PHYSICO-CHEMICAL AND BIOLOGICAL CHARACTERIZATION OF SOILS FROM SELECTED FARMLANDS AROUND THREE MINING SITES IN PHALABORWA, LIMPOPO PROVINCE

by

MASETLE NELSON RAMAHLO

MINI-DISSERTATION
Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

AGRICULTURE (SOIL SCIENCE)

in the

FACULTY OF SCIENCE AND AGRICULTURE
(School of Agricultural and Environmental Sciences)

at the

UNIVERSITY OF LIMPOPO

SUPERVISOR: PROF. FR KUTU
CO-SUPERVISOR: MR. VL MULAUDZI

2013

DEDICATION

I dedicate this mini-dissertation to the following people who at various times had made meaningful contributions to my life:

- My mother for being a pillar of my strength and support throughout the period of my study.
- My brother Geoffrey and my sister Jane for their motivational support.
- My high school teacher, Mr PE Ramokgata for the courage, motivation and his prayers.
- Pastor MJ Makgopa for his spiritual support.
- And above all, to God who gave me life and made all things possible.

DECLARATION

I declare that this research project titled ‘Physico-chemical and biological characterization of soils from selected farmlands around three mining sites in Phalaborwa, Limpopo Province’ is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other institution.

M. N. RAMAHLO DATE

ACKNOWLEDGEMENTS

I would like to acknowledge with thanks, the following people and organisations for their contributions to this study:

Prof FR Kutu, my supervisor, for investing tirelessly his time and efforts in my research work through his commitment, regular availability and accessibility, motivational and always ready to assist. He is greatly acknowledged for his remarkable contribution including human and financial resources to support me.

My sincere thanks also go to Mr VL Mulaudzi for the co-supervision role he played and thus demonstrated his commitment to ensure that the project becomes a success.

The assistance received from Mr OHJ Owen and his technical team from ARC-Grain Crops Institute, Potchefstroom for the microbiological data is highly appreciated. I also acknowledge with thanks, my various financial support sources particularly the National Research Foundation (NRF) South Africa through Prof Kutu's research grant (Grant number 76215) for the support to visit my study sites and also partly assist with covering the cost for my laboratory analysis. Finally, my sincere appreciation goes to the management of Leon Tom, Mogoboya, Hans Merensky and Waterbok Farms used in this study for granting me permission and access to their facilities.

ABSTRACT

The study was conducted to assess the impact of mining activities on selected soil physical, chemical and microbial properties on farmlands around three selected mining sites. Nine soil samples were collected from each of the following farms : Hans Merensky, Mogoboya and Leon Tom, Foskor Mine and JCI mining sites, respectively. Additional nine soil samples were collected from non-polluted Waterbok farm that serves as a control for the purpose of comparison. The samples were taken at 0–15, 15–30, 30–45 cm depths at three sampling points on each farm for physical, chemical and biological studies. However, soil samples collected for microbial (fungi, bacteria and actinomycetes) counts were surface (0–15 cm) soil samples. Soil chemical properties determined include pH_w, electrical conductivity (EC_e), exchangeable acidity (EA), organic carbon, available phosphorous, exchangeable cations as well as heavy metal (i.e. Mn, Zn, Cu, Pb, Cd, As and Sb) concentrations. The physical parameters determined include texture (sand, silt and clay) as well as bulk density.

Soil pH_w and EC_e values decreased with depth; and ranged from 6.94 to 6.50 and from 12.24 to 10.76 mS cm^{-1}, respectively. Exchangeable acidity showed a gradual increase with depth and ranged from 0.72 to 0.80 cmol(+)(kg), while percent organic carbon decreased with depth ranging from 1.41 to 2.19 %. Exchangeable cations, particularly K and Mg increased with depth while Ca decreased marginally with soil depth. Available phosphorous content decreased following increases in distance from the pollution source while heavy met.al contamination decreased with soil depth but increased further away from the pollution source. Significantly high loads of Pb, As and Sb were recorded at all depths on the three farms around the mining sites, which were largely responsible for the pollution but worse on the Leon Tom farm; with Pb constituting the greatest pollutant. The concentration of extractable heavy metals in the studied areas was in the order: As >Sb>Pb>Zn>Cu >Mn >Cd. Cadmium level appeared generally very low in all samples while elevated levels of Mn, Cu and Zn were detected at all depths in the polluted soils.

Significant differences in microbial levels were detected at the various sampling points. The highest count of 3.82 and 6.20 CFU g^{-1} for fungi and actinomycete, respectively were both from the Leon Tom farm, while 6.46 CFU g^{-1} counts for bacteria was obtained from Mogoboya farm. Interestingly, fungal and actinomycetes activities were more sensitive to heavy metal contamination than bacteria that were significantly increased following soil pollution.

Keywords: Mining; heavy metals; soil microbes; soil fertility; soil pollution

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

.

CHAPTER 1

INTRODUCTION

1.1 Background information to the study

Limpopo is one of the country's provinces with enormous mineral reserves that are currently being heavily mined. Apart from the socioeconomic benefits of mining, the activity often poses serious threats to natural resources and impact negatively on human livelihood. The discovery of more mineral reserves in other parts of the province points to the fact that increased hazardous by-products will continue to be produced following increase in mining activities. The study is crucial to providing detailed information on the extent of soil pollution arising from mining activities in the area so as to provide guidance on possible potential remediation and reclamation strategies necessary for the revitalization and improvement of agricultural productivity on such polluted soils. A better understanding of mine polluted soil through detailed characterization will provide guidance to the development of appropriate management strategies for sustainable agricultural production. The findings from this study will thus help land-use planners, farm managers, farmers and other stakeholders have access to better manage soil resources and reverse the current trend of increasing the cultivation of marginal lands through the conversion of unproductive land into potentially suitable agricultural lands. Ultimately, local availability of diverse foods would be guaranteed in many homes.

1.2 Problem statement

Farming communities across the country are presently experiencing considerable low crop yields due to among other reasons, a significant loss in soil quality and productivity arising from pollution (Schlüter, 1993; Yin *et al.,* 1996). Agricultural activities around mining areas globally, are severely under threat due to pollution of the environment, which impact negatively on soil, crop and animal health (Chow and Hong, 2002). Farmlands around the three mining industries in the Phalaborwa municipality are not shielded from these pollution threat that are often generated from tailing dams, rock dumps and dusts around mining sites. Thus, the potential arable lands in such mining communities have decreased at an increasing rate while the cultivation of marginal lands has also grown steadily (Golder Associates, 2009). Hence, food production efforts are negatively affected through loss in soil quality and land degradation. Similarly, farmers' profit margin and other natural resource quality are negatively affected; and consequently lead to a serious compromise on food security efforts in many rural mining communities. These could potentially escalate the social crises that existed in numerous mining towns and villages.

1.3 Motivation of the study

The recent increase in the cultivation of marginal lands in many parts of the country due to the rising pressure on available land to meet the ever increasing food demand is responsible for the escalating problem of low productivity on most farmlands. This has serious negative consequences on the food security situation in the country.

Providing detailed information regarding mining pollution is critical so as to alert farming communities around the mining sites about the pollution build up in the key natural resources of agricultural importance such as soil, water and air that have serious implication on human and animal health.

1.4 Purpose of the study

1.4.1 Aim

The aim of this study is to assess selected physical and chemical characteristics as well as microbial properties of mine polluted soils around the three Mining sites in Phalaborwa so as to ascertain the chemical elements responsible for the pollution.

1.4.2 Objectives

The objectives of this study include among others:

i. To quantify the distribution of mine pollutants in the field and at different soil depths in selected farming communities within the three mining sites in Phalaborwa area

ii. To assess the impact of mining activities on selected soil physical, chemical and microbial properties at different soil depths

1.5 Hypotheses

The hypotheses for the study include the following:

i. Mine pollutants are uniformly distributed in the field and at different soil depths in farms around the three mining sites

ii. The different mine pollutants have no effect on any of the soil physical, chemical and microbial properties in terms of spatial distribution (i.e. horizontal and vertical).

CHAPTER 2

LITERATURE REVIEW

2.1 Limpopo Province as a mining Province

Limpopo Province is one of the country's provinces with a large number of mining industries due to the presence of numerous minerals. Phalaborwa area is renowned for its mining activities for such minerals as copper, phosphate, antimony and gold production among others. Phalaborwa Mining Company, a member of Rio Tinto Group, quarries copper bearing mineral ore in the area, which is a highly valued commodity in the metal industries for its wide application. Foskor Company on the other hand excavates phosphate ore and beneficiates the mineral ore into granular phosphate based fertilizer while JCI Mining Company mines antimony and gold bearing ores, which have a long standing application history in the automobile industries. According to 2008 economic data baseline survey report, the Mining industries contribute approximately 60% of the Municipal district GDP (Ba-Phalaborwa Municipality Draft IDP document 2012/17). The figures contained in the Municipality Annual Report 2009/10 integrated development plan (IDP) showed that the mining sector alone in the Phalaborwa area employs 5, 949 people (Foskor, 2010).

2.2 Impact of mining activities on soil and the environment

Beside the socioeconomic benefits of mining, the activity poses huge threats to natural resources such as soil, water, air as well as aquatic and terrestrial animals including humans. Water and wind seepages from mines and mine tailings pollute natural resources while damages by mining products such as pyrite (iron sulphite mineral) occur when it oxidizes through bacterial action upon exposure into sulphuric acid and leads to the production of acid mine, which constitutes a hazardous product to the soil and the environment (Pierzynski *et al*., 2005). The discovery of more mineral reserves in other parts of the province will lead to an intensification of mining activities in the near future and result in continuous production of similar or other by-products that are hazardous to the soil. Most of by-products particularly heavy metals, are toxic to living organisms primarily due to their protein-binding capacity and hence ability to inhibit enzymes (Renella *et al*., 2003). The nature and degree of inhibition of soil enzymes by metals is strongly related to soil (Perez-de-Mora *et al*., 20.06). Metals have a varying impact on soil enzyme activity depending not only on their total concentration in the soil but also on their capacity to interact with enzyme protein (Schlüter, 1993).

Strip or surface mining of coal can completely eliminate existing vegetation, destroys genetic soil profile, displaces or destroys wildlife and habitat, degrades air quality, alters current land uses, and to some extent permanently change the general topography of the area mined (Rule and Iwashchenko,1998). The community of microorganisms and nutrient cycling processes are upset by the movement, storage, and redistribution of soil (Biester *et al*., 2002). Generally, soil disturbance alters or destroys many natural soil characteristics, and may reduce its productivity for agriculture or biodiversity (Schlüter, 1993). Strip mining of coal leads to exposure of nearby streams to the dangers of acidification with sulfuric acid thereby causing subsoil infertility and stream pollution, which could lead to the killing of fish, plants and aquatic animals that are sensitive to drastic pH shifts (Boominathan and Doran, 2003).

Elevated concentrations of mining pollutants of heavy metals in soils have been reported to produce adverse effects on microorganisms and microbial processes (Biester *et al*., 2002). Among soil microorganisms, mycorrhizal fungi are the only ones providing a direct link between soil and roots, and can therefore be of great importance in heavy metal availability and toxicity to plants (Schlüter, 1993). An understanding of the various aspects of interaction between heavy metals and mycorrhizal fungi is therefore crucial particularly in soils with different kinds and levels of metal pollution. Such interactions include the effects of heavy metals on the occurrence of mycorrhizal fungi, heavy metal tolerance of these microorganisms, and their effect on the metal uptake and transfer of plants (Schlüter, 1993; Leyval *et al*., 1997). However, limited study of the mechanisms involved in metal tolerance, uptake and accumulation by mycorrhizal hyphae and endo- or ecto-mycorrhizae have been documented (Leyval *et al*., 1997).

Homeostatic potentialities of microbial communities in soils contaminated with heavy m.etals have been studied (Alloway, 1995). An estimate of the effect of contaminants on soil microflora was proposed using indices that characterize homeostasis of microbial communities. These indices include microorganisms survivability in contaminated soil and the period of restoration of their number as well as sensitivity to certain contaminants. In a modelled experiment on dark-grey podzolized soil conducted by Biester *et al*. (2002), it was reported that contamination of soil with heavy metals such as $Cu^{2+,}$ $Cd^{2+,}$ $Sr^{2+,}$ $Pb^{2+,}$ Hg^{2+} in doses of 2 and 4 of the maximum permissible concentrations provoked a short-term inhibition of microorganism development after which their number restores. The results further revealed that the introduction of a mixture of metals in soil evokes more intensive inhibition and extends the period of microorganisms number restoration as compared with the effect of certain metals in the same doses.

2.3 Effect of mine pollution on agricultural productivity

Carbon monoxide and sulphur dioxide are presently the most pervasive mine pollutants affecting agricultural production (Chow and Hong, 2002). They exert major negative impact on the growth and productivity of sensitive cultivated and native species of plants as well as crops (Aragon and Rud, 2013) through nutrients and moisture stress (Barcelo *et al.,* 1990; Arsova; Raychev, 2001; Frietas *et al.,* 2004) and damaged plant structures (Fernandes and Henriques, 1991; Levesque and King, 1999). Pollutants also exert serious national problems on humans as labour sources around urban and rural farming centres where agricultural industry plays a dominant role in the life of communities (Aragon and Rud, 2013). Major losses of animal fed on pastures exposed to mine pollutants by livestock farmers have been reported for decades in the eastern Australia due to high levels of potentially toxic hazardous heavy metal pollutants such as arsenic (As), lead (Pb), cadmium (Cd) and mercury (Hg) found in the food chain (Chow and Hong, 2002). Mine pollutants destroy many natural soil characteristics, and may reduce its agricultural productivity (Yin *et al*., 1996; Frietas *et al.,* 2004). A diverse population of small and large forms of soil lives responsible for decomposition of plant and animal residues and nutrient cycling processes are upset by high concentration of pollutants (Yin *et al*., 1996); and hence impairs natural nutrient cycling processes as well as the yields of agricultural produce (Loredo *et al*., 1988).

2.4 Spatial distribution of mine pollutants in soil

Yang and Wang (1998) investigated the origin, distribution and migration of Hg and other heavy metals contained in ores, waste tailings and slag in three typical soil profiles (far from mine entrance, near mine entrance and profile under slag) in Chatian mercury mining deposit (CMD), western Hunan Province of China. Their results revealed that Hg was enriched at the bottom of the soil profile far from mine entrance but accumulated on the surface of soil profiles near mine entrance under slag. The soil profiles near mine entrance under slag are both contaminated by Hg with the latter being most heavily contaminated. Their results revealed 640 µg/g Hg concentration in the surface soil in profile under slag with an average of 76.74 ± 17.71 µg/g concentration in the profile at a leaching depth of more than 100 cm. The mercury concentration of 6.5 µg/g with an average of 2.74 ± 1.90 µg/g concentration were found in the soil profile at 40 cm near mine entrance. Hence, their study concluded that soils in the mercury mine area was polluted by Hg, Cd, As, Pb and Zn with the mobility of heavy metals in soil in the order of Hg > Cd > As > Zn ≈ Pb. Hence, Alloway (1995) revealed that the leaching depth of heavy metals in soil is influenced by the total concentration in the surface soil and soil physico-chemical parameters.

2.5 Relevance of physico-chemical and mineralogical characterization of soil

The relevance of physico-chemical and mineralogical characterization of soils in crop production includes the development of the concept of soil quality (Loredo *et al*., 2004). It explores the use of soil chemical, physical and mineralogical properties as determinants of agricultural soil quality; presents challenges and opportunities for soil scientists, agronomists and farmers to play relevant roles in the assessment and advancement of sustainable crop production through implementation of relevant s.cientific approaches in a remediation effort (Burger and Kelting, 1998).

The need for assessing soil properties is necessitated by the growing population and agricultural research communities' interest in determining the consequences of management practices on soil as a medium for crop production, sustainability of agricultural production and food processing industries (Biester et al., 2002). The concept of physico-chemical and mineralogical characterization of soils includes assessment of soil properties and processes as they relate to ability of soil to function effectively and as an important component of a healthy ecosystem (Arshad and Coen, 1992). Soil physical and chemical characterization entails the quantification of such factors as organic matter content, nutrient supplying capacity, acidity, bulk density, porosity, available water holding capacity and many others. However, their distribution often differs significantly across spatial and temporal scales (Loredo *et al.,* 1988). Any of these soil properties may be simultaneously relevant to several soil functions and will have varying levels of influence that can be weighted accordingly in soil quality index models (Letey, 1985).

2.6 Indicators of environmental pollution in the study area

Due to mining operations in Phalaborwa areas, huge varieties of invasive weed and plant species have established themselves around the mining sites as well as on the farmlands (Table 1; Figure 1). Some of these species include *Lantana camara* (Lantana); *Tecoma stans* (Yellow bell/Geelklokkie); *Ricinus communis* (Castor oil); *Xanthium strumarium* (Large Cocklebur); *Chromolaena odorata* (Triffid weed/Paraffienbos) and *Opuntia sp.* (round leaved-prickly pear). These invasive weeds and plants are actively controlled by a joint venture of mining companies, Department of Water and Forestry and Sanparks (Golder Associates, 2009).

Pollution impact is not only around the immediate mining sites, but also further down in the rivers. A high mortality of catfish, crocodiles and crabs has been recorded in recent years around the Olifants and Selati Rivers in Kruger National Park (Golder Associates, 2010). High levels of copper sulphate and other geochemically associated minerals that are highly toxic to aquatic species and sometimes terrestrial ecosystem had been recently reported after an environmental impact assessment (EIA) study (Golder Associates, 2009). Earlier study revealed high concentrations of dissolved copper sulphate ($CuSO_4$) and other metals in rivers and dams at six water quality monitoring stations and much higher sulphate values were in Kruger National Park site (Golder Associates (2009). The study further attributed the most likely source of the elevated sulphate levels observed at the park to the Selati River and more specifically, copper and other mining activities at the Phalaborwa Mining Company (Ltd.) that is just upstream. The study also revealed that the pollution from the natural water sources exceeded the threshold value of 200 mg/l required for human consumption as well as the threshold value of 100 mg/l for aquatic ecosystem health.

Table 1: Distribution of alien plant and invasive species across farmlands and mining areas in the Ba-Phalaborwa Municipality

Botanical name	Common name	Type	Category	Location	Distribution (%)	GPS Co-ordinates
Lantana and Ricinus Communis	Lantana and castor oil	Weed and invader	1	Hans Merensky Farm	1	23°96.155'S; 31°25.198'E
Lantana and Ricinus Communis	Lantana and castor oil	Weed and invader	1	PMC Mine	2	23° 58' 35’S; 31° 6' 120’E
Ricinus Communis	Castor oil plant	Invader	2	Mogoboya Farm	0 ,5	23°55.811'S; 31°00.020'E
Opuntia Lindheimeri	Small round leaved, Prickly pear	Weed	1	Foskor Mine	2	23°58`130’S; 31°00`450’E
Dutara	Thorn apple , Lantana and stink blaar	Invader	2	Leon Thom Farm (Gravelotte)	1	23°42.052'S; 30°37.056'E
Dutara	Thorn apple , Lantana and stink blaar	Invader	2	JCI Mine (Gravelotte)	2	23°90.690’S; 30.68150’E
Argenome Mexicana	Yellow flowered Mexican Poppy	Weed	1	Mogoboya Farm	0.5	23°55.811'S; 31°00.020'E
Chrmolaena odorata	Triffid weed/Paraffienbos	Weed	1	Hans Merensky Farm	1	23°96.155'S; 31°25.198'E
Xanthium strumarium	Large Cocklebur	Weed	1	Selati River Bank	1	23°54.811’S; 31°02.020'E
Tecoma stans	Yellow bell/Geelklokkie	Weed	1	Leon Tom Farm	1	23°42.052’S; 30°37.056’E

Source: Golder Associates, (2009)

Figure 1: Selected identified invasive plant species and mine dump due to mine pollution around Leon Tom farm

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Description of study sites

The study was conducted on one farmland each around the three mining sites in Phalaborwa area, Limpopo Province. The farms are Hans Merensky (23°96.155'S, 031°25.198'E), Mogoboya Integrated (23°55.811'S, 031°00.020'E) and Leon Thom (23°42.052'S, 030°37.056'E) farms. Leon Thom Farm is located about 56 km from other two farms and about 3 km from the JCI Mining Company in the Gravelotte farming community. On the other hand, Hans Merensky and Mogoboya Integrated farms are located at about 2 km from the Phalaborwa Mining Company (PMC) and Foskor Mining Company, respectively (Figure 2). Phalaborwa Mining Company (PMC) mines and refines copper as its major product, Foskor Mine beneficiates phosphate rocks into phosphoric acid and phosphate based granular fertilizers, while JCI Mine exploits soil mineral resources for gold and antimony.

Figure 2: Map of the trial sites around the three Phalaborwa mining sites (Source: Golder Associates, 2009)

The wind in Phalaborwa is mostly from south-easterly direction for nearly 70 % of the time and of which over 60 % is between 1.1 and 3.5 m/s with an average rarely exceeding 8 m/s (Golder Associates 2009). The Hans Merensky and Leon Tom Farms faced the wind direction from mining sites while Mogoboya Integrated Farm is lined up along the two mines (Foskor and PMC). The geological formation of the study area is Phalaborwa Alkaline Igneous Complex while the area is characterized by a flat to gentle undulating bushveld landscape with mixed vegetation dominated by Mopani biome on sweet veld with sandy clay soil (Golder Associates, 2010). The mean annual rainfall in the area is 500 mm with average summer and winter temperature of 37 ^{0}C and 22 ^{0}C, respectively (van der Spuy, 1982). Agricultural and mining as well as tourism industries in the area rely mainly on Selati, Letaba and Olifants River as well as boreholes as sources of water. The major farming activity in the area is livestock while crop production is mostly done at subsistence level by many farmers in the area (Mathivha, 2010).

The farmer at Hans Merensky Farm produces Lucerne, grass and golf course lawn. The farmer’s fertilization program consists of the use of superphosphate and potash fertilizers and lime ammonium nitrate (LAN). The farmer at the Mogoboya Integrated Farm on the other hand extensively produces crops under dryland conditions, which mostly consists of maize, groundnuts, pumpkins and dry beans with mango trees on a half hectare land. The farmer has no conventional fertilizer management practices except for the use of compost as a soil amendment. The farmer on Leon Thom Farm mainly breeds cattle for dairy industry and grows his own pasture to feed his animals. The pasture species grown consists mainly of grass and Lucerne using superphosphates and potash fertilizers.

Additional soil samples that serve as control were similarly collected from unpolluted Waterbok farm, Seloane (23°55.710' and 031°03.040') for the purpose of comparison. The 250 ha farmland is located at about 70 km distance further away from mining sites and situated 30 km North-East of Eiland Resort in Ba-Phalaborwa Municipality. The farm produces wide varieties of agronomic crops such as tomato, butternut, green pepper, baby marrow, petty penns, chilli and okra on reddish–brown loamy sand soil. The area receives an average annual summer rainfall of 550 mm and average summer and winter temperatures of 36 and 20°C, respectively.

3.2 Description of soil sampling procedures

A total of thirty six soil samples representing nine from each farm around the mines and Waterbok farm were systematically taken at three different points on each farm using a soil auger at 0–15, 15–30 and 30–45 cm depth. Another three separate samples were randomly collected from the topsoil (0–15 cm) across each farm, bulked together and used for microbial analysis. Prior to sampling for microbial study, the soil auger was sterilized by immersion into 20 % ethanol solution. Sampling points for the physico-chemical and microbial properties were systematically selected to cut across each farm, with the first sampling point selected closer to the direction of the mining site. The remaining sampling points were selected at a fairly uniform distance away from the first sampling point depending on the size of the each farm. All soil samples collected except for those to be used for microbial study were air-dried, sieved through a 2 mm sieve and used for the various laboratory determinations. Samples for the microbial study upon collection on the field were kept under freeze conditions and transported in an iced cooler box before transfer to the laboratory and analysed as fresh material.

3.3 Laboratory determination on soil samples

3.3.1 Procedures for physical and chemical analysis

Soil samples collected were subjected to selected physical, chemical and microbial determinations following procedures summarized below in Table 2. For the purpose of comparisons, results for the concentration of the different heavy metals obtained will be compared with those from unpolluted soil samples obtained from Waterbok farm as well as the standard permissible pollutant limits values obtained from literature.

3.3.2 Methodology for microbial counts

Standard microbiological procedures were employed for the isolation and enumeration of the different microbial groups. Different microbial growth media designed to be selective for heterotrophic microbes; actinomycete and filamentous fungi were used in the microbial analyses. These microbial populations were subjected to the physiological ability of microbes to grow in each of the selected media. General heterotrophic plate counts were done on nutrient agar (NA), (Biolab, Midrand, South Africa). Actinomycete was isolated and enumerated on Actinomycete isolation agar (Sigma-Aldrich, South Africa). Obtaining filamentous fungal counts, malt extract agar (MEA), (Biolab (Merck), South Africa) was used and supplemented with 30ppm chloramphenicol and 50 ppm streptomycin. These various media were all sterilized at 121 °C for 15 min and made into pouring plates, each consisting of a Petri dish (90mm in diameter) containing an isolation medium. A soil dilution series ranging from 10^{-1} to 10^{-5} was prepared in triplicate using 1 g of soil in 9 ml of saline solution and a 100 µL aliquot of each dilution was spread on the isolation plates. The various isolation plates were incubated at room temperature and enumerated after 3 days for the bacteria and 7 days for the actinomycete and fungi. The results of microbial determinations obtained from polluted soils were compared with those from the unpolluted Waterbok farm as well as others reported in literature (Hinojosa *et al*., 2004).

3.4 Data analysis

All data generated were subjected to simple descriptive statistics such as mean, standard error and coefficient of variation as well as analysis of variance (ANOVA) using Statistix 8.1 software. Mean separation was done at 5 % probability level. Microbiological data were log transformed prior to statistical analyses to fulfil the conditions of normality. Where significant differences were found, the differences in means across treatments were further compared using the post-hoc Tukey test.

Table 2: Summary of methodology used for the various laboratory determinations

Parameters measured	**Methodology for determination**
Particle size distribution	Hydrometer method described by Gee and Bauder (1986)
Bulk density	Method described by Tisdall (1951) for disturbed soil.
pH (H_2O & KCl)	Water (pH_w) and KCl extraction and measured in a 1:2.5 suspension using pH meter (Okalebo *et al*., 2002)
.Electrical conductivity (EC_e)	Saturated paste using water and measured using electrical conductivity meter (Okalebo *et al*., 2002)
Exchangeable acidity (EA)	Determined by pH change of a buffered solution-soil suspension (Mehlich, 1976).
Available P content	Bray P-1 procedure described by Bray and Kurtz (1945)
Percent organic carbon	Walkley-Black wet digestion, oxidation-titration method (Nelson and Sommer, 1975)
Exchangeable K, Ca, Mg & Na (TEB)	Ammonium acetate extraction (pH 7.0) method
Effective cation exchange capacity (ECEC)	Estimated as the sum of exchangeable bases (Ca, Mg, K, Na) and exchangeable acidity expressed in cmol(+)/kg
Extractable Mn, Zn & Cu; and heavy metals (Pb, Cd, As & Sb)	EDTA extraction, Inductively coupled plasma -atomic emission spectrometry (Herbert *et al*., 1994)
– Microbial population: Fungi & bacteria – Actinomycete	– Agar plate procedure – (Fredrickson and Balkwill, 1998; Alef and Nannipieri, 1995) – Dispersion and differential centrifugation procedure according to Yang and Wang (1998)

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Physical properties of the soil samples collected from the different farms

Soil textural characteristics and bulk density

Table 3 shows the percent distribution of total sand, silt and clay content as well as bulk density in the soil samples across the four farms. The clay content ranged from 11.0 to 21.3 % depending on soil depth with the highest percent clay content obtained in soil samples from the Leon Tom farm. The silt content in the soil samples varied between 8.0 and 12.7 % across all depths and farms while the total sand content varied between 66.0 and 87.7 %. The percent total sand content is highest in soil samples obtained from Waterbok farm while the clay and silt contents showed a general increase with soil depths across all the farms. The results of statistical analysis of the distribution of the three primary particles of sand, silt and clay showed a significant difference in percent soil textural characteristics among all the sources (farms, sampling depths, sampling points as well as their interactions with farms). Significant interaction effect of sampling depth (SD) x farms (ID) as well as sampling points (SP) x farms on percent clay and total sand content were also observed.

The bulk density in the soil samples ranged from 1.31 to 1.59 g cm^{-3} with soil samples from Waterbok being the highest and Mogoboya farm the least. Significant difference in the values of bulk density of soils between different farms, sampling depths as well as sampling points was observed. The sampling depth x farms as well as sampling points x farms interaction effect of on bulk density were also significant ($p<0.05$). The significant difference in bulk density among these farms may be due to varying degrees of parent materials (limestone and dolomite rocks) in the Phalaborwa igneous complex as well as differences in agricultural land use practices (Chamber of Mines of SA, 2005). The results also revealed that the bulk density of soil samples from around the mining sites decreased further away from the pollution sources, possibly attributed to less accumulation of the particles of pollutants from mining activities and more disturbance of soil. This is in agreement with the work reported by Ibanga *et al*. (2005). The bulk density of soil samples from the Waterbok control farm showed a relatively constant value across the field.

Table 3: Selected physical properties of the soil samples studied

Soil physical parameters	LTM	MGB	HMK	Waterbok
% clay				
0-15	17. 7	13.7	18.0	11.0
15-30	19.0	16.0	18.7	16.0
30-45	21.3	16.0	18.7	17.7
% silt				
0-15	11.3	8.0	10.0	11.0
15-30	9.7	7.7	8.7	11.6
30-45	12.7	9.0	8.0	12.7
% total sand				
0-15	71.0	78.3	72.0	87.7
15-30	71.3	76.3	72.6	82.0
30-45	66.0	75.0	73.3	77.0
Bulk density (g cm^{-3})				
0-15	1.346	1.489	1.451	1.560
15-30	1.320	1.560	1.440	1.563
30-45	1.313	1.592	1.420	1.567
SEM values	Clay	Silt	Total sand	Bulk density
Farms (ID)	*	NS	*	*
Sampling depth (SD)	*	NS	*	*
Sampling points (SP)	NS	NS	NS	*
ID*SD interaction	*	NS	*	*
ID*SP interaction	*	NS	*	*

SE implies standard error of mean; NS implies at not significant while *** implies significant at probability level of 5%; LTM, MGB and HMK implies Leon Tom, Moogoboya and Hans Merensky farm, respectively.

4.2 Chemical properties of the soil samples collected from the different farms

Soil pH and electrical conductivity

The mean value of pH, EC_e, EA, organic carbon, available P and exchangeable cations contents in soil samples across farms are contained in Table 4 below. The values of pH_w obtained from study areas ranged from 6.30 to 7.24 and pH_{KCl} ranged from 5.44 to 6.39 with their mean values of 6.69 and 5.89, respectively. The results reflect a range of slightly to very slightly acid soil and further confirmed by higher concentrations of heavy metals. The pH (water) values obtained for soil samples from the control site (Waterbok) are ranging from 5.92 to 7.86 with a mean value of 6.89. The results reflect a medium acid to a slightly alkaline soil pH condition. The mean pH value of soil samples from farms around the mining areas is lower than that from the control site of the study. This result is in agreement with earlier studies reported by Fowles (2007). Furthermore, the results of the pH values showed a decreasing value with increase in soil depths suggesting that the mine tailings produced exert acidic effects on the underlying soil (Rosner and Van Schalkwyk, 2000).

The EC_e values obtained in soil samples from farms around the mining sites ranged from 11.42 to 11.97 mS/cm with a mean value of 11.74 mS/cm as compared to the range of 4.94 to 15.14 mS/cm with a mean value of 9.38 mS/cm in soil samples from the control farm. The higher mean EC values in mine-polluted soils than those of unpolluted soils observed in this study may be attributed to the high load of pollutants from the mines as well as micronutrient-rich fertilizers and pesticides used by the farmers as previously reported by Fowles (2007). The implication is that the soils have tendency for salt problem that may impact negatively on water and nutrient uptake by crops. A significant ($p<0.05$) sampling depth x and farms as well as sampling points x farms interaction effect on soil pH_w and electrical conductivity were also obtained.

Organic carbon, exchangeable acidity and phosphorus

Table 4 also contains the distribution of soil exchangeable acidity, percent organic carbon and available phosphorous. The percent organic carbon content in the soil samples varied between 1.29 and 2.46 across all depths and the four farms while available P ranged from 4.86 to 13.32 mg kg^{-1}. Percent organic carbon increases with an increase in distance away from the mining area due to vegetation and topsoil removal around the mining area and the immediate surrounding (Agboola, 1982; Salami *et al.* 2002). The value of exchangeable acidity in the soil samples varied between 0.39 and 0.88 cmol(+)/kg across soil depths, sampling points and the four farms. Values of exchangeable acidity increase with increasing distance from the pollution source. This observation is in perfect agreement with earlier findings reported by Wild (1995).

Table 4: Mean values of selected soil chemical properties in soil samples obtained from the different farms

Indicators	pH_w	pH_{KCl}	Electrical conductivity (mS/cm)	Exchangeable Acid (cmol(+)/kg)	% Organic Carbon	Avail P	Exch K	Exch Ca	Exch Mg	Exch Na
						(mg kg^{-1})				
Soil depths (cm)										
0-15	6.94a	6.21a	11.53a	0.72a	1.86a	10.28a	176a	1130a	391a	43a
15-30	6.77a	5.96b	11.16b	0.72a	1.97a	9.09b	180a	1078a	394a	44a
30-45	6.50b	5.65c	10.76c	0..80a	1.53b	6.63c	191a	1084a	408a	43a
Sampling points (S)										
Point1	6.70ab	5.93a	12.24a	0.65b	1.76b	13.32a	127b	1078a	402a	51a
Point2	6.91a	6.02a	10.76b	0.79a	1.41c	7.82b	212a	1065a	381a	38b
Point3	6.00b	5.88a	10.45b	0.80a	2.19a	4.86c	208ab	1149a	409a	42ab
Locality										
Hans Merensky Farm	6.53c	5.83c	11.97a	0.88ab	2.46a	6.03d	119b	913a	432b	66a
Leon Tom Farm	6.30c	5.44d	11.83a	0.80b	1.29c	6.93c	136b	1232a	634a	49b
Mogoboya Farm	7.24a	6.39a	11.42b	0.92a	1.90b	11.87a	125b	1214a	213c	35bc
Waterbok Farm	6.89b	6.11b	9.38c	0.39.c	1.49c	9.84b	351a	1030a	311bc	24c
Significance										
Sampling depth (SD)	***	***	***	NS	***	***	NS	NS	NS	NS
Sampling point (SP)	***	***	***	***	***	***	***	NS	NS	***
Locality (ID)	***	***	***	***	***	***	***	***	***	***
ID*SD interaction	***	***	***	***	***	***	***	***	***	***

NS implies at not significant while *** implies significant at $p = 0.001$; figures within the same column with same letters are not significantly different

The results of available P content showed a decrease further away from the pollution source while the low available P content in the soil samples may be attributed to inherent soil characteristics such as high calcium content across the study areas which could potentially render P unavailable through fixation (Wild, 1995; Dutta and Agrawal, 2002). The results of statistical analysis showed a significant difference in organic carbon and exchangeable acidity across sampling depths, sampling points and the four farms. The interaction effect of sampling depth (SD) and farms (ID) as well as sampling points (SP) and farms on exchangeable acidity, organic carbon and available phosphorous content were also significant ($p<0.05$).

4.3 Extractable cations and heavy metal distribution in the samples

4.3.1 Concentration of extractable cations

The distribution of soil extractable K ranged from 176 to191 mg kg^{-1}, 208 to 212 mg kg^{-1} and 119 to 351 mg kg^{-1}, respectively across sampling depths, sampling point and farms. Calcium content ranged from 1078a to 1130 mg kg^{-1}, 1065 to 1149 mg kg^{-1} and 913 to 1232 mg kg^{-1}, Mg ranged from 391 to 408 mg kg^{-1}, 381 to 409 mg kg^{-1} and 213 to 634 mg kg^{-1}, and that of Na ranged from 43 to 44 mg kg^{-1}, 38 to 51 mg kg^{-1} and 24 to 66 mg kg^{-1} across sampling depths, sampling point and farms respectively. Potassium concentration in soil from Waterbok (control) farm recorded the highest value as compared to all the farms as shown in Table 4, which could probably be a reflection of land use rather than of inherent soil characteristics (Mandiringana *et al*., 2005). The mean exchangeable K, Ca and Mg concentrations across the farms for all sampling points and depths varied between 119 and 351 mg kg^{-1}, 913 and 1214 mg kg^{-1}, and between 213 and 634 mg kg^{-1}, respectively while the mean Na concentration across the farms ranged from 24 to 66 mg kg^{-1}. Generally, the extractable K, Ca and Na concentrations showed a marginal increase further away from the pollution source while K concentration follows no definite pattern with increasing distance further away from the pollution source. The sampling depth x farms as well as sampling point x farms interaction effects on K, Ca, Mg and Na were all significant ($p\leq0.05$) suggesting that availability of these nutrient elements is affected regardless of sampling depth or sampling point in polluted soils. This confirms the findings of Ratcliffe (1974) who also observed reduced availability of essential plant nutrients in soil due to pollution arising from mining activities.

4.3.2 Heavy metal distribution in the soil samples

Table 5 below shows the concentration of heavy metal across the different sampling depths and farms. Generally, the concentration of heavy metals in soil of the four farms decreased with increase in soil depth. The level of pollution in the soil of the farms differs depending on the sources of the pollutants. Lead (Pb) concentration at the soil surface of farms around the three mining sites ranged from 9.61 to 13.38 mg kg^{-1}, which is considerably higher than the value of 3.70 mg kg^{-1} from the surface soil sample from Waterbok farm used as control to measure the degree of pollution. The Pb concentrations at the surface (0-15 cm) soils from around the three mining sites exceed the critical range level of 0.59 to 7.48 mg kg^{-1} for South African soils reported by Alloway (1995) and the FAO (1985) threshold level of 5 mg kg^{-1} for crop production. Leon Tom Farm recorded the highest level of arsenic and antimony concentrations of 21.69 and 15.79 mg kg^{-1}, respectively. Comparatively, surface soil samples from Mogoboya, Hans Merensky and Waterbok Farms contained an average antimony concentration level of 0.03; 0.17 and 0.18 mg kg^{-1}, respectively.

Soil samples from Waterbok Farm which serves as the control site for this study contained negligible amount of copper concentration at virtually all sampling depths clearly suggesting that the elevated copper concentrations detected in soil samples collected from Hans Merensky, Leon Thom and Mogoboya Farms are as a direct result of pollution from nearby mining operations. Except for soil samples at Leon Tom farm, copper concentrations in samples from Hans Merensky and Mogoboya farms at all depths were generally higher than the critical level of 0.2 mg kg^{-1} reported by FAO (1985). The high accumulation of these heavy metals at virtually all the soil depths may be related to the percent clay and organic carbon content. This is confirmed by earlier findings by Schoer (1985) that heavy metal accumulation in the primary mineral soil particles is in the order of clay > silt > total sand. Extractable Mn content ranged from trace amount to 0.4 mg kg^{-1} depending on soil depth and sampling point. Generally, the Mn concentration observed in the surface soil samples from Hans Merensky and Waterbok farms was above the critical level of 0.2 mg kg^{-1} reported by FAO (1985) probably due to the fertilizer use on those farms.

Table 5: Selected micronutrients and heavy metals concentration (mg kg^{-1}) of the soil samples studied

Parameters per soil depth	LTM	MGB	HMK	Waterbok
0-15 cm				
Mn	0.001	0.07	0.31	0.23
Zn	2.26	0.58	4.53	0.33
Cu	0.05	0.47	0.51	Trace
Pb	9.61	13.38	12.09	3.70
Cd	0.06	0.056	0.08	0.02
As	21.69	0.01	0.01	0.34
Sb	15.79	0.03	0.17	0.18
15-30 cm				
Mn	0.16	0.03	0.004	Trace
Zn	0.99	Trace	4.53	0.06
Cu	Trace	0.42	0.39	Trace
Pb	8.67	11.84	13.96	3.82
Cd	0.05	0.04	0.07	0.02
As	3.56	0.01	0.01	0.46
Sb	1.05	0.03	0.07	0.15
30-45 cm				
Mn	0.25	0.28	Trace	0.40
Zn	0.7	0.82	1.209	0.19
Cu	0.01	0.38	0.22	Trace
Pb	9.27	13.21	11.69	4.45
Cd	0.04	0.10	0.039	0.02
As	4.53	0.01	0.01	0.62
Sb	1.00	0.01	0.036	0.10

*Critical values: Mn = 20-10000; Zn = 0.2-3.1; Cu = 0.4-6.4; Pb = 0.59-7.48; Cd = 0.002-0.04; As = 0.1-40; Sb = 50 mg kg^{-1} (Alloway, 1995; FAO, 1985; Steyn and Herselman, 2005); LTM, MGB and HMK implies Leon Tom, Moogoboya and Hans Merensky farm, respectively.

4.4 Microbial properties of the soil samples

The mean distribution of microbial count of fungi, bacteria and actinomycetes within the surface 0-15 cm soil depth across the different localities and sampling points is presented in Table 6. There is a significant difference ($p<0.05$) in the distribution of actinomycete and bacteria counts across all the farms and sampling points while fungi counts in polluted soil samples did not differ significantly. Fungi and actinomycete activities were more sensitive to heavy metal contamination than bacteria and were significantly increased following soil pollution. The findings reported in this study are in agreement with earlier findings reported by Biester *et al.*

(2002). The significantly high microbial counts obained in this study is probably attributed to the long period of pollution particularly for soils around the three mining sites relative to the soil from the control Waterbok farm. Table 7 contained data on the mean microbial counts in soil samples taken further away from the pollution source. The data revealed that fungi, bacteria and actinomycete counts increase with increase in the distance away from the pollution source. The data on the microbial counts from polluted soils showed an increase in microbial activity further away from pollution source. This trend is in agreement with earlier findings reported by Mikanova *et al*. (2002) that the values of enzymatic activities were highest in soil samples further away from the source of contamination but decreased as the source of contamination is being approached. The results however contradicts findings reported by Hinojosa *et al*. (2004) that all enzymes and general microbiological rates detected in unpolluted soils were more than two times higher than in polluted soils. Hinojosa et al., (2010) also indicated that the total number of colony forming unit (CFU) of fungi and actinomycetes was significantly reduced after heavy metal contamination. Mining also resulted in the clearing of vegetation and thus reduces the concentration of essential nutrients through reduced soil organic matter level of the soil and biological activities; and consequently decreases the productivity of the soil (Pandey and Kamur, 1996).

Table 6: Mean distribution of microbial count (CFU g^{-1} soil) within the surface 0-15 cm soil depth at different localities across sampling points

Locality	**Fungi**	**Bacteria**	**Actinomycete**
Leon Tom Farm	3.82a	6.44a	6.20a
Mogoboya farm	3.51a	6.46a	5.97a
Hans Merensky farm	3.80a	5.91b	5.51b
Waterbok farm	2.14b	5.70c	4.90c
SEM	0.09	0.03	0.08

** Values reported in the Table are Log CFU g^{-1} soil; values within the same column with same letters are not significantly different; SEM implies standard error of mean.

Table 7: Effect of sampling points on the distribution of microbial count (CFU g^{-1} soil) within the surface 0-15 cm at different localities

Locality/sampling points	**Fungi**	**Bacteria**	**Actinomycetes**
Leon Tom farm			
SP1	3.83a	6.53c	6.20bc
SP2	3.62a	5.59e	5.15ef
SP3	4.00a	7.2a	7.25a
Mogoboya farm			
SP1	3.52a	6.82b	6.38b
SP2	3.23a	6.6c	5.92cd
SP3	3.77a	5.96d	5.62de
Hans Merensky farm			
SP1	3.76a	5.55e	5.62de
SP2	3.80a	5.59e	5.34e
SP3	3.84a	5.97d	5.55de
Waterbok farm			
SP1	2.31a	5.89d	4.72fg
SP2	2.10a	5.88d	4.51g
SP3	2.00a	5.96d	5.47de
SEM	008	0.05	0.11

** Values reported in the Table are Log CFU g^{-1} soil; SP 1, 2 & 3 connote sampling points on each farm; values within the same column with same letters are not significantly different; SEM implies standard error of mean.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The discovery of more mineral reserves in the Limpopo Province, and many parts of the country poses a threat to the agricultural ecosystem due to hazardous by-products which will continue to be produced following increased mining activities. The sources of these pollutants are mine dumps, acid mine drainage and tailings dams, which exert serious negative consequences on the the environment including our non-renewable natural resources such as water and soil. Thus the primary goal of this study was to quantify the impact on mine pollution on soil.

The findings of this study revealed that mining activities constitute sources of pollutants which impacted negatively on soil physical, chemical and biological properties. This is further confirmed by the recent incidence of high catfish crocodiles and crabs mortality in the Olifants and Selati Rivers which were exposed to mine pollutants as well as the presence of different varieties of invasive weed and plant species observed during the study on and/or around farmlands located around the mining sites. The concentration of Pb obtained in soil samples around the mining sites far exceeds the acceptable limits/threshold level. The concentration of extractable heavy metals in the studied areas was in the order: As >Sb>Pb>Zn>Cu >Mn >Cd. The concentrations of Cd appeared very low in all samples while elevated levels of Mn, Cu and Zn were detected at all depths relative to values from non-polluted control. Significantly higher Pb, As and Sb concentrations were obtained in polluted samples than those from the control samples.

The findings further revealed that the activities of microorganisms were less affected by pollution in fine-textured soils than in sandy loam possibly because of differences in the sorption capability of soils with different textures as reported by Hinojosa (2004). Soil microbial levels were significantly higher in mine polluted than non-polluted soils except in Hans Merensky samples where bacterial and actinomycete counts were lower. Future studies on soil from affected areas should focus on assessment interventions to reduce the impact of the pollutants on crop production so as to improve soil quality and agricultural productivity in these farming areas.

LIST OF REFERENCES

AGBOOLA, A.A., 1982. Soil fertilizer and fertilizer use in Nigeria. A paper presented at the First National Seminar in Agricultural Land Resources held at Kaduna, Nigeria.

ALEF, K. & NANNIPIERI, P., 1995. Methods in applied soil microbiology and biochemistry, Academic Press, New York.

ALLOWAY, B.J., 1995. Soil processes and the behaviour of metals. Pp. 11–37. Heavy metals in soils. 2nd edition, Blackie Academic and Professional, London.

ARSHAD, M.A. & COEN, G.M., 1992. Characterization of soil quality: physical and chemical criteria. America Journal Alternative Agriculture, 7: 25–31.

ARAGON, F.M. & RUD. J.P., 2013. Natural resources and local communities evidence from a Peruvian gold mine, American Economic Journal 5 (2): 1–50.

ARSOVA, A. & RAYCHEV T., 2001. Bio-ecological effect of waste treatment lime sludge and their effectiveness as agricultural limestone substitutes.Journal of water pollution control fed, 60(5):674 –680.

BA-PHALABORWA MUNICIPALITY DRAFT IDP DOCUMENT 2012/17. 229pp.

BARCELO, J., POSCHENRIEDER. C., BECH, J., LIUNGAMY. M., TUME. P., TOBIAS. FJ., 1990. Arsenic and heavy metals contamination of soil and vegetation around copper mine in Northern Peru. Sci Total Environment, 203: 83 – 91.

BIESTER, H., MULLER, G. & SCHÖLER, H. F., 2002. Binding and mobility of mercury in soils contaminated by emissions from chlor-alkali plants. Science of the Total Environment, 284 (1–3): 191–203.

BOOMINATHAN, R. & DORAN, P.M., 2003. Organic acid complexation, heavy metal distribution and the effect of ATPase inhibition in hairy roots of hyper-accumulator plant species. Journal of Biotechnology, 101: 131–146.

BRAY, R.H.L. & KURTZ, L.T., 1945. Determination of total and available forms of P in soils. Soil Science, 53: 39–45.

BURGER, J.A. & KELTING, D.L., 1998. Soil quality monitoring for assessing sustainable forest management. Soil Science Society of America, Special Publication No. 53: 17–52.

CHOW, C.K. & HONG. C.B., 2002. Dietary vitamin E and selenium and toxicity of nitrite and nitrate. Toxicology., 180 (2): 195–207.

DUTTA, R, K. & AGRAWAL, M., 2002. Effect of tree plantations on the soil characteristics and microbial activity of coal mine spoil land. Tropical ecology, 43 (2): 313 –324.

FAO, 1985. Water quality for irrigation for agriculture. Irrigation and Drainage Paper number 29, 130pp.

FERNANDES, J.C. & HENRIQUES, F.S., 1991. Biochemical, physiological and structural effects of excess copper in plants. The Botanical Review, 57 (3): 246-273.

FOSKOR, 2010. Foskor annual report. 142pp.

FOWLES, M., 2007. Black carbon sequenstration as an alternative to bioenergy. Biomass and Bioenergy, 31: 426 –432.

FREDRICKSON, J.K. & BALKWILL, D.L., 1998. Sampling and remuneration techniques. p. 239-252. In: Burlage; R.S. (ed.), Techniques in microbial ecology, Oxford University Press, Inc., New York.

FREITAS, H. & PRASAD, M.N.V., 2004. Feasible biotechnological and bioremediation strategies for serpentine soils and mine soils. Journal of Biotechnology 2: 36–50.

GEE, G.W. & BAUDER, J.W., 1986. Physical and mineralogical methods, Soil Science Society of America, Madison, WI, USA (1986), pp. 383–412.

GOLDER ASSOCIATES. 2009. Environmental impact assessment (EIA) for Foskor's pyroxenite expansion project phase 3, Phalaborwa Limpopo Province report No.12114-9282-3, 156 pp.

GOLDER ASSOCIATES. 2010. Environmental impact assessment (EIA) for Foskor's pyroxenite expansion project phase 3, Phalaborwa Limpopo Province report No.12114-9282-5, 169 pp.

HERBERT, E.A., CHIN, P.H., GEORGE, W.B. & ALAN, R.B., 1994. Metal speciation and contamination of Soil. 1st edition, Lewis Publishers, London, 285 pp.

HINOJOSA, M.B., GARCÍA-RUÍZ, R., VIÑEGLA, B. & CARREIRA, J.A., 2004. Microbiological rates and enzyme activities as indicators of functionality in soils affected by the Aznalcóllar toxic spill. Soil Biology Biochemistry, 36: 1637–1644.

HINOJOSA, M.B., GARCIA-RUIZ, R., and CARREIRA, J.A., 2010. Utilizing Microbial Community Structure and Function to Evaluate the Health of Heavy Metal Polluted Soils, 185-224. In: I. Sherameti and A. Varma (eds.), *Soil Heavy Metals*, Soil Biology, Vol 19, Springer-Verlag Berlin Heidelberg 2010.

IBANGA, I.J., UDOMA, G.H.,EDET, A.B. & AKPAN, F.S. 2005. Physico-chemical properties of some limestone soils in southeastern Nigeria. Nigerian journal of Soil Science, 15: 81–86.

LETEY, J., 1985. Relationship between soil physical properties and crop production. Advances in Soil Science, 1: 227–294.

LEVESQUE, J & KING, D.J., 1999. Airborne Digital Camera Image Semivariance for evaluation of a forest structural damage at an acid mine site. Remote Sensing of Environment, 68 (2): 112-124.

LEYVAL, C., TURNAU, K. & HASELWANDTER, K., 1997. Effect of heavy metal pollution on mycorrhizal colonization and function. Physiological, Ecological and Applied Aspects, 7 (3): 139-153.

LOREDO, J., FERNÁNDEZ-MARTÍNEZ, R., ORDÓÑEZ, A. & RUCANDIO, M. I., 2004. Distribution and mobility of mercury in soils from an old mining area in Mieres, Asturias Spain. Science of the Total Environment, 346 (1–l3): 200– 212.

LOREDO, J., LUQUE, C. & GARCIA IGLESIAS, J., 1988. Conditions of formation of mercury deposits from the Cantabrian Zone, Spain. Bulletin of Mineralogy, 3: 393-400.

MANDIRINGANA, O.T., MNKENI, P.N.S., MKILE, Z., VAN AVERBEKE, W. VAN RANST, E. & VERPLANCKE, H., 2005. Mineralogy and fertility status of selected soils of the Eastern Cape Province, South Africa. Communications in Soil Science and Plant Analysis, 36: 2431- 2446.

MATHIVHA, F.K., 2010. Zwavhulimi: An official Newsletter of the Limpopo Department of agriculture (January–March 2010). 14pp.

MEHLICH, A. 1976. New buffer method for rapid estimation of exchangeable acidity and lime requirement. Commun Soil Sci Plant Anal, 7(7): 637–52.

MIKANOVA, O., KUBAT, J., NOVAKOVA, J., 2002. Some microbial characteristics and enzymatic activities in soils polluted with heavy metals, 792: 1– 7.

NELSON, D. W. & SOMMER, L E., 1975. A rapid and accurate method for estimating organic carbon in soil. Proceeding of the Indiana Academy of Science, 84: 456-462

OKALEBO, J.R., GATHUA, K. W. & WOOMER, P.L., 2002. Laboratory methods of soil and water Analysis: A working manual. Second edition, 236pp.

PANDEY, D.D. & KAMUR, S. 1996. Impact of cement dust pollution on biomass, chlorophyll, nutrients and grain characteristics of wheat. Environmental Ecology, 14 (4): 872 –875.

PEREZ-DE-MORA, A., BURGOS, P., MADEJON, E., CABRERA, F., JAECKE, P. & SCHLOTER, M., 2006. Microbial community structure and function in a soil contaminated by heavy metals: effects of plant growth and different amendments. Soil Biology Biochemistry, 38: 327–341.

PIERZYNSKI, G.M., SIMS, J.T., VANCE, G.F., 2005. Trace elements. pp. 331–361. In: Skousen, J. J. and P. F. Zienkiwicz (eds.), Soils and environmental quality, 1st edition, Taylor and Francis Group, London.

RATCLIFFE, D., 1974. Ecological effect of mineral exploitation in the United Kingdom and their significance to nature conservation. Royal Security of London proceedings Series A. 339: 355–372.

RENELLA, G., ORTIGOZA, A.L.R., LANDI, L. & NANNIPIERI, P., 2003. Additive effects of copper and zinc on cadmium toxicity on phosphatase activities and ATP content of soil as estimated by the ecological dose (ED_{50}). Soil Biology Biochemistry, 35: 1203–1210.

ROSNER, T. & VAN SCHALKWYK, A., 2000. The environmental impact of gold mine tailings footprints in the Johannesburg region, South Africa. Bull Engineering Geological Environment, 59: 137-148.

RULE, J, H. & IWASHCHENKO, M. S., 1998. Mercury concentrations in soils adjacent to a former chlor-alkali plant. Journal of Environmental Quality, 27 (1): 31–37.

SALAMI, A.T., FAOUNBI, A.I., MOUGHALU, A.J., 2002. Effects of cement production on vegetablein part of Southwestern Nigeria. Tanzania Journal of Science 28, (2):70–82.

SCHLÜTER, K., 1993. The fate of mercury in soil: A review of current knowledge. Soil and Groundwater Research Report IV, Commission of the European Communities, Luxembourg, and UK, 75 pp.

SCHOER, J., 1985. Iron-oxo-hydroxides and their significance to the behavior of heavy metals in estuaries, *Environmental Technology Letter*, 6 : 189–202.

STEYN, C. E. and HERSELMAN, J. E. 2005. Trace Elements in Developing Countries Using South Africa as a Case Study. Communications in Soil Science and Plant Analysis 36 (1): 155 – 168

TISDALL, A.L., 1951, Comparison of methods of determining apparent density of soils.Australian Journal of Agricultural Research, 2: 349-354.

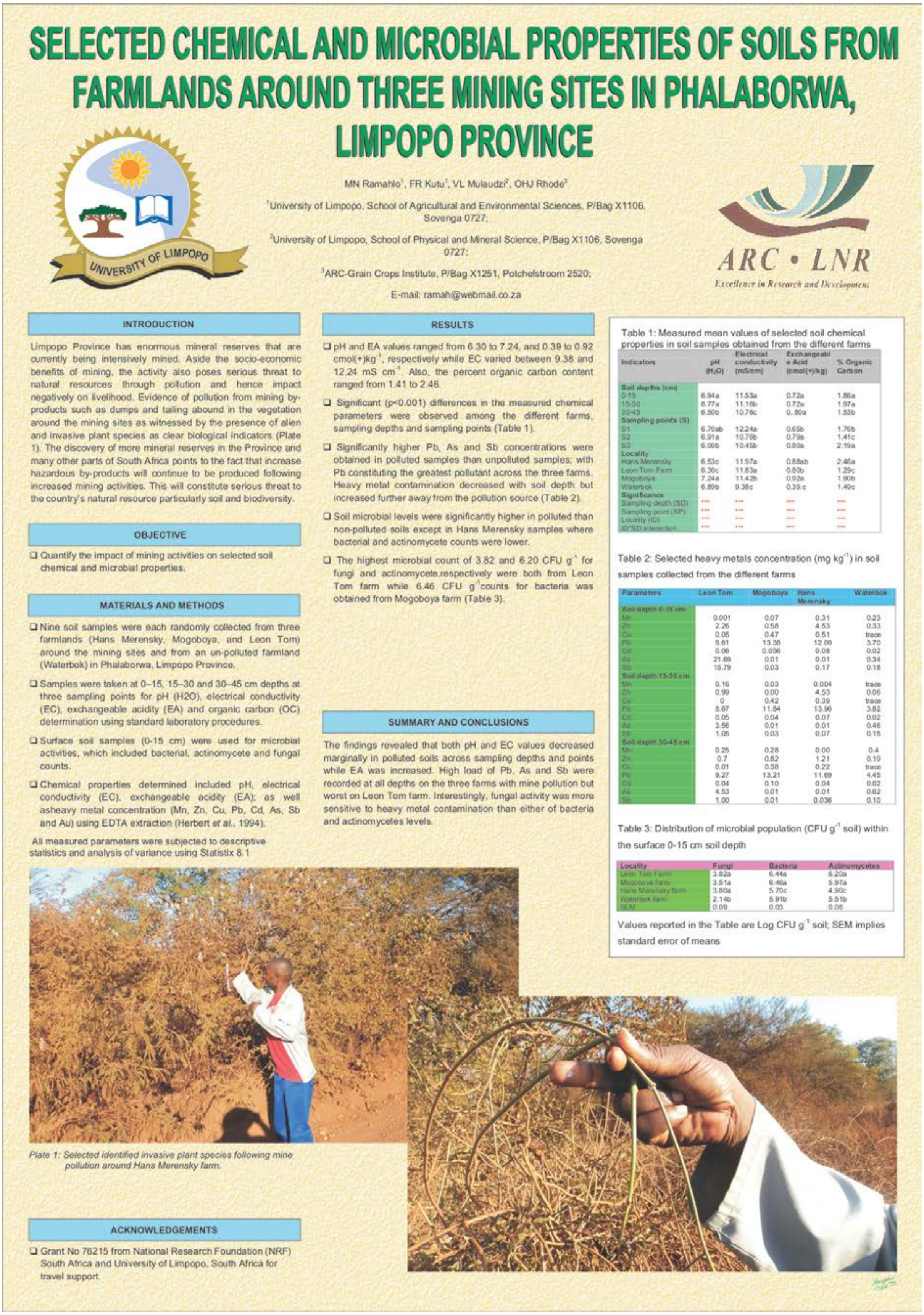
VAN DER SPUY, R. C. M., 1982. The heavy-minerals plant at Phalaborwa Mining Company - a Low-grade, high-tonnage gravity concentration. Journal of the Southern African Institute of Mining and Metallurgy, 26 (3): 3–11.

WILD, A., 1995. Soil and the environment: An introduction .Cambridge University Press, Great Britain, pp 287.

YANG, L.S & WANG, W.Y., 1998. Spatial distribution and ecological significance of heavy metals in soils from Chatian mercury mining deposit, western Hunan Province. Journal of Environmental Quality, 15 (11): 1069–1073.

YIN, Y. H.E., ALLEN, Y., HUANG, C. P. & SANDERS, P. F., 1996. Adsorption of mercury (II) by soil: effects of pH, chloride, and organic matter. Journal of Environmental Quality, 25 (4): 837–844.

Appendix 1: Poster of paper presented from the study during the Durban 21-25 January 2013 Combined Congress



SELECTED CHEMICAL AND MICROBIAL PROPERTIES OF SOILS FROM FARMLANDS AROUND THREE MINING SITES IN PHALABORWA, LIMPOPO PROVINCE

MN Ramahlo[1], FR Kutu[1], VL Mulaudzi[2], OHJ Rhode[3]

[1]University of Limpopo, School of Agricultural and Environmental Sciences, P/Bag X1106, Sovenga 0727;

[2]University of Limpopo, School of Physical and Mineral Science, P/Bag X1106, Sovenga 0727;

[3]ARC-Grain Crops Institute, P/Bag X1251, Potchefstroom 2520;

E-mail: ramah@webmail.co.za

INTRODUCTION

Limpopo Province has enormous mineral reserves that are currently being intensively mined. Aside the socio-economic benefits of mining, the activity also poses serious threat to natural resources through pollution and hence impact negatively on livelihood. Evidence of pollution from mining by-products such as dumps and tailing abound in the vegetation around the mining sites as witnessed by the presence of alien and invasive plant species as clear biological indicators (Plate 1). The discovery of more mineral reserves in the Province and many other parts of South Africa points to the fact that increase hazardous by-products will continue to be produced following increased mining activities. This will constitute serious threat to the country's natural resource particularly soil and biodiversity.

OBJECTIVE

☐ Quantify the impact of mining activities on selected soil chemical and microbial properties.

MATERIALS AND METHODS

☐ Nine soil samples were each randomly collected from three farmlands (Hans Merensky, Mogoboya, and Leon Tom) around the mining sites and from an un-polluted farmland (Waterbok) in Phalaborwa, Limpopo Province.

☐ Samples were taken at 0–15, 15–30 and 30–45 cm depths at three sampling points for pH (H2O), electrical conductivity (EC), exchangeable acidity (EA) and organic carbon (OC) determination using standard laboratory procedures.

☐ Surface soil samples (0-15 cm) were used for microbial activities, which included bacterial, actinomycete and fungal counts.

☐ Chemical properties determined included pH, electrical conductivity (EC), exchangeable acidity (EA); as well asheavy metal concentration (Mn, Zn, Cu, Pb, Cd, As, Sb and Au) using EDTA extraction (Herbert *et al.*, 1994).

All measured parameters were subjected to descriptive statistics and analysis of variance using Statistix 8.1

Plate 1: Selected identified invasive plant species following mine pollution around Hans Merensky farm.

RESULTS

☐ pH and EA values ranged from 6.30 to 7.24, and 0.39 to 0.92 cmol(+)kg^{-1}, respectively while EC varied between 9.38 and 12.24 mS cm^{-1}. Also, the percent organic carbon content ranged from 1.41 to 2.46.

☐ Significant ($p<0.001$) differences in the measured chemical parameters were observed among the different farms, sampling depths and sampling points (Table 1).

☐ Significantly higher Pb, As and Sb concentrations were obtained in polluted samples than unpolluted samples; with Pb constituting the greatest pollutant across the three farms. Heavy metal contamination decreased with soil depth but increased further away from the pollution source (Table 2).

☐ Soil microbial levels were significantly higher in polluted than non-polluted soils except in Hans Merensky samples where bacterial and actinomycete counts were lower.

☐ The highest microbial count of 3.82 and 6.20 CFU g^{-1} for fungi and actinomycete,respectively were both from Leon Tom farm while 6.46 CFU g^{-1}counts for bacteria was obtained from Mogoboya farm (Table 3).

SUMMARY AND CONCLUSIONS

The findings revealed that both pH and EC values decreased marginally in polluted soils across sampling depths and points while EA was increased. High load of Pb, As and Sb were recorded at all depths on the three farms with mine pollution but worst on Leon Tom farm. Interestingly, fungal activity was more sensitive to heavy metal contamination than either of bacteria and actinomycetes levels.

Table 1: Measured mean values of selected soil chemical properties in soil samples obtained from the different farms

Indicators	pH (H_2O)	Electrical conductivity (mS/cm)	Exchangeable Acid (cmol(+)/kg)	% Organic Carbon
Soil depths (cm)				
0-15	6.94a	11.53a	0.72a	1.86a
15-30	6.77a	11.16b	0.72a	1.97a
30-45	6.50b	10.76c	0..80a	1.53b
Sampling points (S)				
S1	6.70ab	12.24a	0.65b	1.76b
S2	6.91a	10.76b	0.79a	1.41c
S3	6.00b	10.45b	0.80a	2.19a
Locality				
Hans Merensky	6.53c	11.97a	0.88ab	2.46a
Leon Tom Farm	6.30c	11.83a	0.80b	1.29c
Mogoboya	7.24a	11.42b	0.92a	1.90b
Waterbok	6.89b	9.38c	0.39.c	1.49c
Significance				
Sampling depth (SD)	***	***	***	***
Sampling point (SP)	***	***	***	***
Locality (ID)	***	***	***	***
ID*SD interaction	***	***	***	***

Table 2: Selected heavy metals concentration (mg kg^{-1}) in soil samples collected from the different farms

Parameters	Leon Tom	Mogoboya	Hans Merensky	Waterbok
Soil depth 0-15 cm				
Mn	0.001	0.07	0.31	0.23
Zn	2.26	0.58	4.53	0.33
Cu	0.05	0.47	0.51	trace
Pb	9.61	13.38	12.09	3.70
Cd	0.06	0.056	0.08	0.02
As	21.69	0.01	0.01	0.34
Sb	15.79	0.03	0.17	0.18
Soil depth 15-30 cm				
Mn	0.16	0.03	0.004	trace
Zn	0.99	0.00	4.53	0.06
Cu	0	0.42	0.39	trace
Pb	8.67	11.84	13.96	3.82
Cd	0.05	0.04	0.07	0.02
As	3.56	0.01	0.01	0.46
Sb	1.05	0.03	0.07	0.15
Soil depth 30-45 cm				
Mn	0.25	0.28	0.00	0.4
Zn	0.7	0.82	1.21	0.19
Cu	0.01	0.38	0.22	trace
Pb	9.27	13.21	11.69	4.45
Cd	0.04	0.10	0.04	0.02
As	4.53	0.01	0.01	0.62
Sb	1.00	0.01	0.036	0.10

Table 3: Distribution of microbial population (CFU g^{-1} soil) within the surface 0-15 cm soil depth

Locality	Fungi	Bacteria	Actinomycetes
Leon Tom Farm	3.82a	6.44a	6.20a
Mogoboya farm	3.51a	6.46a	5.97a
Hans Merensky farm	3.80a	5.70c	4.90c
Waterbok farm	2.14b	5.91b	5.51b
SEM	0.09	0.03	0.08

Values reported in the Table are Log CFU g^{-1} soil; SEM implies standard error of means

ACKNOWLEDGEMENTS

☐ Grant No 76215 from National Research Foundation (NRF) South Africa and University of Limpopo, South Africa for travel support.