from 448.50 - 888.60 ppm at Louis Moore and 251.5 – 1423.7 ppm at Klein Letaba site. The average concentrations of Ni were recorded to be 726.8 ppm and 799.94 ppm in Louis Moore and Klein Letaba respectively. Such average concentrations of Ni exceeded the South African Soil Quality Standard and WHO of 50 ppm and 10 ppm respectively, thus, indicating a serious contamination of the soil by the artisanal and small-scale gold mining operations in the study area. In all collected samples the concentration of Ni was found to be exceeding both South African Soil Quality Standard and WHO standard. According to Nazier *et al.* (2015), the high concentration of Ni in soils may lead to reduction in plant growth and health risks. In addition, the contact and breathing of dust with high concentration of Ni may lead to serious effects on human body as it may results to fatalities and/or long-term effects on the brain and kidneys (Nazier *et al.,* 2015).

The Pb concentration was recorded at the range of 30.60 - 132.30 ppm and 74.5 - 7981.1 ppm in Louis Moore and Klein Letaba mining sites respectively. Its average concentration was found to be 62.56 ppm at Louis Moore and 3286.7 ppm at Klein Letaba mining sites. The comparison of Pb with the South African Soil Quality and WHO standards showed that Pb levels were above the standard of 6.6 ppm and 2 ppm respectively. The average concentration of Pb in Louis Moore mine was found to be above both the South African Soil Quality and WHO standards by 55.96 ppm and 60.56 ppm respectively. Thus, indicating a serious contamination of Pb in soil by the artisanal and small-scale mining operation. According to Singh and Kalamdhad (2011), the concentration of Pb above the permissible standards in soils may decrease soil productivity while very low concentration may inhibit some vital plant processes, such as photosynthesis. When the Pb in soil rises above the permissible standard, it may lead to poisoning through the food chain and most of the risk is from Pb contaminated soil (Kalshetty *et al.,* 2014).

The concentration level of Zn in soils ranged from 18.2 ppm to 14.2 ppm and 98.3 ppm to 641.1 ppm in Louis Moore and Klein Letaba artisanal and small-scale mining sites respectively. The average concentration of Zn was found to be 75.82 ppm and 252.04 ppm in Louis Moore and Klein Letaba sites respectively. In both artisanal and small-scale mining sites, the Zn concentration was found to be above the South African Soil Quality and WHO Standard (See Figure 4.6). Such results of Zn indicate a serious contamination of soil quality (World Health Organisation, 2006). According to Wauna and Okieimen (2011), Zn concentration above 46.6 ppm in soil gives an indication that there is soil contamination. Soils polluted by Zn may lead to accumulation of Zn in plant leaves, reduction in plants growth, decrease in plant nutrient content and reduction of efficiency of photosynthetic energy conversion (Chibuike and Obiora, 2014).

In both mining sites, the pH values of soils were measured to be ranging from 7.16 to 9.87, the highest recorded at Klein Letaba mining sites. The average level of soil pH was found to be 8.61 at Louis Moore and 8.07 at Klein Letaba sites. Such values were found to be above the permissible standards in soil set by World Health Organisation. Soil pH is a measure of the acidity or alkalinity. Such average results of pH analysis in soil revealed that the soil is strongly alkaline in nature at both mines. Alkaline soil affects availability of plant nutrients and results in an increase in Aluminium which is toxic to plants (Kalshetty *et al.,* 2014). The availability of toxic metals (*i.e.* Aluminium) in soil affects the activity of soil micro-organisms. Thus, affecting nutrient cycling and increasing the risk of diseases to human (Moody, 2006). This is the evidence that the soil pH had the effects of the plant growth in the study area as it alkaline. The electrical conductivity in soils was ranged between 48 - 203 µs/cm and 68 – 105 µs/cm at Louis Moore and Klein Letaba mine respectively. The average levels of electrical conductivity were found to be 84.84 µs/cm and 81.4 µs/cm at Louis Moore and Klein Letaba mine respectively.

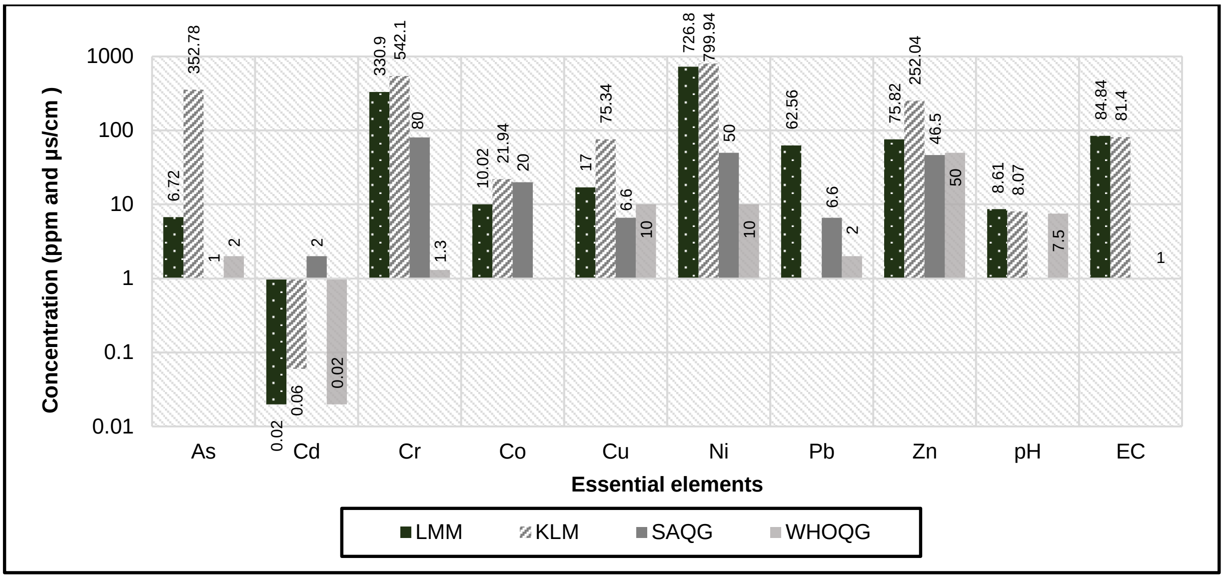

Figure 4.6: Comparison of the concentration of toxic elements in soil.

4.3.2 Concentration trace elements in soil

The concentrations of trace elements in soil were determined in both selected mines, namely; Louis Moore and Klein Letaba Mine. Both mining sites were found with high concentration of Sr in soil. The average concentration of Sr was found to be 337.44 ppm and 231.94 ppm in Louis Moore and Klein Letaba respectively. Such average concentrations of Sr were recorded above the World Soil Average of 175 ppm (Herselman, 2007). The uptake of high concentrations of Sr is generally not known to be great danger to human health (McLaughlin, 2001). According to McLaughlin (2001), the only strontium compound that is considered a danger to human health, even in small quantities is strontium chromate which causes cancer. However, high concentrations of Sr can be accumulated by plants which in turn can have effect to plants growth, development and re-vegetation of plants (Kabat-pendias, 2011).

The samples from Klein Letaba had high concentrations of Ba and La while samples from Louis Moore mine had low concentration of these trace elements. The average concentrations of Ba and La were found to be 487 ppm and 103.92 ppm in Klein Letaba mine site respectively while that of Ba and La were found to be 233.78 ppm and 41.96 ppm in Louis Moore mining site respectively. The world soil average of Ba and La is 460 ppm and 27 ppm respectively (Kabat-pendias, 2011). The contact with high concentration of barium can have adverse effects on the human health. The breathing of dust with high concentration of barium, eating of plants/vegetables and drinking water that is polluted with barium may cause paralyses and in some cases even death (Vandenhove, 2005).

The samples from Louis Moore mine had low concentrations of V and Ce while those from Klein Letaba mine were found with high concentration of V and Ce. The average concentration of V and Ce was found to be 60.38 ppm and 40.58 ppm in Louis Moore respectively. Such concentrations of V and Ce were found to be below the world soil averages of 123 ppm and 56.7 ppm respectively. On the other hand, the concentrations of V and Ce were found to be 136.32 ppm and 78.34 ppm respectively in Klein Letaba. These concentrations were recorded above the world soil averages. According to WHO (1996), the high concentration of Ce is mostly dangerous in the working environment (i.e. mining sites) due to the fact that it can be inhaled with air which during long-term exposure can cause lung embolisms. In addition high concentration of Ce can be a threat and damage liver when it accumulates in the human body (WHO, 1996). On the other hand, the uptake of high concentration of V can cause acute effects in human body such as irritation of lungs, throat, eyes and nasal cavities (Butu and Inguisi, 2013).

Both the mining sites had average concentration of Mo, Nb, Rb, Zr and Ga recorded to be below the world soil averages adopted from Kabata-pendias (2011). The soil samples from Louis Moore had average concentration of 0.64 ppm and 2.34 ppm Mo and Nb respectively while Klein Letaba Mine had an average concentration of 0.46 ppm and 1.11 ppm for Mo and Nb respectively. As shown in Figure 4.7, these concentrations in both mines were found to be below the world soil averages.

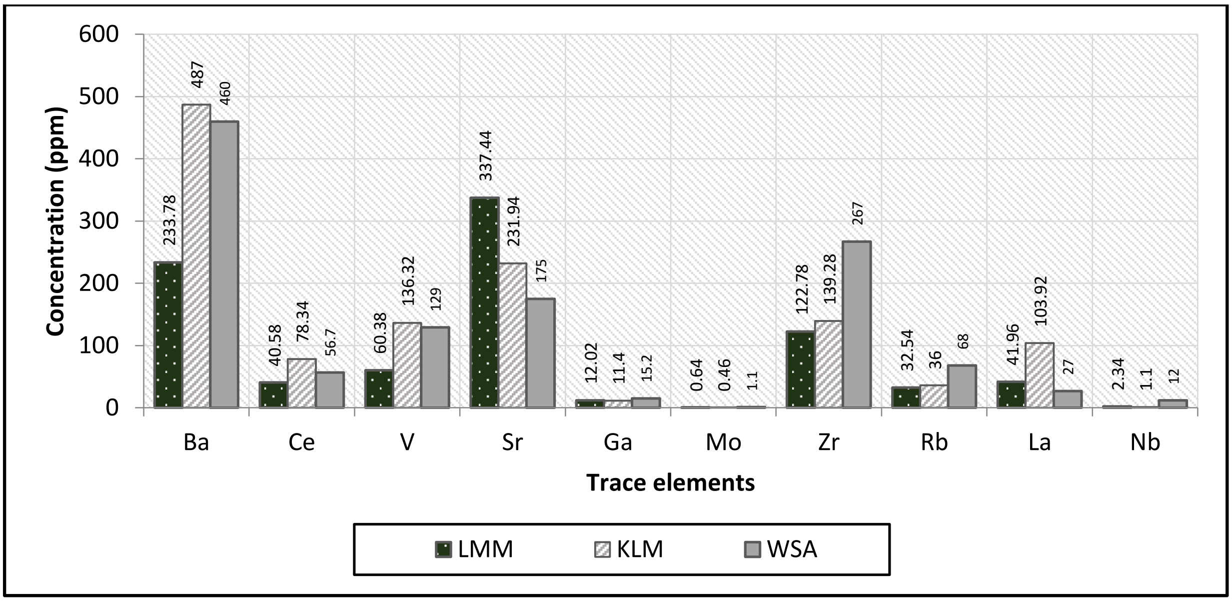

Figure 4.7: Comparison of the concentration of trace elements in soil.

The average concentration of Ga was found to be 12.02 ppm and 11.4 ppm in Louis Moore and Klein Letaba mine respectively which were in both sites below the world soil average of 15.2 ppm. The average concentration of Rb and Zr were found to be 3.54 ppm and 122.78 ppm respectively in Louis Moore. While the concentration of Rb and Zr had average values of 36 ppm and 139.28 ppm respectively in Klein Letaba Mine.

4. 4 Results of Analysis of River Sediment Samples

This section presents the results of the concentration of the toxic and trace metals and pH as well as the corresponding electrical conductivity in sediments samples. The results showed that mining activities in the study area had extensive environmental contamination due to serious release of toxic and trace elements into river sediments.

4.4.1 Concentration of toxic elements in river sediments

The concentrations of Cr in sediments were found ranging from 200.90 ppm to 495.50 ppm and 100 to 1064.5 ppm in Louis Moore and Klein Letaba respectively. The average concentration of Cr was found to be 1614.4 ppm and 358.96 ppm in Louis Moore and Klein Letaba mines respectively. Such concentration were found to be above the WHO and USEPA Sediment Quality Guidelines of 25 ppm. According to USEPA Sediment Quality Guideline, the concentration of Cr above 76 ppm indicates severely polluted or contaminated sediments. Therefore this suggests that sediments in the Louis Moore site are severely contaminated by Cr. According to Sany *et al.* (2013), sediments which are heavily contaminated by Cr have the adverse effects on the organism that live in the sediments (*i.e.* high concentration of Cr to aquatic species can cause damage to cell membranes).

Cu concentration was found to be between 35.80 ppm to 43.40 ppm (with the average of 36.42 ppm) and 39.7 ppm to 165.4 ppm (with the average of 78.52 ppm) in Louis Moore and Klein Letaba mining sites respectively. According to the USEPA pollution sediments ratings, the concentration of Cu between the ranges of 25 ppm to 50 ppm indicates slightly contamination of the sediments. Since the average concentration of Cu (36.42 ppm) in Louis Moore and 78.52 ppm (in Klein Letaba) falls within the slightly polluted sediments ratings according to UESEPA standards, it indicates that sediments in Louis Moore are slightly polluted or contaminated by the Cu. Nevertheless, slightly contamination of Cu in sediments can be toxic to the aquatic organism as it has negative influences on the reproduction and on the functions of the nervous system (Sekabira *et al*., 2010).

The concentrations of Ni in sediments respectively ranged from 448.50 to 1186.90 ppm and 225.6 to 1422.1 ppm of Louis Moore and Klein Letaba mining sites. The average concentration of Ni was found to be 831.06 ppm and 568.18 ppm respectively. These concentrations of Ni were recorded above the WHO and USEPA standards of 20 ppm and 16ppm respectively. According to these standards, such high concentrations of Ni in sediments (above the 50 ppm) indicate severely polluted or contaminated sediments. The severely Ni contaminated or polluted aquatic environment (i.e. sediments and water) poses a serious threat to the survival of aquatic organisms which can lead to damage and fatalities of fish (Salah *et al.,* 2012).

Pb concentration in river sediments ranged between 70.80 to 119.50 ppm and 35.3 to 5988.5 ppm in both mining sites (Louis Moore and Klein Letaba sites). The average concentrations of Pb in sediments were recorded to be 107.4 ppm and 1239.2 ppm in Louis Moore and Klein Letaba sites respectively. Such concentrations were recorded above the USEPA Sediment Quality Standards of 40 ppm. According to this standard, the concentration of Pb above 60 ppm in sediments indicates the severely polluted or contaminated sediments. This is the evidence that the sediments in the Louis Moore mining sites are severely or heavily contaminated by the Pb. According to Rehman *et al.* (2016), the high concentration of Pb has serious effects on human body as it can cause death or permanent damage to the central nervous system, the brain, and kidneys.

Zn concentration was found to be ranging between 96.1 ppm to 912.7 ppm and 45.9 ppm to 1790.4 in Louis Moore and Klein Letaba river mine sediments. The average concentrations of Zn in river sediments were recorded 321.56 ppm and 413.22 ppm in Louis Moore and Klein Letaba mine respectively. These concentrations were recorded above the WHO and USEPA standards of 123 ppm and 110 ppm respectively and they are reported to be an indication of severely or heavily polluted of the river sediments. This shows that in both mining sites the sediments are severely polluted or contaminated by the concentration of Zn. According Rehman *et al.* (2016), Zn is one of the essential toxic elements that play a fundamental role in the physiological and metabolic process of many organisms. Nevertheless, higher concentrations of Zn can be in the sediments is poisonous to the aquatic organism (Sekabira *et al*., 2008).

River sediments were found with As concentration ranging between 4.20 ppm to 27.60 ppm in Louis Moore and 4 ppm to 642.8 ppm in Klein Letaba mining sites. The average of concentration of As was found to be 13.6 ppm in Louis Moore and 133.8 ppm in Klein Letaba mine sites. According Shrivastava *et al.* (2015), high concentration of As may lead to clinical manifestations (i.e. melanosis, keratosis, and leukomelanosis, carotid atherosclerosis, ischemic heart disease, and impaired cognitive abilities). According to Nazir *et al.* (2015), there are no As, Co and Cd standards limit of sediments from WHO and USEPA guidelines.

The concentration of Cd was found to be 0.14 ppm in Klein Letaba while in Louis Moore mine it was not detected in the sediments. Consumption and contact with high concentration of Cd may cause an asthma-like disease with symptoms such as coughing, shortness of breath, permanent disabilities and fatalities (Nazir *et al.,* 2015). In Louis Moore site the concentrations of Co in sediments ranged between 7.80 ppm to 20.10 ppm while in Klein Letaba site ranged between 11.8 ppm to 29.8 ppm. The average concentration of Co was found to be 12.14 ppm in Louis Moore and 16.63 ppm in Klein Letaba mine. The uptake of high concentration of Co may results to health effects which include thyroid damage, heart problems, vomiting and nausea (Chik and Islam, 2011),

In addition, the pH of the river sediments was measured to be at alkaline level (9.0 and 8.9) in both mining sites. The comparison of the average pH values with the standards prescribed by the World Health Organisation was found to be above the target sediments quality as shown in Figure 4.6. According to Chik and Islam (2011), alkaline sediments have the adverse effects on the aquatic species which results to death of such species. The average electrical conductivity for the sediments was found to be 70.1 µs/cm and 145.46 µs/cm in Louis Moore and Klein Letaba mines respectively. The results of the average pH level and electrical conductivity are shown in Figure 4.8. In Figure 4.8, WHO SQG is the World Health Organisation Sediment Quality Guidelines. USEPA SQG is the United States Environmental Protection Agency Sediment Quality Guidelines.

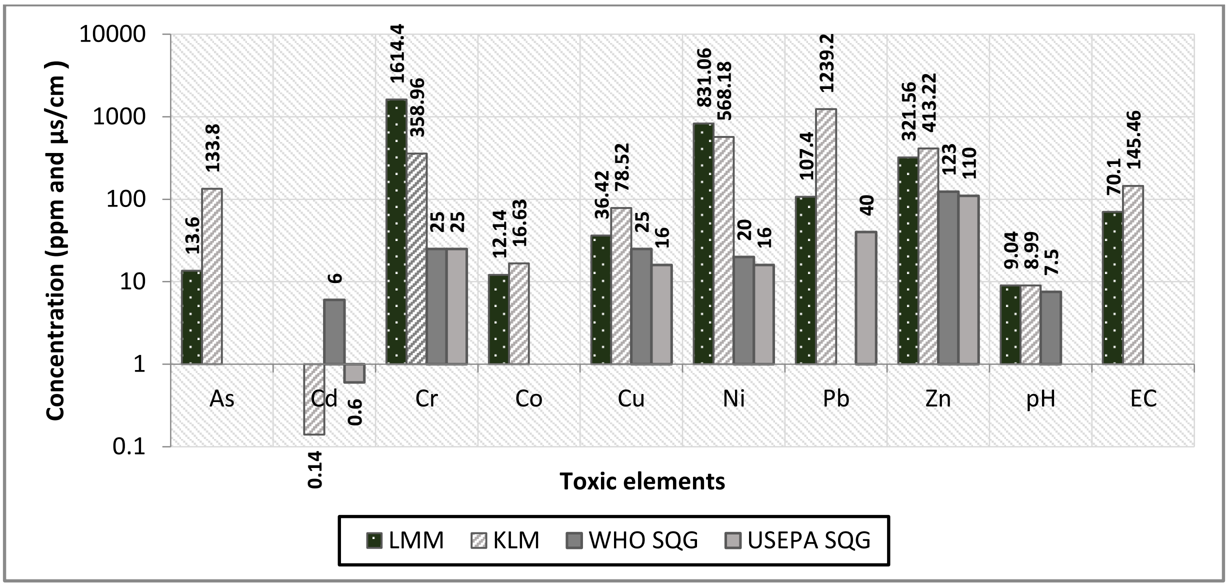

Figure 4.8: Comparison of concentration of toxic elements in sediments.

4.4.2 Concentration of trace elements in river sediments

The concentrations of the trace elements in river sediments were determined in Klein Letaba and Louis Moore Mines. The average concentrations of Ba were found to be 465.22 ppm and 251 ppm in Klein Letaba and Louis Moore Mine respectively. The average concentrations of Ba in both mines were found to be above World Health Organisation Sediment Quality Guideline of 0.3 ppm (Butu and Iguisi, 2013). According to WHO (2008), the high concentration of barium in sediments and water can cause abnormal high blood pressure (*i.e.* hypertension) through skin contact and drinking of contaminated water. The average concentrations of Ce were found to be 126 ppm in Klein Letaba and 80.16 ppm in Louis Moore Mine respectively.

The sediments samples from Louis Moore mine had an average concentration of 153.82 ppm and 37.72 ppm vanadium (V), and rubidium (Rb) respectively. While the sediments samples from Klein Letaba had an average concentration of 72.74 ppm and 54.1 ppm vanadium (V), and rubidium (Rb) respectively. According to Butu and Iguisi (2013), the essential elements such as vanadium (V) and rubidium (Rb) do not have the WHO standards in sediments. The average concentration of V and Rb were found to be high in both mines but comparison with the WHO was not made as there are no permissible standards for such elements. The concentration of Mo was recorded 1.28 ppm in Louis Moore Mine and 0.48 ppm in Klein Letaba Mine.

Trace elements such as gallium (Ga), zirconium (Zr), lanthanum (La), and niobium (Nb) does not have the WHO and Canadian Sediment Quality Guidelines (Butu and Iguisi, 2013). The samples from Klein Letaba mine had a concentration of 14.62 ppm and 3.54 ppm in Ga and Nb respectively. While the samples from Louis Moore mine had average values of 9.32 ppm and 2.76 ppm in Gallium (Ga) and niobium (Nb) respectively. The average concentrations of Zr were found to be 163.2 ppm in Klein Letaba mine and 88.06 ppm in Louis Moore respectively. Lastly, La had an average concentration of 94.34 ppm in Klein Letaba and 57.42 ppm in Louis Moore mine respectively. In Figure 4.9 LMM is Louis Moore Mine, KLM is Klein Letaba Mine.

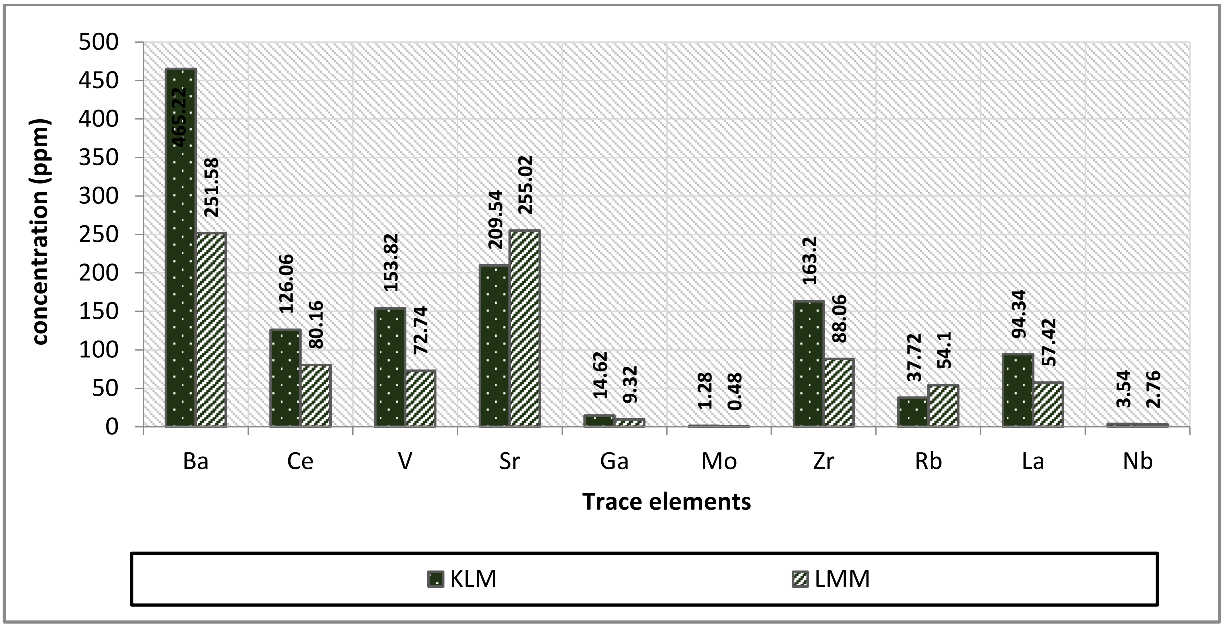

Figure 4.9: Comparison of the concentration of trace elements in sediments. Note: LMM is Louis Moore Mine, KLM is Klein Letaba Mine.

4.5. Results of Water Analysis

This section presents the results of the concentration of the toxic metals, pH and corresponding electrical conductivity in water samples. The results showed that mining activities in the study area had extensive environmental contamination due to serious release of toxic and trace elements into water bodies. This is due to washing and processing of soil deemed to be having gold within the water bodies.

4.5.1 Concentration of toxic elements in water

The average concentration of As was found to be 1.1 ppm and 1.5 ppm in Louis Moore and Klein Letaba Mine respectively. These concentrations were found to be within the range of 0 – 10 ppm of South African permissible standard set by DWAF (2006). According to this standard no human health effects are expected within such ranges. The concentration of Cd was found to be 0.00 ppm which is below the South African water quality and WHO of 5 ppm and 0.01 ppm respectively. The water samples from Louis Moore had average values of 0.05 and 0.07 zinc

(Zn) and lead (Pb) respectively. Then the Klein Letaba Mine had an average concentration of 0.01 of both the Zn and Pb. Such average concentrations of Zn and Pb were found below the South African water quality and WHO standards.

Both the selected mine had low concentrations of Cu, Co, Ni and Cr which were below the permissible standards of South African Water Quality and World Health Organisation guidelines. The concentration of were found to be 0.1 ppm in Louis Moore and 0.01 ppm in Klein Letaba mine. The average concentration of Cr in Louis Moore was at the same level as the WHO guidelines. The water samples from Louis Moore mine had values of 0.03 ppm and -1 ppm for Co and Cu respectively. While the water samples from Klein Letaba mine had an average concentration of 0.00 ppm and -0.99 ppm respectively. Such average concentrations of Cu in both mines were below the South African Water Quality Standards and WHO guidelines. According to these standards no health or aesthetic effects are expected when the concentration of Cu is within target water quality range.

4.5.2 pH and electrical conductivity of water

The average value of the water pH was found to be 9.2 in Louis Moore Mine. The results of water pH analysis revealed that the water is strongly alkaline in nature. The comparison of the average water pH level of Louis Moore site with the South African Water Quality Standard for domestic use as recommended by the Department of Affairs and Forestry (1996) was found to be above the normal water quality range as shown in Figure 4.9. The average water pH level in Louis Moore Mine was also found to be above the World Health Organisation standard of 6.8 – 8.5. According to these standards the water pH level of 9.2 has increased potentials of toxic effects associated with deprotonated species such as ammonium and to cause the water to taste bitter.

In Klein Letaba Mine, the average water pH was recorded 7.7. This average value of water pH was recorded within the normal ranges of South African Water Quality and World Health organisation Standard. According to DWAF (1996), such average values indicate no significant effects on health due to toxicity of dissolved metal ions and protonated species, or on taste are expected. The average values of toxic elements in water are presented in Figure 4.10.
The average electrical conductivity of the water was found to be 1886 µs/cm and 1837 µs/cm in Louis Moore and Klein Letaba Mine respectively. Such average electrical conductivity of Louis Moore and Klein Letaba Mines was recorded above the permissible limits set by the Department of Water Affairs and Forestry and World Health Organisations. According to these standards the average electrical conductivity of greater than 450 µs/cm has aesthetic/economic effects

(i.e. water tastes extremely salty and bitter and effects such as corrosion and/or scaling increase) and health effects (i.e. short-term consumption leads to disturbance of the body's salt balance and at high levels, noticeable short-term health effects can be expected). The average pH values and electrical conductivity of water samples are presented in Figure 4.10. SA WQG is South Africa Water Quality Guideline and WHO SQG is the World Health Organisation Sediment Quality Guidelines.

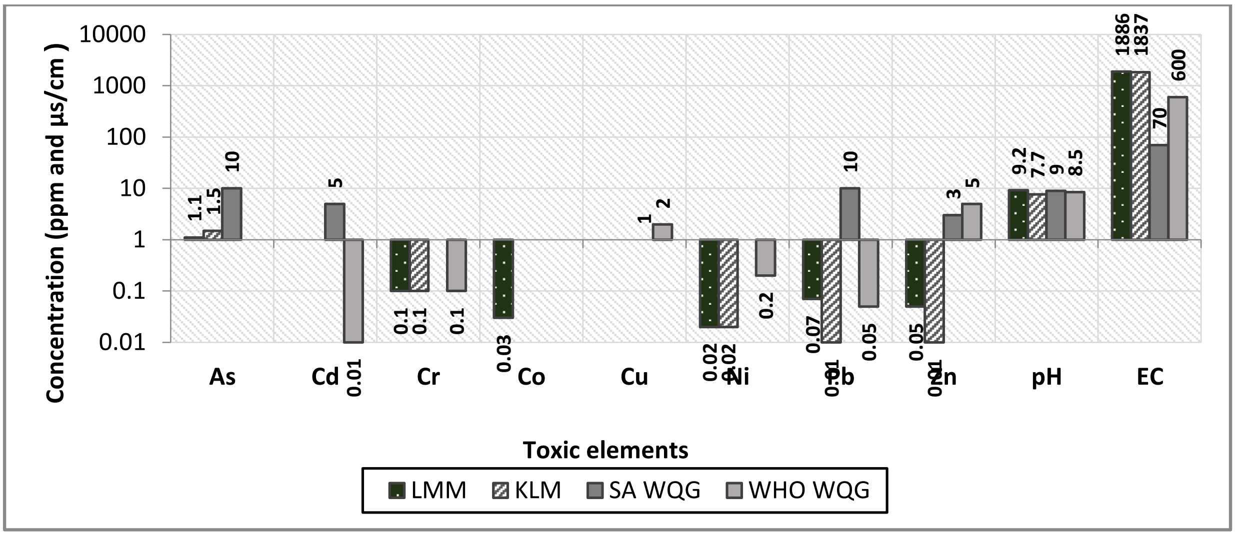

Figure 4.10: Comparison of concentration of toxic elements in water.

4.6 General Socio-economic Issues of ASGM

This section presents the demographic information, gender and age distributions, educational level, and proximity of the respondents to the mining area. It also discusses the reasons for engaging in ASGM and the period of involvement.

4.6.1 Demographic information

This section provides the statistical data about the characteristics of the populations involved in the artisanal and small-scale gold mining in Giyani Greenstone Belt. It also presents that statistical data of the communities around the Louis Moore and Klein Letaba Gold Mines. These statistical data about the characteristics of the populations include the age and gender.

4.6.2 Gender and age distributions of the respondents

It was observed that in the study area both males and females were involved in artisanal and small-scale mining gold operations. The results of socio-economic issues were obtained from population involved in mining activities and the community population not involved in mining activities that were available and willing to provide data for this research. A total of 53.3% in Klein Letaba and 44.7% in Louis Moore sites were drawn from population not involved in ASGM activities. While a total of 49.1% and 50.9% were the respondents involved in ASGM activities in Klein Letaba and Louis Moore sites respectively.

A total of 65.4% of the artisanal and small-scale gold miners in the study area were found to be males and the total of 34.6% was found to be females. This gave an indication that in the study area the majority of people involved in ASGM are severely males. It was also established that about 20.4% of the artisanal and small-scale miners were between the age of 18 to 25 years while 67.3% was between the age group of 20 to 35 years and the rest was between the ages of 36 – 50 years (See Figure 4.11). According to African Union (2006), people of the age group between 15 to 35 years are classified as youth. Therefore, the results presented in Figure 4.11 shows that the majority of artisanal miners in the study area are generally youth populations. Adults and old people involved in the artisanal and small-scale mining activities were found to be only 12.2%. Normally, people who are involved in ASGM are people between the age group of 25 to 35 years (Mwakaje, 2012). According Kessey and Arko (2013) the involvement of the youth in artisanal and small-scale gold mining leads to a huge number of illiterate and uneducated youth as they will quite school for mining.

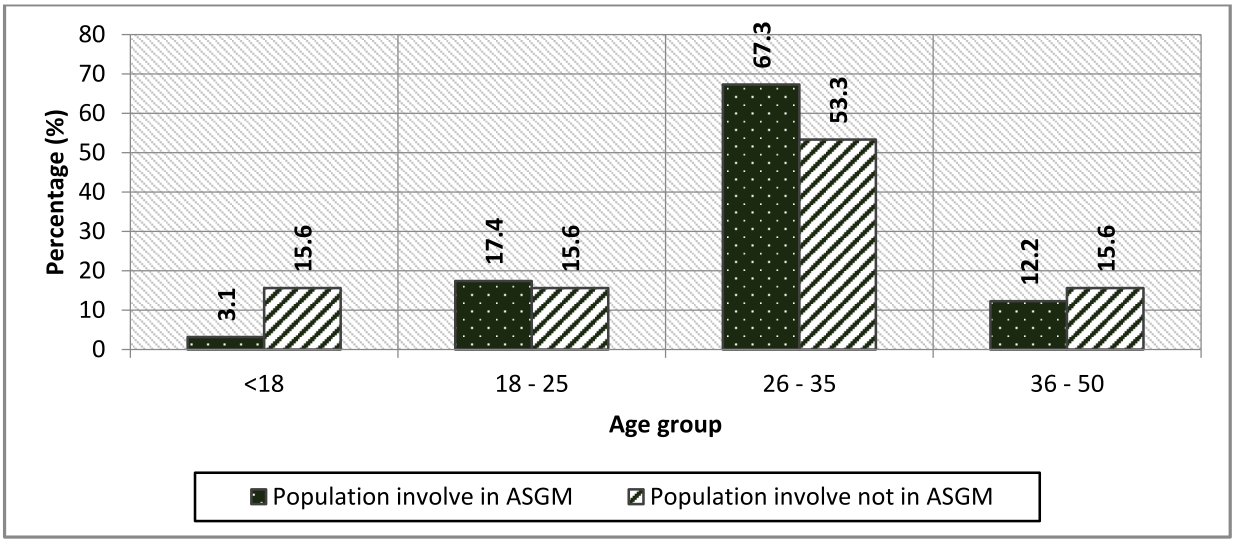

Figure 4.11: Respondents by age groups

4.6.3 Education level of the respondents

The results in Figure 4.12 show that the majority (67.3%) of artisanal and small-scale miners had secondary qualification and a total of 21.2% of miners had primary level qualifications. It was also established that a total of 5.8 % of artisanal miners had only tertiary qualifications.

Approximately 67.3% of the miners who had secondary qualification were found to be between the ages of 26 to 36 years. It was found that a total of 67.3% involved in mining activities left school to generate income from artisanal and small-scale mining operations. They indicated that they were pushed into mining activities in order to generate an income so that they could be able to support their families financially. This clearly shows that in African societies poverty is to some extent inherited from one generation to the next due to family backgrounds and circumstances.

According to the results presented in Figure 4.12, artisanal and small-scale mining in the study area has serious effects on education for the youth. Figure 4.12 shows that the majority of community members (44.4%) who are not involved in mining operations had tertiary qualification and a total of 37.8% of communities had secondary level. This shows that mining in the study area is having serious negative educational effects because individuals who are not involved in mining had tertiary qualifications as compared to youths involved in mining activities. There was a significant difference between the artisanal miners and the community members' qualifications. The community qualifications indicate that they take education more seriously than the miners. According to Hoedoafia (2014), people who are involved in artisanal and small-scale gold mining are generally uneducated and unskilled people who depend on mining activities for living. Based on the results in Figure 4.12, people who are involved in artisanal and small-scale gold mining are uneducated.

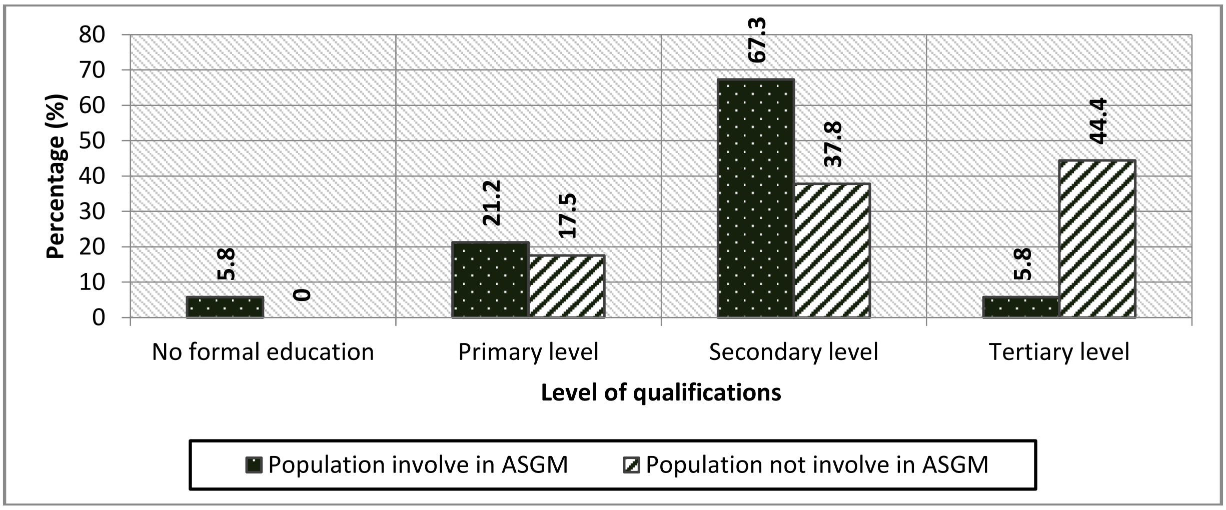

Figure 4.12: Level of qualification respondents.

4.6.4 Proximity of the respondents to the mining site

The majority of the community members who took part in this research were less than a kilometre away from mining site and they provided sufficient information about the artisanal and small-scale gold mining operations in the study area. Respondents who reside at a distance of about 501 -1000m from the mine were found to be 48.9% and those from 1000 - 1500m were 31.9%. Those respondents had a good understanding of the ASGM in the study area. Few (8.5%) provided insufficient data this research due to the fact that they were less or not affected by the mining activities in the area (See Figure 4.13). In addition, they had very little knowledge of artisanal and small-scale gold mining activities. Although people involve in ASGM activities are migratory (*i.e.* they move from one site to the other searching for easy ways to extract minerals), majority of the people involved in artisanal and small-scale mining activities stays close to the mining sites (Hoedoafia, 2014; Hilson, 2002).

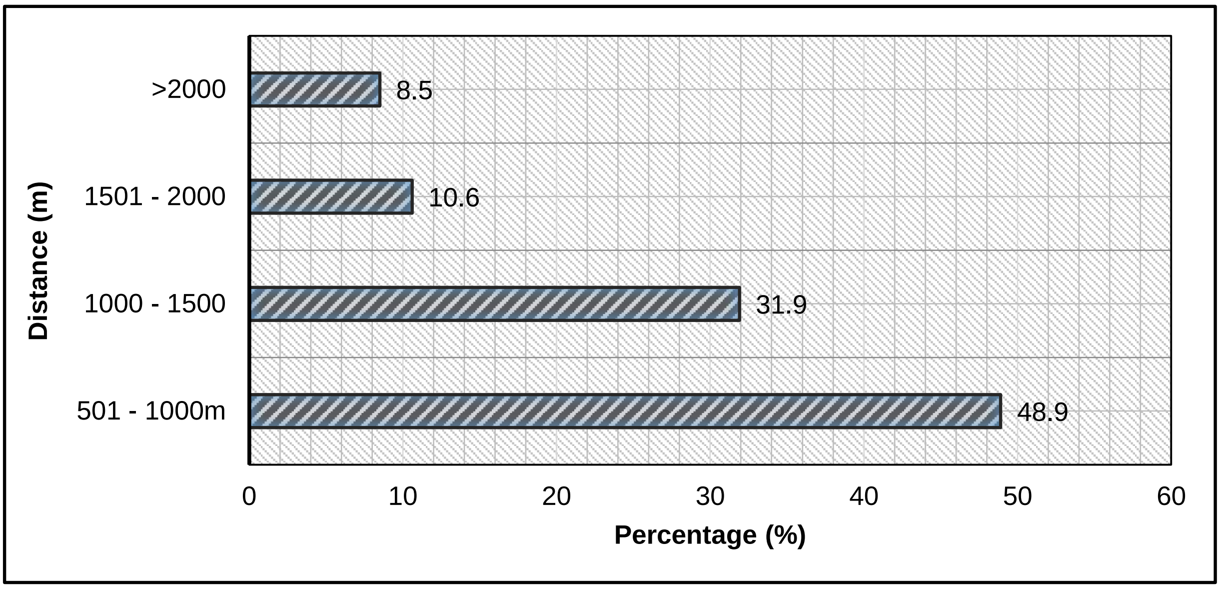

Figure 4.13: Distance of respondents from the ASGM mining sites.

4.6.5 Reasons for involvement in ASGM

According to Rico (2007), artisanal and small-scale gold miners are engaged in mining operations because of push and pull factors. The main reasons people got involved in artisanal and small scale gold mining in the study area were found to be lack of employment and income generation opportunities. These can be classified into both pull and push factors. A total of 64.3% of people involved in artisanal and small-scale gold mining established income generation alternative as the main reason they are involved in mining operations. It was also established that a total of 35.7% of people involved in artisanal mining indicated that they are involved in artisanal mining because of lack of employment.

Figure 4.14 depicts that the majority of artisanal and small-scale gold miners got involved in artisanal and small-scale gold mining activities as it seemed to be only alternative of income generation opportunity in the area. While some of the miners were pushed into mining activity by lack of employment in the region and the country at large. A total of 55.3% of a population not involved in small-scale mining indicted that lack of family income is the main reason as to why people are involve in artisanal and small-scale mining in the study area followed by the lack of the employment opportunities in the region and the country at large (See Figure 4.14). According to Phiri *et al.* (2015), the main drivers behind involvement of people into artisanal and small-scale gold mining activities is lack of income, lack of job opportunities and severely drought.

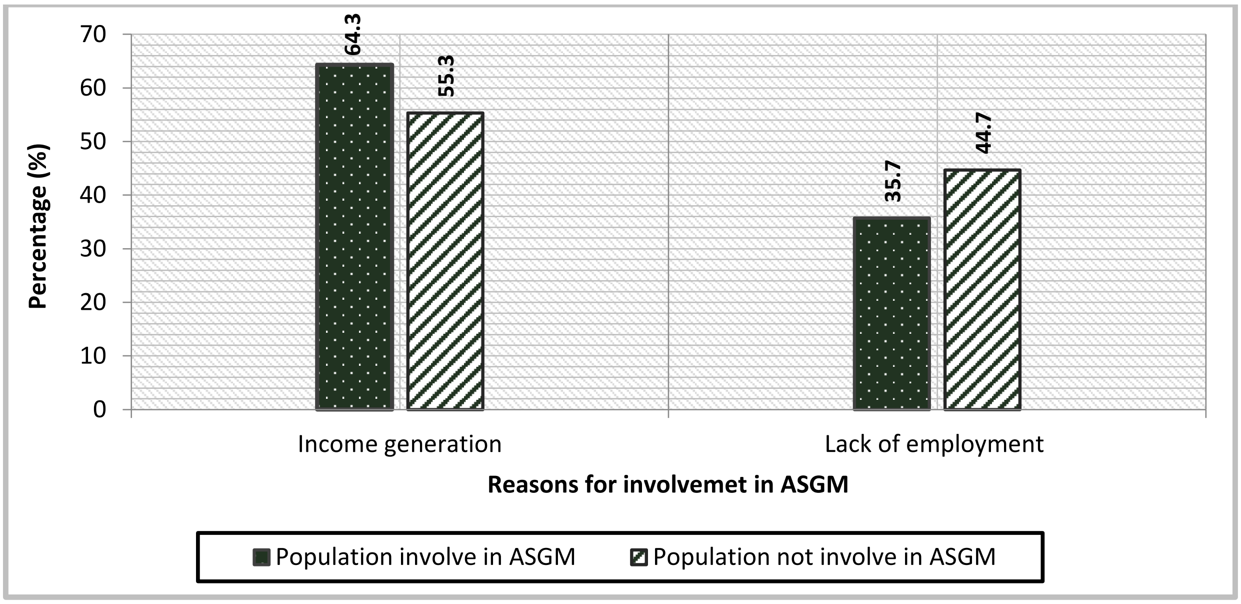

Figure 4.14: Reasons of involvement in ASGM.

4.6.6 Period of involvement in ASGM

A total of 49.1% of the artisanal and small-scale gold miners indicted that they are full time involved in ASGM activities. They also indicated that they do not have any other sources of income thus they rely on ASGM for survival. This gave an indication that the majority of people involve in artisanal mining of gold in the study area depend on mining for living. A total of 39.6% of part-time miners indicated that other than artisanal and small-scale mining activities, they were also involved in semi-skilled and unskilled works such as construction labourer, vegetable harvesting, furniture mover, house maid, restaurant dishwasher, painting and garden works. They indicated that they participate in such work only when they are not in the mining site. This suggests that artisanal and small-scale gold mining in the study area plays a significant role in the survival of any people around local community or communities.

As shown in Figure 4.15, occasional miners were found to be few as compared to part-time and full-time miners. This also suggest that most of the artisanal gold mining activities in the study area enables many people to support their families or dependencies since the majority of the people (49.20%) were fully involved in small scale mining activities in the study area. People involved in ASGM activities were managing to support their families and there was extensive potential in these small scale mines to at least change the quality of lives of the people. Artisanal and small-scale mining may be practiced seasonally, occasionally, part-time or full time in some areas (Hentschel, 2002). According Obiri *et al.* (2015), in developing countries where there is high lack of employment rate and economic crisis, majority of artisanal and small-scale miners engage in mining activities for full time basis. As shown in Figure 4.15, there are many full time miners in the study area.

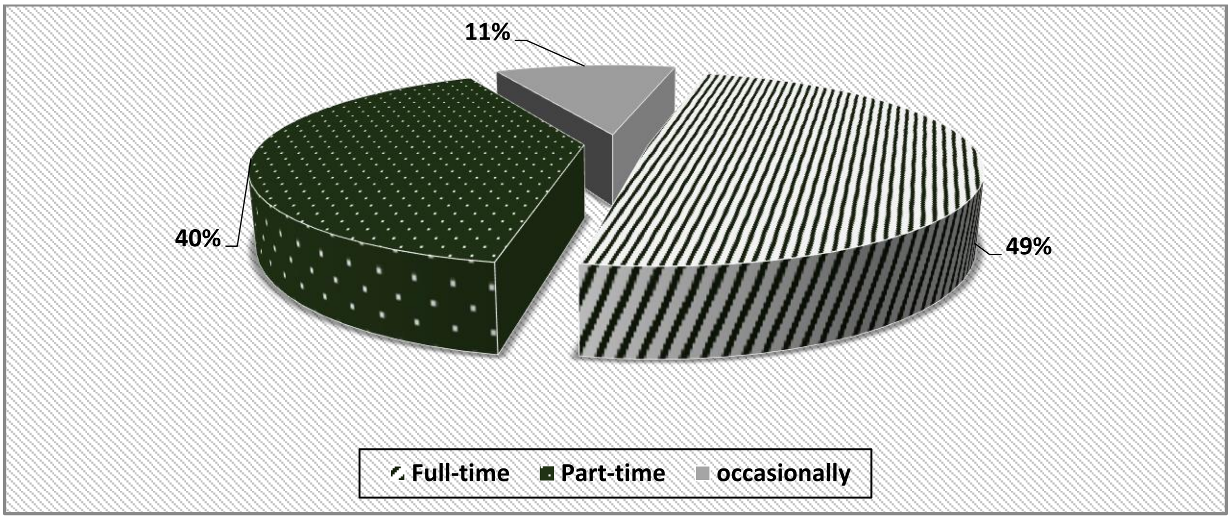

Figure 4.15: The period of involvement of the community miners to ASGM.

4.7 Social benefits and problems of ASGM

This section provides the positive and negative impacts of artisanal and small-scale gold mining identified in Giyani Greenstone Belt. The positive impacts of ASGM in Giyani Greenstone Belt include the income generation and employment opportunities while the negative issues include the health and safety problems, use of child labour and education problems.

4.7.1 Income generation and employment opportunities

In general, artisanal and small-scale gold mining has the socio-economic impacts to the host and surrounding communities. This research identified and assessed socio-economic issues around Giyani Greenstone Belt (GGB) communities. A total of 43% of the people involved in artisanal and small-scale gold mining and a total of 40% of the people not involved in artisanal and small-scale mining identified the income generation as one of the main positive impacts of artisanal mining in the study area. Artisanal and small-scale gold miners generate income through the exploitation and selling of gold. Some of the miners (*i.e.* 23.23%) indicated that they generate income only through the digging and selling of sediments deemed to be containing gold to people who further process them to extract gold.

People who are involved in artisanal and small-scale gold mining activities indicated that they are able to produce one to five grams of gold which they sell it with approximately two hundred and fifty rand to the local dealers. The amount of money obtained from the selling of gold shows that mining operation in the area is contributing to poverty at a lower extent. This shows that mining in the study area is not contributing to the improvement of living standard in terms of infrastructure (*i.e.* building of quality houses), however, contributing to survival of the miners.

A total of 20% and 17% of the people involved and people not involved in ASGM respectively established job creation as one of the positive impacts in the study area. All of the artisanal and small-scale gold miners acknowledged that mining jobs and income generated enabled them to provide basic needs (i.e. water, electricity, food, provision of books and other learning materials) for their families. This shows that mining in the study area is contributing to the needs of surrounding communities. According to Kitula (2006), artisanal and Small-scale Gold Mining contribute to poverty alleviation through the creation of jobs, generation of income, improvement of local economy and improvement of infrastructure (*i.e.* quality houses and roads). Artisanal and small-scale gold mining is a source of income generation which enable people to support their families (Phiri *et al.*, 2015).

4.7.2 Influence of ASGM on education in the study area

Besides the positive impacts of artisanal and small-scale gold mining operations in the study area, artisanal and small-scale gold mining had negative educational effects to the host and surrounding communities. Figure 4.16 shows that in the study area, there are less positive impacts generated from mining operations as compared to the negative impacts. A total of 20% of the populations involved in artisanal and small-scale gold mining identified the effects of education caused by artisanal mining. A total of 35% of populations not involved in ASGM also identified the influence of ASGM on education in the study area. This includes young population withdrawing from school to engage in mining activities. When a large number of youth withdraws from school and engages in mining activities, the rate of school dropouts in the communities' increases and also increase in the number of illiterate population (Hilson, 2002). However, this is also the case in the study area as approximately 67.3% (See Figure 4.16) of the youth miners were not having tertiary level. The consequences of illiterate youth include the increase of uneducated people in the country which might lead to high crime rate by the youth.

4.7.3 Problems of use of child labour in ASGM

The issue of child labour was mentioned by a total of 5% of the people involved in artisanal and small-scale gold mining. A total of 10% of the people not involved in artisanal and small-scale gold mining also identified the issue of child labour in study area as a serious problem as children tend to leave school to undertake mining activities. In the study area, children often work in artisanal and small-scale gold mining to help their families. It was observed and found that they work in harsh and difficult conditions for long hours for little or no pay. Such conditions create serious problems for their growing bodies.

A total of 10% of the population involved in artisanal and small-scale gold mining operations in the study area indicated that the main reasons children are involved in ASGM activities are poverty-related which includes low family income and lack of employment. A total of 5% of the population not involved in artisanal and small-scale gold mining indicated that children are involved in ASGM because parents are not interested enough in the education of their children. In addition, parents have insufficient knowledge about the risks of mining of children.. According to Owusu and Dwomoh (2012), the tendency of children working in mining encourages truancy in school and increases the school dropout rate. This gives an indication that the increase of children dropout in the study area and surrounding communities might be due to artisanal and small-scale gold mining activities..

4.7.4 Health and injuries problems

Results of the study showed that 5% of people involved in the artisanal and small-scale gold mining mentioned the issue of occupational health and safety while 3% of people not involved in artisanal and small-scale gold mining operations also identified the issue of health problems in the study area as presented in Figure 4.16.The health problems identified was associated with the dust pollution generated from the digging and uprooting of trees when collecting the soil and sediments deemed to be containing gold. According to Hoedodia (2014), the dust emission through artisanal and small-scale mining exposes miners and their communities to severe health risks. The prolonged exposure of children and adults to dust can cause silicosis and silico-tuberculosis (Obiri *et al.*, 2015).

Other health problems identified in the mining site were dizziness, weakness, rapid heartbeat, extreme thirst, and fainting. Artisanal and small-scale gold mining activities are associated with diseases such as coughing, weakness, reddening of eyes, dizziness, collapsing, hearing problems due to noise, heart and lung cancer (Hilson, 2002). Such health problems in the study area were found to be caused by working in very hot conditions without drinking enough water. Only two artisanal and small-scale miners indicated that they use mercury for gold processing and the rest of miners indicated that they do not use mercury. This indicates that the health risk/problems associated with the mercury might be minor or not present in the area. The artisanal and small-scale gold activities are characterized by lack of safety measures and health care (Obiri *et al.,* 2015).

The artisanal and small-scale miners (5%) raised the issue of injuries during the mining activities in the site, the causes of injuries to the artisanal and small-scale miners were found to be the use poor and inappropriate tools in the site. The lives of the miners are in danger as the tools and methods used in the mining activities exposes them to a high risk of injuries (Hoedodia, 2014). Artisanal and small-scale miners dig the soils and sediments deemed to be containing gold, lift them into half truck and/or carry them on shoulders to processing gold area (i.e. to the river). According to the 5% of the people involved in artisanal mining, heavy lifting of the sediments bags deemed to be containing gold found to be causing serious pains and injuries to the arms, legs, and at the back part of the body. Artisanal and small-scale miners further indicated that inappropriate tools and the methods used limit them in terms of gold production.

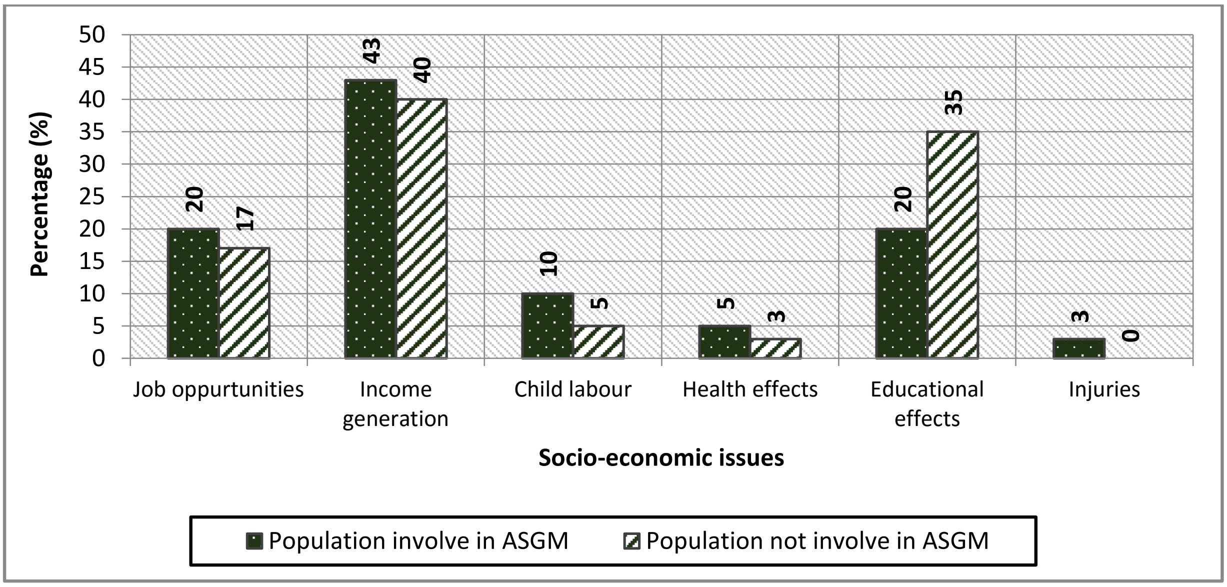

Figure 4.16: Socio-economic issues of ASGM in GGB.

4.8 Challenges faced by artisanal and small-scale gold miners

This section presents the results of the challenges faced by the artisanal and small-scale gold mining in Giyani greenstone belt. These challenges were identified by population involved in ASGM only.

4.8.1 Police Disturbance and arrests

A total of 94.3% of the populations involved in artisanal and small-scale gold mining indicated that police disturbance is the main challenge of the mine sites. From the interview results, artisanal and small-scale gold miners are chased away from mining sites and sometimes get arrested almost twice a month. It was found that artisanal and small-scale gold mining activities in the study area is informal or illegal. This is the reason why the police or law enforcement officers are not allowing any mining activity to take place in the area. As shown in Figure 4.17, in the study area, the majority of the artisanal and small-scale gold miners (about 94.3%) indicated that the disturbance and chasing by police from mining sites affect their gold production, thus, increasing income crisis and lack of employment in the area. According to the study conducted by Mwakaje (2012) in Tanzania, the main challenge facing ASGM is lack of license security as it also leads to lack of access to credit and finance.

4.8.2 Lack of mining equipment and machinery

A total of 5.7% of the population involved in artisanal and small-scale gold mining mentioned that lack of mining equipment and machinery is one of the major challenges in the study area. It was found that artisanal and small-scale gold miners use the shovel, pick, wheelbarrows and/or truck in the mining operations. The lack of quality machinery was found to limit the gold production as the work is done manually which takes time and energy to complete. Population involved in ASGM indicated that problems such as pains in the shoulder are caused by the heavy lifting of soils deemed to be containing gold to processing areas. According to Hilson (2002), lack of access to quality technologies and mining equipment in artisanal and small-scale gold mining means that work in mines will be undertaken manually, thus increasing and causing high chances of injuries and fatalities. According to Mensah (2015), the management of such challenge is the provision of appropriate mining machinery, equipment, skills and training. The figure 4.17 illustrates the challenges faced by the ASG miners in the study area.

Figure 4.17: Challenges facing artisanal and small-scale gold mining

4.9 Addressing the challenges of ASGM

Population involved in artisanal and small-scale gold mining activities suggested that the government can enhance mining operations in the study area. The majority of 43.59% of the population involved in artisanal and small-scale gold mining activities suggested that the state can enhance the ASGM in the study area by granting permission or legalising artisanal mining which will enable them to mine without being chased or arrested. A total of 34.62% of respondents involved in artisanal mining suggested that, providing of proper mining equipment and working materials can lead to more production of gold and reduction of health risks as well as injuries.

The study also revealed that miners are in serious need of suitable equipment that can reduce dust and materials that will protect them from breathing dust (*i.e.* proper mask). The more the gold produced the more the income is generated from mining operations. As presented in Figure 4.18, only 12.82% of the respondents involved in artisanal mining indicated that mining training and education are important as it helps to minimise the environmental impacts while extracting and processing gold. According to Mensah (2015); Phiri *et al*., (2015); Kitula (2006) and Hilson (2003), informal artisanal and small-scale gold mining can be enhanced by provision of mining licence, provision of environmentally friendly mining machinery and technologies, easing the registration process of ASGM, strengthening regulatory frameworks and provision of environmental awareness and campaigns.

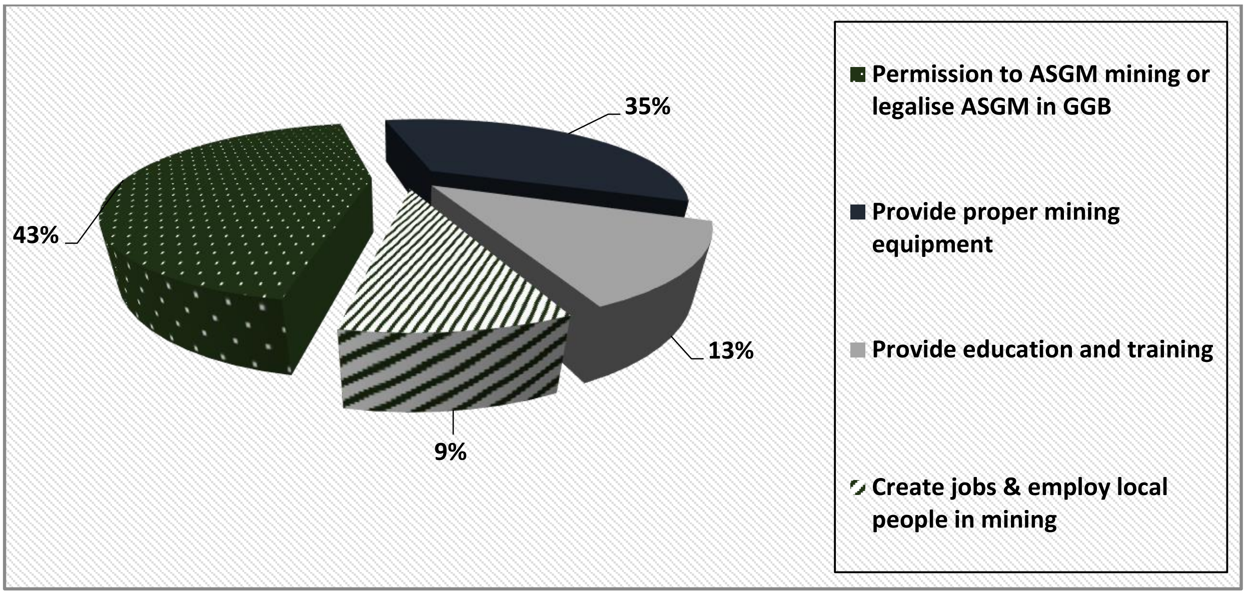

Figure 4.18: Ways in which government can enhance mining in GGB

CHAPTER FIVE: MANAGEMENT OF ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS OF ASGM

This chapter presents management strategies for addressing/mitigating the environmental and social problems of ASGM in the study area. These include mine site rehabilitation, remediation of contaminated area, raising of environmental awareness and campaigns, enforcement and compliance of environmental policies. The management strategies for social problems include formalising and easing registration process of ASGM, provision of appropriate mining equipment and machinery and enforcement and compliance of social policies. These management strategies have been given prominence in order to adequately address the most pressing issues and adverse impacts associated with the artisanal and small-scale gold mining operations in the two study areas.

5.1 Management of Environmental Impacts of ASGM

This section presents the management strategies of environmental impacts associated with the artisanal and small-scale gold mining in both mining sites (*i.e.* Louis Moore and Klein Letaba sites). The main environmental impacts include the removal of vegetation, contamination of the soil, water and sediments. These impacts are serious problem as they affect the surrounding communities. Therefore, management strategies of these impacts include the mine site rehabilitation, remediation of the contaminated/polluted area, environmental awareness and campaigns as well as the compliance and enforcement of the environmental policies.

5.1.1 Mine site rehabilitation

The study culminated in development of NDVI maps and this was used to assess the effects of ASGM on vegetation cover. Results showed that the mining activities in the area had caused extensive environmental degradation due to serious removal of vegetation cover. This environmental degradation was also caused by uprooting of trees and digging of the soils deemed to be containing gold during ASGM activities..Land rehabilitation is recommended as it will reduce land degradation and ecosystems disruptions in the study area. This process will entail artisanal small-scale gold miners' backfilling their excavations. The backfilling of the mining excavations will play a significant role in the protection of the wildlife and livestock from falling into such pits.

According to Mwango (2010), in Kenya the requirements of the Forest Commission requires artisanal and small-scale miners to plant two trees after cutting one tree. This research recommends such strategy in the study area whereby artisanal and small-scale gold miners need to be encouraged to practise such ethics as it will promote environmental sustainability and reduce the loss of vegetation in the Giyani Greenstone Belt. This will help in recovering of the vegetation cover which was lost during small-scale mining activities. In general, this will help in returning the land to some degree of its former state after the ASGM operations.

5.1.2 Remediation of contaminated area

Soil remediation is a critical issue that must be addressed if there is environmental contamination of toxic and trace elements (Obiri *et al.,* 2015). In the study area there was contamination or pollution of soil, sediments and water by the toxic and trace elements. The soil, sediments and water were also strongly alkaline in nature which affects the plant growth and aquatic organisms. Therefore, remediation of high concentrated elements and alkaline should be applied at both mining sites (Louis Moore and Klein Letaba mine sites). This will help in reducing the concentration of toxic and trace metals which are higher than the recommended standard concentration at the artisanal and small-scale gold mining sites to ensure that the sites are suitable for plants growth.

Remediation can be done through the use of chemical and physical methods. Chemical method of soil reclamation aims at degrading the pollutants accumulated in the soil and sediments or make changes to their physico-chemical properties as it will contribute to the reduction of their ecological hazard. The chemical method entails soil washing (ex-situ method) which is mostly used for removing inorganic contamination such as toxic and trace metals, radio-nuclides, toxic anions and others. In some cases, it can be applied to organic contamination through the use of a wide spectrum of leaching solutions from water to strong inorganic acids.

Chemical methods of remediation are also developed on the basis of the pH stabalization. Physical methods of soil reclamation are those that do not change the physico-chemical properties of the pollutants accumulated in the soil to be cleaned. This could be applied on-site of artisanal and small-scale gold mines without the removal of the soil from the polluted site but through electro kinetic cleaning and soil covering methods. This is an electrochemical processing or method of the soil which uses electric current to remove heavy metals. This will help in the reduction of the high concentration of toxic and trace elements in the area. In the study area, the pH was found to be alkaline in nature. The lowering of the pH was an option, this can be done by application of acidifying fertilizers, such as ammonium sulfate.

5.1.3 Environmental Education and Awareness Campaigns

The problems of environmental degradation and contamination or pollution as a result of artisanal and small-scale gold mining operations can be addressed by environmental education and raising awareness campaign in mining and surrounding communities. According to Obiri *et al.* (2015), the environmental education and raising awareness campaigns is one of the common and effective environmental management strategies of artisanal and small-scale gold mining activities. In the study area, there was a serious environmental problem of loss of vegetation cover due to artisanal and small-scale gold mining activities. Therefore, there should be a need to create environmental awareness campaigns and education in mining and surrounding communities as a way of ensuring sound and sustainable use of the environment during the artisanal and small-scale gold mining activities. This strategy can be implemented through the conduction of public participation meetings with the communities around the ASGM area.

The raising of environmental educations and awareness campaigns will be able to create the necessary balance between economic growth and mandatory environmental necessities for community livelihoods. This recommended environmental management strategy will assist in the improvement of sustainable mining. In addition, this will reduce and/or prevent the adverse environmental impacts that undermine the sustainability of the mining and environmental policies towards achieving environmental sustainability in the study area. This management strategy can play a crucial role in the reduction and management of the loss of vegetation cover in the study area as a result of artisanal and small-scale gold mining activities.

5.1.4 Enforcement and compliance of environmental policies

Enforcement and compliance refers to complying with the relevant legislations and acts in order to protect the environment and health of the community. According to Phiri *et al.* (2015), all the environmental problems associated with the artisanal and small-scale gold mining can be managed through enforcement and compliance of the environmental policies on mining. The environmental degradation was one of the serious problems that resulted to the loss of vegetation cover in the study area. This could be managed or reduced through addressing the weakness in environmental policies on artisanal and small-scale gold mining in South Africa while strengthen the enforcement in order to realize sustainability of the environment. In the absence of actual and/or active environmental governance and regulatory framework of illegal ASGM is hard to understand and/or realize the environmental sustainability and management.

Environmental policies and the enforcement should include the actions that will be taken to manage artisanal and small-scale gold mining activities with the aim to prevent, reduce, or mitigate harmful effects of nature and natural resources. Such actions should include the reduction of environmental contamination in the study area such as soil, sediments and water contamination. In general, the enforcement of regulatory framework should ensure that artisanal and small-scale gold mining activities do not have harmful effects on the physical environment (i.e. resources degradation) and humans (i.e. health and safety problems).

5.2 Management of Socio-economic Impacts of ASGM

This section presents management strategies of socio-economic impacts associated with the artisanal and small-scale gold mining of Louis Moore and Klein Letaba Mine sites. The management strategies for environmental impacts of artisanal and small-scale gold mining are addressed as follows:

5.2.1 Formalising and easing the registration process of ASGM

Formality in artisanal and small-scale gold mining refers to the operations in mining activities with an applicable or appropriate legal framework. In the study area, it was found that about 94.3% of the population involved in artisanal and small-scale gold mining are concerned about the police disturbance and arrests during mining operations due to the fact that mining operations are conducted illegally in the area. It is therefore, recommended that government formalise mining operations in the study area. According to Kitula (2006), legalising or formalising the mining activities is the best way to deal with the issue of chasing and arresting miners at the site. Formalising or legalising the mining operations in the area will encourage environmental sustainability and increase the production of gold in the area, thus, significantly contributing to poverty alleviation.

The government should also revise and eliminate the unreasonably and difficulties in registration, regulations and policies for illegal small-scale gold operators as it will inspire more people to register and acquire mining licenses. Thus, reducing and/or preventing high rates of environmental degradation associated with illegal artisanal and small-scale mining activities and enhancing the positive aspects of the operations. In addition, since illegal artisanal and small-scale mining are determined exclusively by livelihood and survival motives, they pay little or no respect and/or attention to the issues of environmental management and sustainability.

5.2.2 Provision of appropriate mining equipment and machinery

In the study area, the problems of health and injuries were identified as results of use of inappropriate mining equipment. This gives an indication that an access to appropriate mining equipment and machinery will reduce and/or prevent the health problems. It emerged from the study that some of the effective ways of addressing and managing the issue of health and safety are the provision of mining skills and training and appropriate equipment and machinery. The issue of dust effects on miners can be reduced or prevented through the use face masks.

Access of artisanal and small-scale gold miners to apprpriate mining equipment and machinery means that work in mining activities will not be undertaken manually, thus reducing and/or preventing injuries and fatalities in the sites that can be caused by doing heavy work manually. The availability of appropriate machinery and technologies will reduce the injuries and health problems due to proper occupational safety standards. The provision of mining skills and training to people who are involved in artisanal and small-scale gold mining will increase the understanding of mining issues such as the causes of the health problems and injuries and ways of preventing them (Kessey and Arko, 2014).

5.2.3 Enforcement and compliance of social policies

In the study area, social problems such as health effects, injuries problems and child labour were identified. According to Phiri *et al.* (2015); Arah (2015); Kitula (2006); Hilson (2002); Hentschel (2002); Dreshler (2001), the best way to address and manage the social problems of artisanal and small-scale mining is through enforcement and compliance of the social policies and/or legislation on mining. Therefore, this research recommended that South African government should enforce and monitor the artisanal and small-scale gold mining in the area. The government should address the social policies on artisanal and small-scale gold mining and strengthen their enforcement in order to realize the social problems on the mining and surrounding communities.

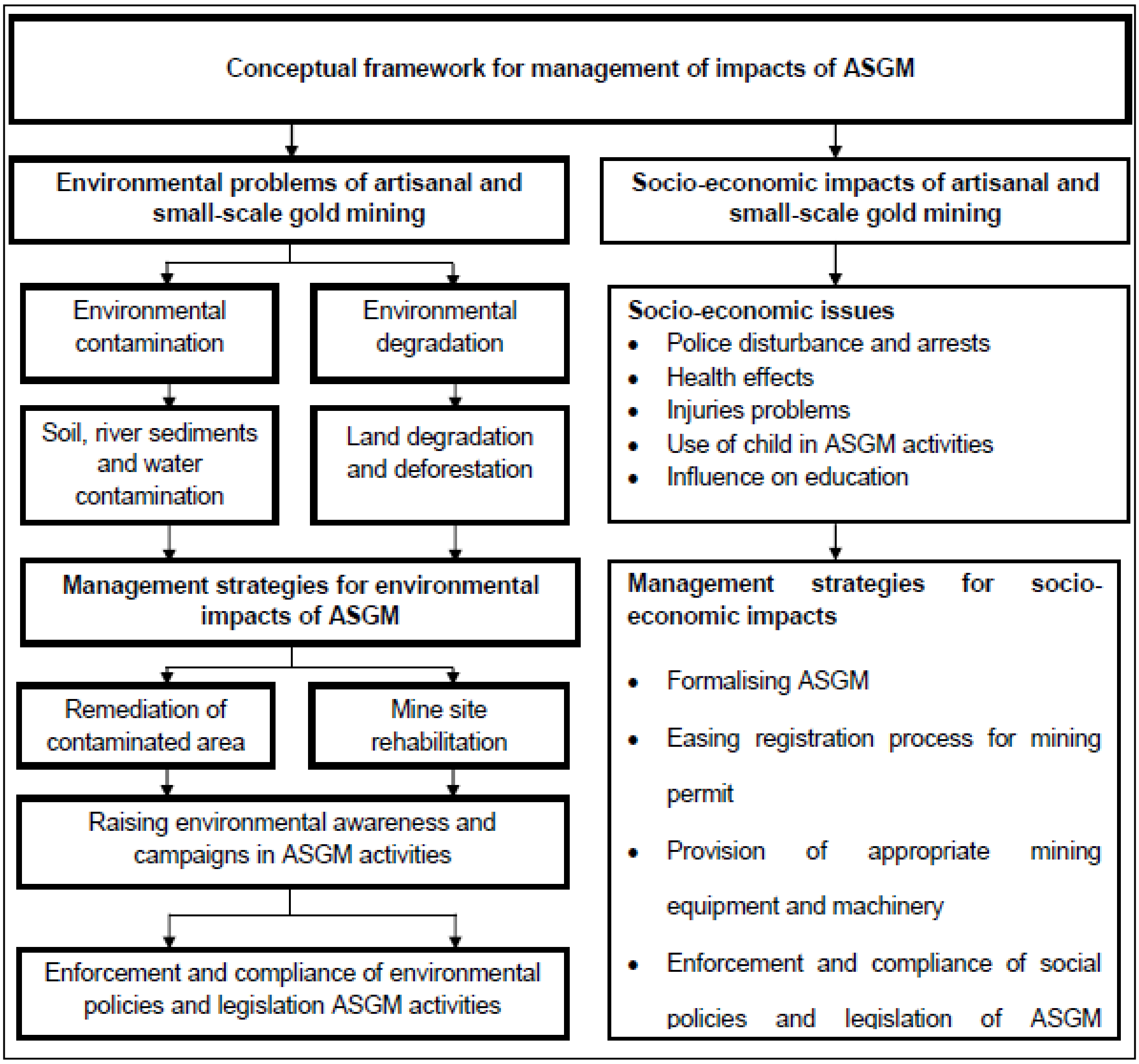

Figure 5.1: Conceptual framework for addressing impacts of ASGM and their management strategies.

The existence of active social governance and regulatory framework will make it easier for socio-economic issues to be realised. Social policies and their enforcement will be actions taken to manage artisanal and small-scale gold mining activities with the aim of enhancing positive aspects (i.e. employment, income and infrastructure improvements) of the mining operations and mitigate the adverse effects such as child labour, health and injuries problems in the study area. The enforcement of regulations will ensure that artisanal and small-scale gold mining activities do not have harmful effects on those who are involved in mining activities and the surrounding communities.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

This chapter presents summary, conclusion and recommendation of the study. The summary of the study include summarizing the problem statement, objectives, methodology and findings of the study.

6.1 Summary of the Study

Artisanal and small-scale gold mining is a major environmental and social problem for the mining industry, surrounding communities and the state. Although artisanal and small-scale mining contributes to poverty alleviation through the creation of employment and income generation, it is a major concern due to its associated physical, environmental and social problems. This concern includes the contamination of the soil, water, aquatic sediments, excavation of river banks, dust emission problems and change of vegetation cover due to land degradation and removal of the vegetation. The concern also include public health and safety, use of child labour, influence of ASGM activities on education and injury problems at mine sites. Although formal and informal artisanal and small-scale gold mining pose noticeable threats to the environment and public health and safety, no management strategies have been proposed for the ASGM in the study area. .Insufficient understanding of the environmental and social problems of artisanal and small-scale gold mining has led to lack of mitigation strategies to reduce environmental impacts and social problems.

The main aim of this research was to assess the environmental and socio-economic impacts of ASGM activities and to come up with action plan for enhancing the positive aspects of the operations and mitigate the adverse effects. The specific objectives were to determine the vegetation cover in the mining site, assess the soil, sediments and water quality and assess the socio-economic issues associated with artisanal and small-scale mining and to develop and recommend action plan for enhancing the positive aspects of the operations and eliminate the adverse effects of mining. The research approach used in accomplishing these objectives involved conducting a comprehensive site observation and characterisation of the mines in order to identify and assess the environmental problems and physical hazards at the mine site. In addition, remote sensing and GIS techniques were used to detect the vegetation cover over a period of 20 years in the artisanal and small-scale mining site. NDVI maps were then developed to assess the effects of mining on vegetation cover.

Soil, sediments and water samples were from the mining site in order to assess the soil, sediments and water quality. The results of analysis of soil and sediments were compared with the South African Soil Quality Standards and World Health Organisation (WHO) threshold values for plants and World Health Organisation standards and United States Environmental Protection Agency (USEPA) Ratings Approach respectively. The results of water were compared with South African Water Quality standards for domestic use (stipulated by Department of Water and Forestry) and World Health Organisation Standards. The comparison of samples results with permissible standards enabled the assessment of artisanal and small-scale mining on water, soil and sediment pollution or contamination. The approach used to assess the socio-economic impacts of mining was open ended interviews and questionnaires. Following the interviews and distribution of questionnaires, the socio-economic issues associated with the artisanal and small-scale gold mining were identified and assessed.

The environmental problems identified in the area were land degradation, removal of vegetation, uprooting of trees and land excavation caused by the digging and collection of soils deemed to be containing gold. The inactive mine sites (i.e. both Louis Moore and Klein Letaba) were extremely degraded with most surface alterations resulting from the extensive digging and collection of soil. The dangerous excavation pits and uprooting of trees were identified to be the major physical hazards in the area. This dangerous pits put people and animals at risk of accidentally falling inside and getting injured. The study culminated in devolvement of NDVI maps and this was used to assess the effects of ASGM on vegetation cover. Results showed that the mining activities in the area had caused extensive environmental degradation due to serious removal of vegetation cover in the site.

The artisanal and small-scale gold mining had effects on the soil, water and sediments quality through the contamination by toxic and trace elements. The laboratory analysis of certain parameters of the soil samples around mining site revealed that soil was heavily contaminated with the concentration of As, Cr, Ni, Pb and Zn. In both mining sites, the concentrations of toxic elements (*i.e.* As, Cr, Cu, Ni, Pb and Zn) were higher than the recommended standards by South African Soil Quality and World Health Organisation guidelines. This presents serious health risk such as the chronic and acute poisoning through the skin contact and consumption of contaminated plants/vegetables.

The high concentration of Sr was detected in both mining sites while only Klein Letaba had high concentration of Ba, La, V, and Ce in soil. This condition limits the plants growth, development and re-vegetation of plants. In addition, such condition may lead to paralyses and in some cases even fatalities through breathing and eating of plants/vegetables and drinking water that is polluted with such trace elements. The pH analysis in soil samples revealed that the soil was strongly alkaline in nature at both mines with the average level of 8.61 in Louis Moore and 8.07

in Klein Letaba mine. This condition affects availability of plant nutrients and results in an increase in aluminum which is toxic to plants.

Sediments from both mining sites were heavily contaminated with toxic elements (i.e. Cr, Ni, Pb, Zn and As) while there was a slight contamination by Cu. This condition poses a serious threat to the survival of aquatic organisms including fish. In addition, such condition has serious effects on human body (i.e. through skin contact and accumulation of such aquatic organism) as it may lead to death or permanent damage to the central nervous system, the brain, and kidneys. Sediments had high concentration of Ba in both mining sites. This high concentration of barium in sediments and water may lead to abnormal high blood pressure (i.e. hypertension) through skin contact and drinking of contaminated water.

In both mining sites, the pH analysis of sediments samples revealed that the sediments are alkaline in nature with the average level of 9.0 and 8.9 in Louis Moore and Klein Letaba mine respectively. This condition has the adverse effects on the aquatic species which may lead to death of such species. In both mining sites, water pH was strongly alkaline in nature. In Louis Moore the pH water levels were above both South African Water Quality and World Health Organisation threshold level for domestic use. This has increased potentials of toxic effects associated with deprotonated species such as ammonium and to cause the water to taste bitter. However, in Klein Letaba, pH in water was recorded within the normal ranges of South African Water Quality and World Health Organisation Standards indicating no significant effects on health due to toxicity of dissolved metal ions and protonated species, or on taste is expected. The direct contact with the contaminated water, sediments and soil by heavy metals were identified as a major pathway to human, aquatic species and terrestrial plants. The consumption of the species that feeds and come into contact with the contaminated grounds and water were identified as indirect pathways.

The assessment of the socio-economic impacts associated with artisanal and small-scale gold mining has provided an increased understanding of the benefits and social problems of the artisanal and small-scale gold mining in the area. In GGB, the artisanal and small-scale gold mining consist of the majority of the males miners (65.4%) as compared to the number of female miners (34.6%). The youth between the ages of 20-35 (67%) are dominating in the mining activities in the area. The main reason individuals are engaged in mining activities in the area is income generation and lack of employment. The high numbers of miners are engaged in mining activities for full time basis as there is lack of employment and no alternative source of income.

The artisanal and small-scale gold mining in the area has the socio-economic impacts (i.e. both positive and negative impacts) to the miners and the surrounding communities. The negative impact include the issue of child labour as the children are engaged in mining activities to help their families, children tend to be into mining more as compared to the school activities. The tendency of children working in mining encourages truancy in school and increases the school dropout rate. This increases the number of illiterate and uneducated population in the GGB. This has serious effects on the education of the state.

Public health and safety problems were the serious issue in the area. These health problems include the dizziness, weakness, rapid heartbeat, extreme thirst, and fainting in the site caused by working in very hot, harsh and bad conditions without drinking and eating enough food. The health problems was also associated with the dust pollution caused by the digging and uprooting of trees when collecting the soil and sediments deemed to be containing gold. The contact with the contaminated soils, sediments and water by heavy metals was playing a vital role in the health problems of the miners.

Besides the negative impacts of artisanal and small-scale mining in GGB, such mining activities contribute to poverty alleviation through the generation of income and creation of employment. All of the artisanal and small-scale miners acknowledged that mining jobs and income generated enabled them to provide basic needs for their families. This basic needs include the water, electricity, food, provision of books and other learning materials. However, the artisanal and small-scale mining operation has no effect on the improvement of infrastructure in the area. The study established that although small-scale mining activities provide certain benefits, the negative impacts are numerous and therefore action ned to e taken to address the problems and to encourage responsible mining.

The artisanal and small-scale gold miners are facing serious challenges during mining. The major emanating from the study was police disturbance and arrests during mining operations due to the fact that such mining activities were conducted illegally. The inappropriate working tools, lack of mining skills and training were some of the challenges and these limit production of gold and increases high risk of diseases and injuries.

The majority of miners (43.59%) want the artisanal and small-scale gold mining to be legalised by the government as it will enable them to mine with no police disturbance. The results from SPSS indicated 32% of the miners want the government to provide appropriate mining equipment and tools as it will increase the production of gold and reduce the health and safety risks. The community and the artisanal miners are aware of the environmental impacts such as deforestation and land degradation. All of the miners indicated that there is no mine site rehabilitation of the environmental impacts of artisanal and small-scale gold mining in the area.

6.2 Conclusion of the Study

This section provides the conclusion of the study derived from the research findings. The main aim of this section is to provide the accomplishment of the research objectives and provide answers to the research questions. One of the specific objectives of this study was to assess the effects of ASGM on vegetation cover. This was achieved through the use of GIS and NDVI maps and results showed that the ASGM activities in the area had caused extensive environmental degradation due to serious removal of vegetation cover. This serious removal of vegetation resulted in the habitat destruction and removal of top soil in the area.

The study assessed the effects of ASGM activities on sediments, soil and water quality, this objective was achieved by collecting river sediments, soil and water samples and conducting laboratory analysis of the toxic and trace elements. The toxic and trace elements of river sediment, soil and water samples were determined using the Atomic Absorption Spectrometer (AAS) and XRF instrument respectively. The findings of laboratory analysis of soil and river sediment samples revealed that soil and river sediment were heavily contaminated with the concentration of As, Cu, Cr, Ni, Pb and Zn. These elements were found to be higher than the recommended standards by South African Soil Quality and World Health Organisation guidelines. This indicates that ASGM activities had serious effects on soil and river sediments quality. This includes a serious health risk such as the chronic and acute poisoning through the skin contact and consumption of contaminated plants/vegetables.

The results of the study showed that pH in river sediments and soil samples was strongly alkaline in nature which affects availability of plant nutrients and lead to increase in aluminum which is harmful to plants. In both mining sites, water pH was strongly alkaline in nature. In Louis Moore the pH water levels were above both South African Water Quality and World Health Organisation threshold level for domestic use. This has increased potentials of toxic effects associated with deprotonated species such as ammonium and to cause the water to taste bitter. The results of the study area shown that ASGM activities have serious effects on water quality which is used for domestic purpose. However, in Klein Letaba mining site, pH in water was recorded within the normal ranges of South African Water Quality and World Health Organisation Standards indicating no significant effects on health due to toxicity of dissolved metal ions and protonated species, or on taste is expected.

The study also assessed the socio-economic impacts associated with ASGM activities in the study area. This objective was achieved by using qualitative approach in the assessment of socio-economic impacts. This involved collection of data using the interview and questionnaire instruments and the collected data was assessed using SPSS. The results showed that the ASGM activities have both negative and positive socio-economic impacts. The positive impacts of ASGM activities included generation of income and creation of employment opportunities in the area. The negative socio-economic issues revealed by the findings of the study include the use of child labour in ASGM activities, influence of ASGM activities on education, occupational health and safety problems such as injuries and diseases. Through the assessment of socio-economic issues, the challenges faced by the ASG miners were found to be police disturbance and arrests due to the illegal mining.

The last objective of this study was to come up with management strategies that will address the overlapping issues of ASGM and mitigate the adverse impacts of the ASGM operations on the environment. Based on the findings and the literature review, the study proposed mine site rehabilitation in order to reduce and mitigate the adverse environmental degradation caused by the removal of vegetation. The environmental contamination (soil, sediment and water) can be reduced by remediation of the contaminated area and stabilizing of pH level in the area. The environmental awareness and campaigns can be used to ensure sound and sustainable use of the environment during the ASGM activities. This will reduce the environmental problems such as removal of vegetation, land degradation and contamination of water, soil and sediments. Enforcement of environmental policies, legislation and regulations was also proposed as mitigation strategy to prevent or reduce the adverse environmental effects (environmental degradation and contamination) of ASGM operations problems such as environmental degradation and contamination.

One the main challenge faced by ASG miners was police disturbance and arrests. Therefore, legalisation of the mining operations in the area and strengthening enforcement of regulations and policies can play a vital role in regularisation of ASGM activities in the area and curb police harassment. The enforcement and compliance with social policies will assist in reducing and preventing socio-economic issues such as use of child labour and occupational health and safety in the area.

6.3 Recommendations of the Study

In the light of the main objective of this research of assessing the environmental and socio-economic impacts of artisanal and small scale gold mining activities in the Giyani Greenstone Belt and coming up with action plan for enhancing the positive aspects of the operations and mitigate the adverse effects and on the basis of the above concluding remarks, the following recommendations are made:

- In order to reduce environmental degradation through removal of vegetation cover this research recommends that small-scale miners should conduct mine site rehabilitation in the study area. Land rehabilitation will reduce land degradation and ecosystems disruptions in the study area. Small-scale miners should backfill the open excavations in such a manner that re-vegetation can take place in the area.

- Environmental awareness campaigns and education in mining and surrounding communities was recommended as a way of ensuring sound and sustainable use of the environment during the artisanal and small-scale gold mining activities. This will reduce the environmental problems such as removal of vegetation, land degradation and contamination of water, soil and sediments. Soils, sediments and water samples had high concentration of toxic and trace elements as compared to permissible standards, therefore, remediation of high concentrated elements is recommended in both mining sites. This will help in reducing the concentration of elements which are higher than the recommended standard and assist in ensuring that the sites are suitable for plants growth. Acidifying fertilizers, such as ammonium sulfate, should be applied at the study area in order to lower the pH level that is ideal for plant growth.

- This research recommends legalization of the mining operations in the area and strengthening of regulations and policies for illegal small-scale gold operators in order to prevent the issue of police disturbance and arrests of the miners. This will also inspire more people to register and acquire mining licenses. Thus, reducing and/or preventing high rates of environmental degradation associated with illegal artisanal and small-scale mining activities and enhancing the positive aspects of the operations. Provision of suitable equipment and machinery means that not all work in mining activities will be undertaken manually, thus reducing and/or preventing injuries and fatalities at the mine sites.

- Enforcement of environmental policies, legislation and regulations was recommended as a way of preventing or reducing the environmental problems such as environmental degradation and contamination. In general, this should include actions that to be taken to manage artisanal and small-scale gold mining activities with the aim of preventing, reducing, or mitigating harmful effects of nature and natural resources. Enforcement and compliance of social policies was recommended in order to prevent the social problems such as use of child labour, health problems and influence of ASGM activities on education. In addition, this should include actions that will be taken to manage ASGM activities with the aim of enhancing positive aspects (i.e. employment, income and infrastructure improvements) and mitigate the adverse effects of the mining operations in the study area. The enforcement of regulations will ensure that artisanal and small-scale goldd mining activities do not have harmful effects on the population involve in mining activities and the surrounding communities

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APPENDICIES

Appendix A

Table A1: Concentration of toxic elements in soil and sediments samples in Klein Letaba Mine

Sample ID	Concentration of Toxic elements (ppm), pH and EC in soil samples									
	As	Cd	Cu	Co	Cr	Ni	Pb	Zn	pH	EC (µs/cm)
KLSS1	856.6	0	86.2	24.1	905.2	1423.7	7981.1	641.2	7.56	105
KLSS2	8	0.1	73.2	12.1	150.4	251.5	74.5	158.6	8.95	95.8
KLSS3	283.2	0.1	72.1	16.6	474.8	898.8	2638.2	98.3	7.21	68
KLSS4	400.2	0	61.9	21.9	742.4	1057.1	3728.2	240.6	9.87	82.3
KLSS5	215.9	0.1	83.3	35	452.7	368.6	2011.5	121.5	6.77	55.9
Sample ID	**Concentration of toxic elements (ppm), pH and EC in sediments samples**									
	As	**Cd**	**Cu**	**Co**	**Cr**	**Ni**	**Pb**	**Zn**	**pH**	**EC (µs/cm)**
KLRS1	4	0	39.7	11.8	198.5	393.4	5988.5	45.9	8.63	79.4
KLRS2	10.1	0	68.4	14	212.9	365.7	35.3	79.4	8.54	43.9
KLRS3	3.8	0.1	48.3	11.9	218.4	434.1	94.4	49.9	9	198
KLRS4	642.8	0.1	165.4	29.8	1064.5	1422.1	37.5	1790.4	9.78	256
KLRS5	9	0.5	70.8	15.65	100.5	225.6	40.5	100.5	9	150

NB: KLSS is Klein Letaba Soil Samples and KLRS is Klein Letaba River Sediments

Appendix B

Table B1: Concentration of toxic elements in soil and sediments samples in Louis Moore Mine

Sample ID	Concentration of toxic elements (ppm), pH and EC (µs/cm) in soil samples									
	As	Cd	Cu	Co	Cr	Ni	Pb	Zn	pH	EC
LMSS1	14.20	0.10	26.90	11.20	308.90	689.60	132.30	140.20	7.71	203
LMSS2	3.20	0.00	15.90	8.30	245.20	485.10	29.60	18.20	9.98	45.3
LMSS3	9.20	0.00	22.50	11.80	441.30	974.80	85.60	123.60	7.16	96
LMSS4	3.70	0.00	19.70	8.50	279.60	595.90	34.80	40.30	9.25	48
LMSS5	3.30	0.00	0.00	10.40	379.00	888.60	30.60	56.80	8.95	31.9
Sample ID	**Concentration of toxic elements (ppm), pH and EC (µs/cm) in sediments samples**									
	As	**Cd**	**Cu**	**Co**	**Cr**	**Ni**	**Pb**	**Zn**	**pH**	**EC**
LMRS1	8.60	0.00	43.40	13.40	495.50	1147.40	79.80	96.10	8.75	78.8
LMRS2	4.20	0.10	24.10	10.20	439.80	1186.90	39.10	73.30	9.51	52.2
LMRS3	27.60	0.00	38.70	20.10	428.00	717.30	257.00	225.50	8.81	49.5
LMRS4	12.80	0.00	35.80	7.80	200.90	448.50	119.50	912.70	8.85	80
LMRS5	5.70	00.00	40.50	8.90	120.00	352.52	70.90	80.15	9.3	90
NB: LMSS is Louis Moore Soil Samples and LMRS is Louis Moore River Sediments										

Appendix C

Table C1: Concentration of trace elements in soils and sediments Klein Letaba Mine

Sample ID	Concentration of trace elements (ppm) in soil samples									
	V	Ga	Ce	Rb	Sr	Mo	Zr	Ba	Nb	La
KLS1	105.4	7	73.3	34.2	191.5	0.3	67.3	336.8	0.3	170.6
KLS2	99.8	7.4	61.3	32.2	176.2	0.9	97.7	362.5	2.5	97.7
KLS3	166.8	15.3	98.5	47.8	327.1	0.3	191.1	611	0.5	76.6
KLS4	177.6	14	95.1	43.4	315.2	0.5	257.7	692.1	2.5	64.6
KLS5	132	13.3	63.5	22.4	149.7	0.3	82.6	434	2	110.1

Sample ID	Concentration of trace elements (ppm) in sediments samples									
	V	Ga	Ce	Rb	Sr	Mo	Zr	Ba	Nb	La
KLRS1	179.5	12.1	99.8	23	118.6	0.3	95	387	3.2	142.6
KLRS2	94.9	16.5	179.1	41.3	222.6	2.5	210.4	382.1	3.4	52.8
KLRS3	197.2	13	105.2	43.8	269.1	0.5	216.9	753.5	4.4	70.3
KLRS4	108	18.4	56.4	47.5	238.8	2.5	208.7	425.9	2.9	53.4
KLRS5	189.5	13.1	189.8	33	198.6	0.6	85	377	3.8	152.6
NB: KLSS is Klein Letaba Soil Samples and KLRS is Klein Letaba River Sediments										

Appendix D

Table D1: Concentration of trace elements in soils and sediments samples in Louis Moore Mine

Sample ID	Concentration of trace elements (ppm) in soil samples									
	V	Ga	Ce	Rb	Sr	Mo	Zr	Ba	Nb	La
LMSS1	82.00	12.20	59.70	26.80	495.10	0.30	149.30	291.60	2.60	45.60
LMSS2	31.90	10.90	15.70	42.40	75.50	0.20	67.40	155.50	2.30	33.40
LMSS3	68.80	13.20	49.80	32.50	271.00	0.20	100.40	258.00	3.50	50.20
LMSS4	58.60	9.60	44.60	32.70	229.50	1.60	148.30	236.30	1.90	35.80
LMSS5	60.60	14.20	33.10	28.30	616.10	0.90	148.50	227.50	1.40	44.80
Sample ID	**Concentration of trace elements (ppm) in sediments samples**									
	V	**Ga**	**Ce**	**Rb**	**Sr**	**Mo**	**Zr**	**Ba**	**Nb**	**La**
LMSS1	85.00	14.20	158.10	62.70	317.90	0.10	84.30	293.90	2.90	59.50
LMSS2	50.60	4.60	25.10	16.00	176.40	0.00	70.30	202.60	1.60	40.40
LMSS3	93.20	7.40	44.20	24.60	356.10	0.40	82.10	319.90	2.30	84.10
LMSS4	64.90	10.20	115.30	94.50	206.80	1.40	129.30	247.60	3.10	33.60
LMSS5	70.00	10.20	58.10	72.70	217.90	0.50	74.30	193.90	3.90	69.50

NB: LMSS is Louis Moore Soil Samples and LMRS is Louis Moore River Sediments

Appendix E

Table E1: Comparison the average concentration of the toxic elements in soil and sediments with the permissible standards

Variables	Average toxic element concentrations in soil samples		S.A SQG	WHO SQG
	Louis Moore Mine	Klein Letaba Mine		
As	6.72	352.78	1	2
Cd	0.02	0.06	2	0.02
Cr	330.9	542.1	80	1.30
Co	10.02	21.94	20	-
Cu	17	75.34	6.6	10
Ni	726.8	799.94	50	10
Pb	62.56	3,286.7	6.6	2
Zn	75.82	252.04	46.5	50
pH	8.61	8.07	-	6.5-7.5
EC	84.84	81.4	-	0 - 1

Variables	Average toxic elements concentrations in sediments samples		WHO SQG	USEPA SQG
	Louis Moore Mine	Klein Letaba Mine		
As	13.6	133.8	-	-
Cd	0.00	0.14	6	0.6
Cr	1614.4	358.96	25	25
Co	12.14	16.63	-	-
Cu	36.42	78.52	25	16
Ni	831.06	568.18	20	16
Pb	107.4	1,239.2	-	40
Zn	321.56	413.22	123	110
pH	9.044	8.99	6.5-7.5	-
EC	70.1	145.46	-	-

NB: SA SQG is the South African Soil Quality Guidelines and WHO SQG is the World Health Organisation Soil Quality Guidelines. WHO SQG is the World Health Organisation Sediment Quality Guidelines and USEPA SQG is the United States Environmental Protection Agency Sediment Quality Guidelines.

Appendix F

Table F1: Comparison the average concentration of the trace elements in soil and sediments with permissible standards

Trace elements	Average concentrations in soil samples		WSA
	LMM	KLM	
Ba	233.7	487	460
V	60.38	136.32	129
Sr	337.44.	231.94	175
Ga	12.02	11.4	15.2
Zr	122.78	139.28	267
Mo	0.68	0.46	1.1
Ce	40.58	78.34	56.7
Rb	32.54	36	68
La	41.96	103.92	27
Nb	2.34	1.11	12
Trace elements	**Average concentrations in sediments samples**		**WSA**
	LMM	**KLM**	
Ba	233.7	487	-
V	60.38	136.32	-
Sr	337.44.	231.94	-
Ga	12.02	11.4	-
Zr	122.78	139.28	-
Mo	0.68	0.46	-
Ce	40.58	78.34	-
Rb	32.54	36	-
La	41.96	103.92	-
Nb	2.34	1.11	-

NB: LMM is Louis Moore Mine and KLM is Klein Letaba Mine NB: WSA is the World Soil Average adopted from Kabata-pendias (2011); Kabata-pendias and Pendias (2001)

Appendix G

Table G1: Comparison of the average concentration of the toxic elements between two mines

Variables	Average concentrations of toxic elements		S.A WQG	WHO WQG
	LMM	KLM		
As	1.1	1.5	10	-
Cd	0.00	0.00	5	0.01
Cr	0.1	0.01	-	0.1
Co	0.03	0.00	-	-
Cu	-1	-0.99	1	2
Ni	0.02	0.02	-	0.2
Pb	0.07	0.01	10	0.05
Zn	0.05	0.01	3	5
pH	9.2	7.7	6.0 – 9.0	6.8 -8.5
EC	1886	1837	0 - 70	400 – 600

NB: LMM is Louis Moore Mine and KLM is Klein Letaba Mine SA WQG is the South African Water Quality Guideline and WHO WQG is World Health Organisation Water Quality Guideline

Table G2: Concentration of toxic elements in water samples in Louis Moore and Klein Letaba

Mines	Concentration of toxic elements (ppm), pH and EC (µs/cm) in water samples									
	As	Cd	Cu	Co	Cr	Ni	Pb	Zn	pH	EC
LMM	1.1	0.00	0.1	0.03	-1	0.02	0.07	0.05	9.2	1886
KLM	1.5	0.00	0.01	0.00	-0.99	0.02	0.01	0.01	7.7	1837

Appendix H: Respondents from populations involve in ASGM

Table H1: Number of respondents from ASGM sites

Mining sites	Frequency	Percentage (%)
Klein Letaba gold mine	26	49.1
Louis Moore gold mine	27	50.9
Total	53	100

Table H2: Number of population involve in ASGM by gender

Gender	Frequency	Percentage (%)
Male	34	65.4
Female	18	34.6
Total	52	100

Table H3: Respondents of population involve in ASGM by Age

Age group	Frequency	Percentage (%)
<18	1	3.1
18-25 years	9	17.4
26-35 years	33	67.3
36-50 years	6	12.2
Total	49	100

Table H4: Level of education of people involve in ASGM

Level of education	Frequency	Percentage (%)
No formal education	3	5.8
Primary level	11	21.2
Secondary level	35	67.3
Tertiary level	3	5.8
Total	52	100

Table H3: Other sources of income of population involve in ASGM

Other source of income	**Frequency**	**Percentage** (%)
Earnings (e.g. agriculture)	16	30.2
Remittance from relatives	23	43.4
Other	14	26.4
Total	53	100

Table H4: Period of population involve in ASGM activities

Period of miners in mining	Frequency	Percentage (%)
0-5 years	28	52.8
6-10 years	24	45.3
11-15 years	1	1.9
Total	53	100

Table H5: Reasons for involvement in ASGM activities

Push and pull factors	Frequency	Percentage (%)
Lack of employment	18	35.7
Income generation	34	64.3
Total	53	100

Table H6: Period of engagement of populations in mining operations

Engagement of miners in mining	Frequency	Percentage (%)
Full time	21	49.1
Part time	26	39.6
Occasionally	6	11.3
Total	53	100

Table H7: Training on artisanal and small-scale gold mining activities

Row labels	Frequency	Percentage (%)
No	52	100
Yes	0	0
Total	52	100

Table H8: Delineation of ore bodies

	Frequency	Percentage (%)
Technically	7	13.5
Guess work	45	86.5
Total	52	100

Table H9: Are there land rehabilitation activities in the mining sites?

	Frequency	Percentage (%)
No	50	100
Yes	0	0
Total	50	100

Table H10: Awareness of the Environmental Problems in the mining sites

	Frequency	Percentage (%)
Yes	50	100
No	0	0
Total	50	100

Table H13: Importance of knowledge on environmental management

Row labels	Frequency	Percentage (%)
Protection of the environment	10	45.45%
Improvement of gold production	9	40.91%
Improvement of safety	2	9.09%
Minimise environmental impacts	1	4.55%
Total	22	100.00%

Table H14: Any recovery strategies of the chemicals used in the sites?

	Frequency	Percentage (%)
Do not know	1	4.55%
No	21	95.45%
Total	22	100.00%

Table H15: Regulations and Policies governing ASGM in GGB

	Frequency	Percentage (%)
yes	0	0
no	52	100
Total	52	100

Table H16: Structures to follow up on regulations of artisanal and small-scale mining

	Frequency	Percentage (%)
No	31	58.5
Yes	0	0
Do not know	22	41.5
Total	53	100

Table H17: Is there any land rehabilitation activities in the mining sites?

	Frequency	Percentage (%)
yes	0	0
No	53	100
Total	53	100

Table H18: Socio-economic impacts of artisanal and small-scale gold mining in GGB

Socio-economic impacts	Frequency	Percentage (%)
Income generation	19	40
Child labour	4	10
Employment opportunities	13	20
Educational impacts	13	20.0
Health effects	2	5
Injuries	2	5.0
Total	53	100.0

Table H19: Challenges faced by populations involve in ASGM activities

Challenges of ASGM	Frequency	Percentage (%)
Police disturbance and arresting	50	94.3
Inappropriate tools	3	5.7
Total	53	100.0

Table H20: Ways in which government can enhance ASGM activities in GGB

Ways of government to enhance mining	Frequency	Percentage (%)
Permission to ASGM mining	34	43.59
Provide proper mining equipment	27	34.62
Provide education and training	10	12.82
Create jobs for local people in mining	7	8.97
Total	78	100.00

Appendix I: Respondents from populations not involve in ASGM

Table I1: Respondents of the population not involve in ASGM around mining sites

Mining sites	Frequency	Percentage (%)
Klein Letaba gold mine	26	55.3
Louis Moore gold mine	21	44.7
Total	47	100

Table I2: Respondents of the population not involve in ASGM by gender

Gender	Frequency	Percentage (%)
Male	25	52.2
Female	22	47.8
Total	47	100

Table I3: Respondents of the population not involve in ASGM by age

Age group	Frequency	Percentage (%)
<18 years	7	15.6
18-25 years	7	15.6
26-35 years	26	53.3
36-50 years	7	15.6
Total	47	100

Table I4: Level of educational of population not involve in ASGM

Level of education	Frequency	Percentage (%)
primary level	8	17.8
secondary level	17	37.8
tertiary level	20	44.4
Total	45	100

Table I5: Employment status of the population not involve in ASGM in GGB

Employment status	**Frequency**	**Percentage (%)**
Unemployed	20	42.6
Self-employed	10	21.3
Other	17	36.2
Total	47	100

Table I6: Respondents by the distance from mining sites

Distance from mining sites	**Frequency**	**Percentage (%)**
501-1000m	15	31.9
1001-1500m	23	48.9
1501-2000m	5	10.6
>2000m	4	8.5
Total	47	100

Table I7: Awareness of environmental problems from population not involve in ASGM

	Frequency	Percentage (%)
Yes	47	95.2
No	2	4.8
Total	47	100

Table I8: Is there any environmental and socio-economic problems awareness campaigns

	Frequency	Percentage **(%)**
No	47	100
Yes	0	0
Total	47	100

Table I9: Reason for involvement in ASGM

Push and pull factors	**Frequency**	**Percentage (%)**
Lack of employment	21	44.7%
Income generation	26	55.3%
Grand Total	47	100%

Table I10: Socio-economic impacts of ASGM in GGB

Socio-economic impacts	**Frequency**	**Percentage (%)**
Income generation	21	40
Child labour	2	5
Employment	9	17
Educational impacts	15	35.0
Health effects	1	3
Total	47	100.0

Table I11: Environmental/ecological problems caused by small-scale gold mining

Environmental problems	**Frequency**	**Percentage (%)**
Deforestation	21	45
River water pollution	14	31
Land degradation	10	19
Removal of vegetation	2	5
Total	47	100