EFFECT OF DEDZA POTTERY MINING ACTIVITIES ON VEGETATION DIVERSITY AND SELECTED PHYSICOCHEMICAL CHARACTERISTICS IN DEDZA AND NTCHEU, MALAWI

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DECLARATION BY THE CANDIDATE

I declare that this work is a result of my own effort and that wherever other people's work has been cited, due reference has been made. I further declare that this work has not been presented for any award at this university or any other university.

Signed:…… Date: ……

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CERTIFICATE OF APPROVAL

This thesis is a result of the candidate's own work and has been submitted with our approval**.**

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DEDICATION

This thesis is dedicated to my wife Annie, and our children Mapopa, Yamikani and Lindiwe. In a special way, I also dedicate this thesis to my parents, Mr. Dominic Mapopa Ndengu and Mrs. Rosa Ndengu, and most importantly to my late great grandmother Magdalena Nkhoma for the big role she played in my life to make me what I am today.

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ABSTRACT

This study was concerned with the *insitu* effects of the Dedza Pottery's mining activities on vegetation diversity, and some selected physicochemical parameters. It was undertaken in six mining sites, five in Dedza and one in Ntcheu districts in Malawi.

Each mining site was stratified into mined section (experiment) and unmined section (control). The study of vegetation diversity involved the identification and counting of species using the quadrat method. Soil study involved the random collection of soil samples from each section, and analysed for physical characteristics (pH, organic matter, moisture content and texture), and chemical characteristics (Ca, Cd, Cu, Mn, N, P, and Pb). The effect of mining on water quality was determined by collecting water samples at two occasions, before mining season (control) and during mining season (experiment). Water samples were analysed for physical parameters (Total suspended solids (TSS), pH, conductivity and turbidity), and chemical parameters (Cd, Cu, Mn and Pb). The rock samples were analysed for content of Cd, Cu, Mn, and Pb by complete decomposition using acids, while silica by molybdenum-blue calorimetric method.

Data analysis involved the use of ANOVA and t-Test to compare characteristics in the mined and unmined sections. Species richness (SR) and species diversity index (SDI) were processed using Ecosim 7.0 ecological software. Relationships between parameters were carried out using Pearson correlation coefficient "r" aided by literature.

Mining activities caused a reduction in vegetation species diversity as evidenced by a decrease in vegetation SR in the mined sections ($p< 0.1$). In the study sites of Mzengeleza, Kuthindi and Mmbale, mining affected the land through the creation of pits and pools, while at Kuthindi and Mzengeleza it encouraged soil erosion. Induction of bank failures was encountered at Kuthindi.

The average texture of soils, changed from sandy clay loam (SCL) to clay (C), caused by the dumping of clay subsoils, while soil organic matter (OM) significantly decreased from $7.4 \pm 2\%$ to $2.94 \pm 3\%$ ($p<0.05$). Available nitrogen in the soil declined significantly ($p<0.05$), from 0.0091 ± 0.005 mg/g in unmined sections to 0.0019 ± 0.005 mg/g in the mined sections. The drop was attributed to the low OM content in mined sections, since OM and N correlated ($r = 0.68$; $p<0.005$). Soil moisture content increased from $2.5 \pm 2\%$ to $7.5 \pm 3\%$ ($p <0.05$),

due to an increase in clay content in mined sections. The heavy metals (Cd, Cu, Mn and Pb) were generally higher in the topsoils of the unmined sections, as opposed to the mined, but lower than the critical content to cause danger. Low values in mined section could have resulted from the leaching of the metals due to low OM, on which they could have adsorbed or formed complexes and be retained. Cd correlated significantly with OM ($r = 0.54$; $p < 0.05$), showing possible formation of complexes with OM.

Quartz and kyanite (raw materials) showed significantly high Cd values of 4.3 ± 1 μg/g and 5.3 ± 1 μg/g respectively. The values are above the critical limit (3 μg/g), raising concerns of danger in the environment. Mining also affected the physical characteristics of water (pH, TSS, and turbidity), as well as the chemical characteristics (Cu, Mn, and Pb). The heavy metals, Cu, Mn and Pb had concentrations of 0.04mg/L, 0.23 mg/L, and 0.13 mg/L respectively, which were within safe limits of the standards.

This study therefore, showed that mining significantly affected the following aspects of the environment: species richness, land, and soil properties. There is a possibility of environmental contamination by cadmium through rock mining, when exposed to acidic environments in Dedza. At Kuthindi, mining affected the water quality through increases in the TSS and turbidity, but also caused a decrease in pH, threatening the aquatic life.

Regular environmental monitoring visits to the sites by the EAD at district level, land remediation in the mined areas by the pottery, and production of a clear environmental management system, specifying roles of personnel, staff trainings, schedules, and reporting methods, are recommended, to effectively reduce the effects.

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ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
ANOVA	Analysis of Variance
APHA	American Public Health Association
AOAC	Association of Official Analytical Chemists
EAD	Environmental Affairs Department
EDTA	Ethylenediamine tetra acetic acid
EIA	Environmental Impact Assessment
EMA	Environment Management Act
FGD	Focus Group Discussion
FRIM	Forestry Research Institute of Malawi
GoM	Government of Malawi
MBS	Malawi Bureau of Standards
NSO	National Statistical Office
NTU	Nephrometric Turbidity Units
OM	Organic Matter
SDI	Shannon Diversity Index
SOM	Soil Organic Matter
SPSS	Statistical Package for Social Scientists
SR	Species Richness
TSS	Total Suspended Solids
UNECECLRTAP	United Nations Economic Commission for Europe Convention on Long Range Transboundary Pollution
UNEP	United Nation Environmental Programme
UNRFNRE	United Nations Revolving Fund for Natural Resources Exploration

UNSDEM	United Nations Sustainable Development and Environmental Management
USAID	United States Agency for International Development
USDA	United States Department Agricultural
Uv/Vis	Ultra violet/ Visible Spectrophotometer
WHO	World Health Organisation
DW	Department of Water

CHEMICAL SYMBOLS OF SOME ELEMENTS

Al	Aluminium
Ca	Calcium
Cd	Cadmium
Cr	Chromium
Cu	Copper
Fe	Iron
Hg	Mercury
K	Potassium
Mg	Magnesium
N	Nitrogen
Ni	Nickel
P	Phosphorus
Pb	Lead

DEFINITION OF TERMS

Benthic microvertebrates	Microinvertebrates living near stream, river, lake, or ocean beds.
Discharge point	A point on the stream, closer to the mining site, where the muddy water from the mining activity was discharged into the stream water.
Ecological niche	Relational position (role) of a species in an ecosystem.
Edaphic	Relating to soil.
Filler	A substance added to other substances (clay, paper, rubber etc) to modify their properties and improve quality.
Firing	Subjecting a ceramic object to high temperatures as a way of strengthening it.
Flux	A substance that lowers the melting point of ceramic objects (or any object) during firing.
Genera	Plural for genus (a family of closely related species)
Isoclinical folding	Earth's folding caused by equal magnetic inclination, due to the earth's magnetic field, from the earth's core.
Metamerization	Segment formation.
Minedsoils	Topsoil samples from the mined section of the sites.
Mullite	An aluminosilicate material formed by high temperature interaction of silica and alumina bearing minerals.
Pyroplastic deformation	Distortion of shape under high temperature, due to lack of rigidity properties.
Refractory	Ability of substance to withstand very high temperatures.
Sample type	Short form for topsoil samples from the unmined sections, subsoils from the unmined sections, and topsoils from mined sections.
Subsoils	Subsoils from the unmined section of the site.
Undercutting	A cut made in the underpart to remove material.
Unminedsoils	Topsoil samples form unmined section of the sites.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Dedza Pottery is located in Dedza district, Malawi (Figure 1.1). It operates under Paragon Ceramics, which includes Nkhotakota Pottery (Paragon Ceramics, 2006). The Pottery is renowned for the production of high quality hand-crafted pottery products, such as pots, tableware, statues, tiles, refractory bricks, and electrical insulators, which are sold locally and also exported (Paragon Ceramics, 2006). Major pottery raw materials include quartz, kaolinitic clay, feldspar, kyanite and other clayey materials, which are all mined locally (Raw Material Employee, *Pers. Comm*., Sept 2006).

Mining activities tend to have associated negative effects on the environment, such as causing negative changes in the bio-ecology, culture, physicochemical characteristics of land, water and air of the area in which it is taking place (UNEP, 1994). Realising problems associated with mining, this study was carried out to determine the effects of mining activities by the Dedza Pottery on the environment.

The term "environment" is defined differently, depending on the circumstances and discipline, but the central concept in all, is that of a surrounding. The Environmental Management Act (EMA), categorises the environment into three main groups: physical (land, water, atmosphere, climate, sound, odour, and taste), biological (fauna and flora), and the non-physical factors (cultural, social, and economic aspects) (GoM, 1996).

Due to the wide scope of the environment, limited time and resources available, this study concentrated mainly on the physicochemical (selected physicochemical characteristics of land and water) and biological aspects (vegetation diversity) in the mining sites of Dedza Pottery.

1.2 Mining and the Environment

1.2.1 Mining Methods and their Effects on the Environment

Mining is defined as 'the extraction of minerals from the earth' *(*UNEP, 2000). Several mining types are used to extract minerals from the earth crust. These include surface, subsurface and solution mining (Selinus *et al*., 2005).

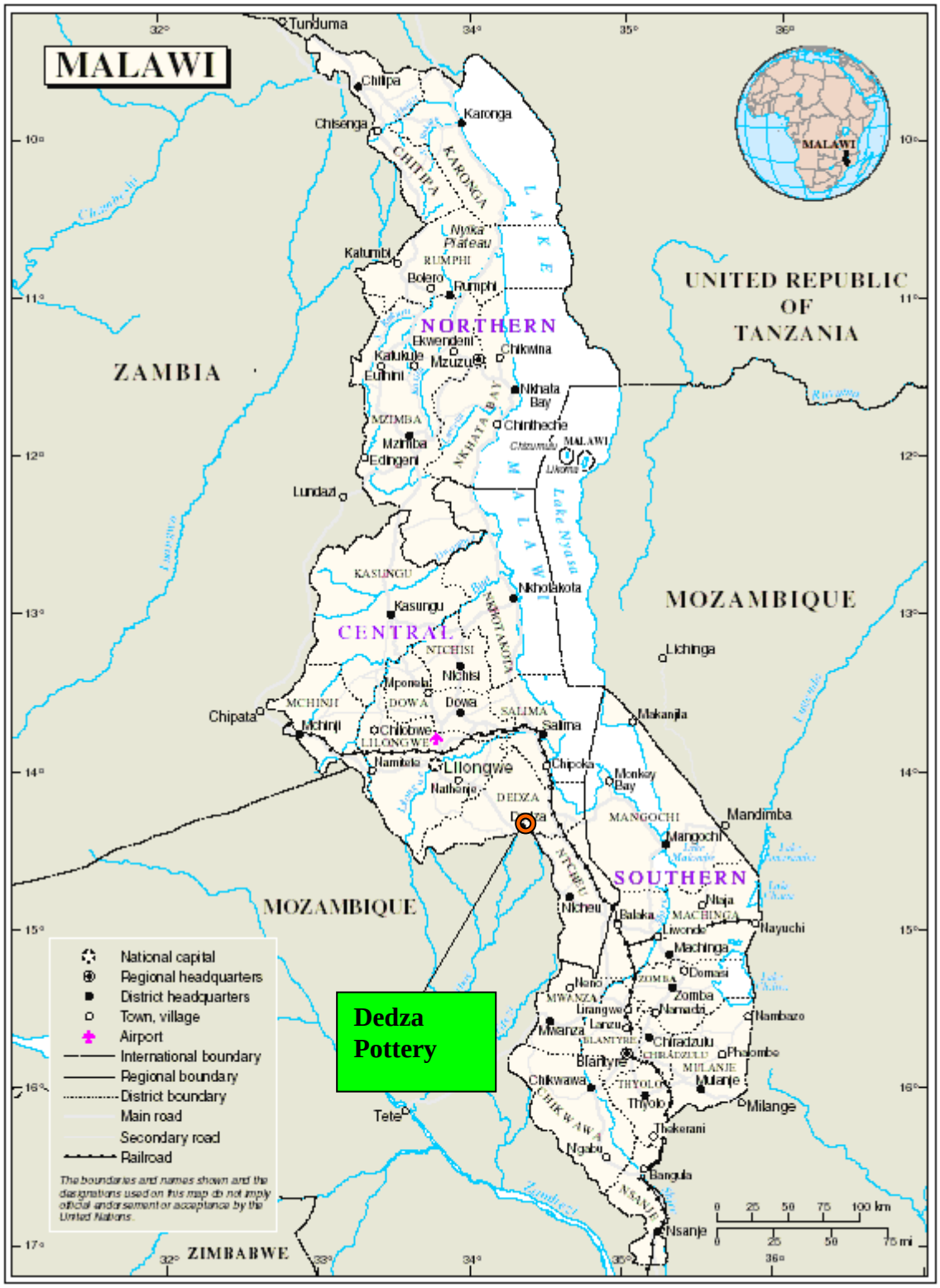

Figure 1.1 Location of Dedza Pottery

Surface mining is a type of mining method used in extracting minerals whose deposits exist on the surfaces of the earth, or closer to it (Miller, 1993; UNEP, 2000).

It is the most commonly used type; over 60 % of minerals are extracted through it (Microsoft Encarta, 2006). This type of mining includes open pit, dredging, placer, area strip and contour mining (Miller, 1993).

Open pit mining involves the removal of overlying layers (called overburden), exposing the underlying target mineral deposit, resulting in the formation of pits and craters in the area of mining (Miller, 1993; Selinus *et al*., 2005). Diamond in South Africa and Nchanga copper mines in Zambia employ this method, and large pits have resulted (UNEP, 1994).

Examples using the method in Malawi include Mchenga Coal Mine and Shayona Cement Company (Dreschler, 2002; Chiona *et al*., 2002). Dedza Pottery uses it as well in the mining of its raw materials. The method is a potential threat to the environment, through underground water pollution, arising from acid drainage and leaking of toxic substances from the piled overburden or waste (Selinus *et al*., 2005). It also causes extensive destruction to vegetation and ecology of the area (Sarma, 2005).

Dredging is especially employed in the mining of sand and gravel in streams or ocean beds, where draglines and buckets are used (Miller, 1993). Dredging pollutes water, as well as reduces the abundance and diversity of benthic microinvertebrates (Prussian *et al.*, 1999), through the destruction of river, stream or ocean beds, which form their habitats (Prussian *et al.*, 1999; Boyd *et al*., 2003; Weeks *et al*., 2003).

Area strip mining demands the removal of the overburden forming terraces. This method favours both flat and rolling terrains. While on the other hand, terrains that are hilly or mountainous require the use of contour strip mining, where terraces are made cutting into the mountain or hill, the resulting overburden is dumped into the lower terrace (Miller, 1993). These methods have negative effects on ground water through pollution by acid drainage and leaking of toxic chemicals, causing deforestation and ecological disturbances, as a vast amount of land is cleared, but also changing the topology of the land due to disturbances on the ground surface (Klemove, 2000).

Placer mining is mainly used for mining precious metals such as gold, silver, tin, platinum etc (UNEP, 2000; Microsoft Encarta, 2006). The method takes advantage of density

differences between the unwanted materials and the mineral. Water is mixed with the sand, sediments or soils containing the mineral and shaken, the high density precious mineral quickly sinks to the bottom allowing the less dense unwanted substances to be separated and discarded, an example here is gold panning (UNEP, 2000). Just like dredging this method affects the water quality by increasing turbidity and reducing the abundance and diversity of aquatic biota (USGS, 1997).

Contrary to surface mining methods described in the above paragraphs, the digging of vertical shafts into the ground, reaching the mineral deposit layers, constitutes subsurface mining (Miller, 1993; UNEP, 2000). It is usually done for high-grade deposits, or if the removal of the overburden is impractical due to depth and uneconomic value of the mineral deposit (Miller, 1993; UNEP, 2000). The mined mineral is conveyed to the surface. It is one of the main methods used at Mchenga coalmines apart from the open cast discussed above (Chiona *et al*., 2002). Main environmental threats of this kind of mining are land subsidence, and ground water contamination, through leaking of toxic metals and acid drainage (Blodgett and Kuipers, 2002).

Solution mining entails the pumping of hot water into the ground through an injection well to the deposits, dissolving the mineral, and the resulting mineral solution is pumped back to the surface (Miller, 1993; Microsoft Encarta, 2006). This method works well for salt minerals (Miller, 1993). An extensive literature search, by the current researcher, has indicated that the method is less common. However, good examples of this mining method are the salt mines in Italy (Microsoft Encarta, 2006). The method has significant effects on ground water pollution, if not well designed (Selinus *et al*., 2005).

The selection of the mining method depends on the shape, location, depth, characteristics, size of mineral deposits in the ground, surrounding host rocks, economic profitability, and environmental risks (UNEP, 1991; UNEP and WHO, 1998; UNEP, 2000; Miller, 1993). Different mining types affect the environment differently (Scribd, 2007; UNEP, 1991), strict adherence to the required method is very important, to protect people and the environment. Such protection could be provided by global and country specific legislation and laws (UNEP, 1994).

1.2.2 Mining and Environmental Management: Global and Malawian Perspective

For over a long time natural resources were exploited with very little interest on the environment (Sarma, 2005; UNEP, 1994), until some time people realized some environmental effects of human activities. This was the period between 1970 and 1980; the decade is associated with the introduction of legislations regulating activities affecting the environment (Miller, 1993). Mining was not an exception in this, and legislations started coming afterwards.

Some of the legislations regulating the world mining industry include the Berlin Guidelines on mining, Mining and Environmental Protection Legislation, calling for countries with mining sectors to incorporate environmental protection requirements within their mining laws (UNEP, 1994). Different United Nations Specialist Agencies have also come up with legislations and guidelines on mining; these include UNEP, WHO, UNSDEM, UNRFNRE and the World Bank (UNEP, 1994). The central theme in all is the management of the environment, prior to the mining, during mining and even after closure of the mine, to protect people and the environment (UNEP, 1994).

Malawi as a sovereign state has its own legislation on mining and environmental protection, but she is without a mining policy (a new policy on mining was being formulated, during the writing of this thesis). Realising this limitation, all mining activities are legally based on the Minerals Act of 1982, Environmental Management Act (EMA) of 1996, Invironmental Impact Assessment (EIA) Guidelines, Natural Resources Management Policies, Laws and institutional Framework in Malawi of 2002, and other relevant documents dealing with the environment (GoM, 1982; GoM, 1996; GoM, 1997a; GoM, 2002a).

The Department of Mining and the Geological Survey are jointly responsible for the legal issues pertaining to mining and the environment, working in liaison with the Environmental Affairs Department (EAD) (Dreschler, 2002). The Geological Survey Department is responsible for mineral explorations, while the Department of Mines is responsible for processing mining licenses, providing guidance in the use of appropriate mining technologies, and undertaking periodical inspections to ensure use of proper mining technologies (GoM, 1982; Dreschler, 2002).

Procedures for obtaining Mineral rights and licences are defined by Minerals Act of 1982, and these include reconnaissance licence, prospecting licence and mining licence (GoM, 1982). It also describes expectations of the proper practices to protect the environment before, during and after the operation stage of the mining (GoM, 1982). On the other hand, the EAD carries the responsibility of evaluating EIAs specific to the mining sector, a prerequisite to the granting of the mining license (GoM, 1996).

Issues of safety and occupational health affecting the mining workers are handled by the Ministry of Labour (GoM, 1997b; Dreschler, 2002). Concerned Industries are required by law to ensure the safety and health of the workers in their work places by providing necessary information, protective gear, and carrying full medical responsibility of workers injured at work (GoM, 1997b). All these legal efforts are complimented by the country's constitution.

The constitution of Malawi chapter three, section 13(d) (GoM, 1999a), stresses the need of being responsible to protect the environment, people and the natural resources (mineral resources inclusive). The constitution reads as follows:

The state shall actively promote the welfare and development of the people of Malawi by progressively adopting and implementing policies and legislation aimed at achieving the following goals:

(d) The Environment

To manage the environment responsibly in order to-

I. *Prevent the degradation of the environment;*
II. *provide a healthy living and working environment for the people of Malawi;*
III. *accord full recognition to the rights of future generations by means of environmental protection and the sustainable development of natural resources; and*
IV. *conserve and enhance the biological diversity of Malawi*.

1.2.3 Mineral Resources in Malawi and the mining activities at Dedza Pottery

Different types of mineral resources exist in Malawi, these include limestone, aquamarine, bauxite, corundum, granite, graphite, kyanite, pyrite, rare-earths, tourmaline, uranium, vermiculite, dolomite, gypsum, columbium (niobium), monazite, silica sand, titanium, terrazzo, zirconium, glass sands (or quartz), kaolinitic clays, feldspar, graphite, gemstones, feldspar, talc, phosphate rock, coal and brick clays (GoM/ USAID, 1990; Malunga, 2002; GoM, 2006). The following are important in ceramics: feldspar, silica sand (or quartz), zirconium, kaolinitic clays, brick clays, kyanite and talc (Lifond, 1983). See Table 1.1

Table 1.1: Information on mineral deposits in Malawi

Mineral	Deposit	Reserve Tonnage(Mt)	Grade	Mineral Content (Mt)
(Bauxite	Mulanje Mountain	25	43.3% Al_2O_3	11 Al_2O_3
Coal	Ngana	15	30%ash,2.2%S & 4708K Cal/Kg	NA
	Mwabvi	5	40%ash,0.76%S&4173 Kcal/Kg	NA
	Livingstone (Mchenga)	1.4	17%ash,0.5%S& 6800 Kcal/Kg	NA
Columbium (niobium)	Tundulu	0.9	0.37% Nb_2O_5	0.003300 Nb_2O_5
	Chilwa Island	0.38	0.95% Nb_2O_5	0.0036 Nb_2O_5
	Ilomba Hill	0.1	3% Nb_2O_5	0.0036 Nb_2O_5
Kaolin	Linthipe	14	33.8% Al_2O_3	- -
Limestone	Malawa Hill	4.1	52% CaO	--
Marble	Malawa Hill	3.7	36.21% CaO	--
Phosphate rock	Tundulu	2	12% P_2O_5	0.24
Pyrite	Chisepo	34	8% S	2.7
Strontium and Rare earths	Kangankunde	11	8% Sr,2% REE	0.88 Sr, 0.22 REE
Titanium	Makanjira	1,000	5.2% imenite	52 imenite
	Lake Chilwa	1,000	7.05% imenite 0.11% rutile 1.16 % Zircon	71 imenite 1.1 rutile 12 Zircon
	Salima	500	8.4% imenite 0.38% rutile 0.28% Zircon	42 imenite 1.9 rutile 1.4 Zircon
	Tengani	108	11% imenite 2% rutile 1% zircon	12 imenite 2.2 rutile 1.1 zircon
Uranium	Kayelekera	7.7	0.23% U_3O_8	0.0177 U_3O_8
Vermiculite	Mwanza District	2.2	10%vermicuite	0.22

Source: US Geological Survey Mineral Year Book (2004) and Ministry of Natural Resources & Environmental Affairs, Department of Geological Surveys (2006)

(NA = Not Available; REE = Rare earth Elements)

Despite the wide availability of mineral resources, the mining sector has not been fully exploited, largely due to lack of the mining culture amongst Malawians (ASEGIMECPD, 2003). The main minerals in the Malawian mining industry are coal, cement limestone, slaked lime, terrazzo, clay pottery, gemstones and ornamental stones (Malunga, 2002; GoM, 2006). The mining is mainly done at small-scale artisan level (Dreschler, 2002). This is the kind of mining that involves individuals, groups, families, close relatives, cooperatives, working in their own land, public land, state owned land, with minimal mechanisation and without license or formal permission (Chakravorty, 2002; Henstchel *et al*., 2003). It involves the mining of mineral deposits, which are close to the earth's surface, or those found in unconsolidated rocks (Chakravorty, 2002).

In Malawi few mines use machinery e.g. Mchenga coal mine (Chiona *et al.*, 2002). The small-scale mining involves the use of simple tools like picks, hoes, hammers, and shovels (Dreschler, 2002). Small - scale mining is an important source of employment to the people (Henstchel *et al*., 2003; Hilson, 2002). There are 40,000 small scale and 3,700 formal miners involved in mining in Malawi alone (Dreschler, 2002). However, the proportion of women involved is still very small (0.75 %), and these are in Mzimba, Ntcheu and Rumphi, where they mine mainly clay, coal, gemstones, limestone, ornamental and dimensional stones, salt, sand, and gold (Dreschler, 2002).

The small-scale mining also contributes positively to the Malawian economy (1.6% of the GDP) (Dreschler, 2002). It is being projected that once the Kayerekera uranium mine is operational, it would provide Malawi with US$ 100Million annually; which is about 5% GDP and 20% annual total earnings, and would be the first large scale mining project in Malawi (Paladin (Africa) Ltd, 2006).

Realising the importance and benefits of the small-scale mining, the government encouraged miners to form associations to facilitate their work by exchanging ideas and knowledge (Dreschler, 2002). Examples of such associations include Gemstone Association of Malawi, Malawi Association of Women Miners, Lirangwi Limemakers Association, and Balaka Limemakers Association (Dreschler, 2002). There are different small-scale mining industries existing in Malawi, but an upbeat example is Dedza Pottery. At this pottery, mining is predominantly artisan, and open pit (Raw Material Employee, *pers. Comm.*,Sept 2006).

Dedza pottery has five major mining sites, in four different places, these are: Kasina (Mtanthila), Kuthindi, Mchekecha, Mmbale, and Mzengeleza (for Clay J and R) (Stevens, *Pers. Comm.*, Sept 2006). Main activities in the sites include the mining of the clay, mining and breaking of rocks, as well as selection of the required grade/quality (Raw Material Employee, *pers. Comm.,* Sept 2006). Those of the right quality are taken to the pottery for processing and used in pottery making, resulting in waste inform of overburden, leftovers, and low quality grades of the raw material. Information on the raw materials mined in the sites is provided in Table 1.2 the next page.

The workforce comprises customary landowners or their relatives, possibly to ease access to the required mineral deposit. All these people have no background in occupational health, environmental protection and management, they work with no protective gear, this is very dangerous to the workers and the environment. Picks, hoes, hummers and shovels are used (Raw Material Employee, *pers. Comm., Sept 2006*).

Due to artisan small-scale and open cast nature, this mining has resulted in different environmental problems, notably creation of pits and pools, mainly in clay mining sites, effects on vegetation, as well as some other physical and physicochemical effects on water and land, as found in this research. Mining activities are known to expose some geochemical substances to oxidation and precipitation, which could be dangerous to the environment (Selinus *et al.*, 2005).

Existing knowledge states that the nature and magnitude of effects depends mainly on the type of mining methods adopted (UNEP, 1991; UNEP and WHO, 1998; Sarma, 2005). Surface mining methods have the most effects the environment (Koranteng, 2005). Important sections of the environment affected include the landscape, water quality, air quality, and the biodiversity (flora and fauna) (Sarma, 2005; Balkau, 1993).

The knowledge of characteristics (biological, chemical, physical and social) defining an area is very important in managing an environment (Padmalal *et al*., 2004). This prompts the need for a research into such characteristics in an area (Padmalal *et al*., 2004). This could be done prior to the project (EIA), to predict the effects, or during the operation stage (Environmental Audits), to determine the effects of the project on the environment, as well, investigate the compliance of the industries to the environmental laws and legislation (GoM, 1996, 1997a).

Table 1.2: Sources of raw materials for Dedza Pottery

Raw Material	Source of Raw Material	Function of Raw Material	Quantities Mined (Tonnes/Yr)
Kyanite	Kaphirimdimba (TA Mpando, Ntcheu)	Refractory Bricks, insulation bricks and all other pots except lead pots	40
Clay J (grey clay)	Mzengeleza (TA Kaphuka, Dedza)	Unglazed tiles, lead clay pots	250
Clay 3	Mmbale (Linthipe 1, TA Kaphuka, Dedza)	All ceramic products	200
Feldspar	Kasina (TA Kaphuka, Dedza)	All pots except lead pots	40
Quartz	Kasina (TA Kaphuka, Dedza)	All pots, added to glazes	40
Clay H	Kuthindi (Bembeke, SC Kamenyagwaza, Dedza)	Wall tiles, added to clay 3 for pots	60
Clay R33 (Red Soils)	Mzengeleza (Dedza)	Floor tiles only	12

TA= Traditional Authority, SC = Senior Chief

1.3 Problem Statement and Justification for the study

Since its establishment in 1987, Dedza Pottery has been mining its raw materials from its five mining sites using open cast method as described in section 1.2.3. However, neither an EIA nor environmental audit has been undertaken in the sites (C. Stevens, *Pers. Comm.*, 2006). This has resulted in the lack of knowledge on the effects of mining on the environment in the mining sites, raising several unanswered questions; is the environment changing, if it does how and why, who and what is threatened? These uncertainities are worsened by the fact that the mining is artisan smallscale, done by people with little or no background of occupational health and safety, and environmental protection measures.

Therefore, this study is very important, as it constitutes the first of its kind in this direction. The results of this work will:

- Assist the pottery in developing effective environmental management plans for better environment;
- inform the Mining department and EAD the state of the environment in the mining sites; and
- provide baseline data on which future scientific researches will be based.

1.4 Objectives of the Study

The general objective of the study was to investigate the effects of mining by the Dedza Pottery on the environment in the mining sites. The specific objectives of the study were three fold:

i. to determine the influence of mining on vegetation species diversity in the mining sites;
ii. to determine the effects of mining on land and some selected physicochemical parameters of soil; and
iii. to determine the effect of mining on selected physiochemical characteristics of water.

1.5 Organisation of the Thesis

In chapter two, a comprehensive review of the literature on environmental effects of mining is provided. Methods used in collecting and analysing data, as well as materials used, are described in chapter three. Results and discussion, conclusion and recommendations for further study, are presented in the fourth and fifth chapters respectively.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a discussion on the ceramics industry, the raw materials used, and their occurrence in Malawi. It goes further describing, explaining, and discussing the effects of mining on the environment.

2.2 The Ceramics Industry

The term ceramics has an origin from the Greek word *Keramos,* which could be translated into English as "*making pottery*" (Microsoft Encarta, 2006). However, presently, it describes the "*science of manufacturing articles prepared from pliable, earthly materials that are made rigid by high temperature treatment"* (Microsoft Encarta, 2006).

Ceramic products are non-metallic, inorganic compounds, oxides of elements; but could also contain carbides, nitrides, borides and Silicides (Microsoft Encarta, 2006). A sintering process strengthens the inorganic substances to produce the final product (Rentz *et al*., 2001).

2.2.1 The Evolution of the Ceramic and Pottery Art

The ceramic art has a long history; it started from simple forms of using clay to more advanced methods of the modern times (Rentz *et al*., 2001). It is evident that by 19,000 BC man had already started processing clay, however real pottery products started in Southern Japan between 8,000 and 9,000 BC (Rentz *et al*., 2001). The processing of clay into fired bricks, was initiated by the Romans as early as 4,000 BC. These bricks were used in the construction of palaces, temple towers etc (Rentz *et al*., 2001). More special forms of ceramics got developed as time went by.

In 2,600 BC the Egyptians developed the art of making glazed ceramic plates (a form of tiles), which were used in decorating pyramids (Rentz *et al*., 2001). Later on, the Chinese invented porcelain making around 2,000 BC (Rentz *et al*., 2001). The development still continues; modern ways of making and using ceramic products are invented.

In modern times, the term ceramics encompasses inorganic products made of clay, little clay, or no clay at all (Rentz *et al*., 2001). Their production involves a sintering process, which

strengthens the inorganic-non-metallic compounds in them (Rentz *et al*., 2001). Classification of the product is done according to the raw materials used and their characteristics (Rentz *et al.*, 2001).

2.2.2 Raw Materials in Ceramic Production

The production of ceramics requires the use of different raw materials mixed in different proportions depending on the product intended. The most used raw materials include the following: clay, kaolin, clayey materials, feldspar, kyanite, silica sand and quartz (Piper, 1982; Lifond, 1983).

Clay is a mineral consisting mainly of hydrated aluminium silicates that occurs naturally in the soil and sedimentary rocks (Microsoft Encarta, 2006), and belongs to a group of the hydrous aluminium phyllosilicate (Wikipedia, 2006). Clay particles are generally of the size less than 2μm in diameter (Gustafsson *et al*., 2005).

Main groups of clay include kaolinite, montmorillonite-smectite, muscovite, ellite etc (Miller and Gardiner, 1998). Within these groups thirty different types of clay occur in pure forms, or as mixtures of the named types (Wikipedia, 2006). In terms of their use in ceramics and pottery, the following are the types: china clays (Kaolin), ball clays, tile, and brick clays (Padmalal *et al.*, 2004).

Kaolin is a white, soft, plastic clay composed of the hydrated aluminium silicate mineral known as Kaolinite (BGS, 2006). Its chemical formula is $Al_2[(OH)_2|Si_2O_5]$, while its density ranges from 2.1-2.6 g/cm^3, with the grain size of 0.2-1μm, which is within the colloidal range (BGS, 2006). It is a product of the complete alteration of the anhydrous aluminium silicate found in feldspar rich rocks by means of weathering or hydrothermal processes (BGS, 2006). The transformation process to kaolin involves the combination of water with silica in feldspar releasing alumina (Piper, 1982).

Clays have different purposes in industries, such as making bricks, ceramics and cement (Microsoft Encarta, 2006; Padmalal *et al.*, 2004). Being clay, kaolin has a wide range of industrial uses too. It is used in ceramic production, where its main function is to provide the strength and plasticity properties responsible for the proper shaping of the ceramic products, as well as lowering the magnitude of pyroplastic deformation at the time of firing (Lifond,

1983). When heated to very high temperatures, of over 1000 ^{o}C, it transforms into mullite and glass (Lifond, 1983). It is therefore, also responsible for the glassy nature of the ceramic products, just as feldspar does (Lifond, 1983). Kaolin is also used for non-ceramic industrial purposes, as a filler in the making of paper, paint, rubber, plastic, adhesive, sealants, making of white cement and pharmaceuticals (BGS, 2006).

Kaolin or kaolinitic clays occur in several places in Malawi, these include, Linthipe (Dedza), Nkhate and Senzani in Ntcheu (Malunga, 2002). Details of kaolin occurrence in Malawi are given in Table 2.1. Linthipe is the largest of all (Figure 2.1).

These kaolinitic clays have high kaolin content, suitable for the production of refractory and ceramic products (Piper, 1982; Malunga, 2002). Currently, the clays of Linthipe are used by some industry in Blantyre for lining refractory furnaces (GoM, undated) and Dedza Pottery for use in the production of different ceramic products. It is estimated that about 800 tonnes of the clay are mined annually for use by industries (Yager, 2005).

Table 2.1: Occurrence of the ceramic raw materials in Malawi

Mineral	**Site**	**District**	**Estimated Abundance (Tonnes)**
Feldspar	Kafungute	Mzimba	90,000
	Mphungu	Mzimba	NA
	Dowa	Dowa	NA
	Mpita/Linthipe	Dedza	5,000
	Chilwa Islands	Zomba	32, 000
	Tundulu	Phalombe	5Million
Kaolinitic Clay	Linthipe	Dedza	15Million
	Nkhate	Ntcheu	600, 000
	Senzani	Ntcheu	500,000
Kyanite	Kaphirimdimba	Ntcheu	300,000

The kaolinitic clays of Linthipe originated from the weathering of the meta-anorthosite bedrock, which consists mainly of labradorite plagioclase feldspar (Piper, 1982). The clays shrink at firing (5-13% shrinkage) and therefore silica sand is added to reduce this to 1.8% (Malunga, 2002).

Another known clay resource is terracotta, existing in Bangwe east (Blantyre city, Southern Malawi), and covers an area of 40 km^2 (Malunga, 2002). The clay could be used for brick

making, and its source is the weathering of the perthite gneisses and perthosites (Malunga, 2002).

Figure 2.1: Kaolinitic clays mined from Linthipe (Mmbale Village)

Reports indicate that the deposit has the capacity of producing a maximum of 26, 500 million bricks (Malunga, 2002). Generally in ceramic work, clays are often mixed with feldspars, kyanite, silica sand, and quartz to get the desired properties (Lifond, 1983; Piper, 1982; Rentz *et al*., 2001).

Feldspars are a large group of rock forming minerals consisting of aluminosilicates of potassium (K), sodium (Na), calcium (Ca) and sometimes barium (Ba) (Deer *et al*., 1966). They have two crystal systems, either monoclinic or triclinic, with a hardness of 6 – 6.5 using Moh scale, and relative density of 2.5 -2.8 (Microsoft Encarta, 2006). The different varieties of the feldspars include orthoclase, microcline, albite, andesine, anorthite, anorthoclase, banalsite, buddingtonite, bytownite, celsian, dmisteinbergite, hyalophane, oligoclase, paracelsian, reedmergnerite, rubicline, sanidine, slawsonite, stronalsite, svatoslavite, and plagioclase (Deer *et al*., 1966).

The feldspar mineral group is very important industrially, and has different uses; it is used in glass and ceramic industries, pottery and enamelware, soaps, abrasives, bond for abrasive wheels, cements and concretes, insulating compositions, fertilizer, poultry grit, tarred roofing materials, and as a filler (sizing) in textiles and paper (Lifond, 1983). In ceramic production, feldspar is used as a flux (vitrification) agent, which lowers the melting point of the ceramic products during firing, but also to give the products a glassy appearance (Lifond, 1983). It also reduces shrinkage of kaolinitic clays during firing (Malunga, 2002)

Feldspars exist in several places in Malawi and important areas include Mzimba, Dowa, Linthipe/ Mpima, Senzani, Mpatamanga, Tundulu and Chilwa Islands (Table 2.1) (Gwosdz *et al*., 1996). Most of the deposits are not mined commercially except for the Mpita / Linthipe deposits, with K-feldspar, occurring in the area, characterised by outcrops and floats of the mineral. Communities collect or most often, mine these deposits and sell the material to Dedza Pottery for use as a refractory and fluxing agent in ceramics production (Gwosdz *et al*., 1996).

The other important mineral in ceramics is silica (SiO_2) (Lifond, 1893). Shrinkage reduction of the kaolinitic clays by the addition of filler is based on the silica content (Lifond, 1893). Silica is the main component of quartz and silica sand (Deer *et al*., 1966). Values of SiO_2 in quartz approximate 100%, depending on the purity of the mineral (Deer *et al*., 1966). Quartz is the most abundant mineral, as well as a major component in igneous rocks such as granite, rhyolite and pegamite, but also in some metamorphic rocks, e.g. gneisses and schists (Microsoft Encarta, 2006). Quartz has an average hardness of 7.0 and a relative density of 2.65 (Microsoft Encarta, 2006). Its crystal system is trigonal (Deer *et al*., 1966). Quartz exists in different varieties, which include rock crystal, rose quartz, smoky quartz, amethyst, rutilated quartz, aventurine, agate, heliotrope, onyx, chrysoprase, jasper and prase (Microsoft Encarta, 2006; Deer *et al*., 1966).

Quartz has different industrial uses. In its pure forms its crystals are used in electronics as crystal oscillators, while in optics they are used for making optical instruments, through the application of their light polarising properties e.g. polarising microscopes (Microsoft Encarta, 2006). It is also used as flux in smelting operations (Microsoft Encarta, 2006). In ceramics, it is used as a ceramic flux, due to the presence of SiO_2 in it, which is responsible for the glass forming properties (Lifond, 1983). Quartz is also used for the production of glass, silica bricks, cement, porcelain, scouring soaps, wood fillers and sand paper (Microsoft Encarta, 2006).

A review of literature has not indicated the occurrence and sites where quartz specifically exists, possibly because the rock is too common. However, quartz used by Dedza Pottery is obtained from Kasina, where it is mined by villagers, and used in glazes, but also as a fluxing and glass bonding agent (Table 1.2 in chapter 1).

The other mineral used at the pottery is kyanite. Kyanite is a blue coloured mineral composed of aluminium and silica (Al_2SiO_2) (Lifond, 1983; Deer *et al.*, 1966). It has a triclinic crystal system with a specific gravity of 3.55 - 3.66 (Lifond, 1983; Deer *et al*., 1966). The mineral possesses high refractory properties, required for the production of furnace linings, foundry casting moulds, and heat resistant bricks (Lifond, 1983; Deer *et al*., 1966).

Its deposit in Malawi is located at Kaphirimdimba (Mchekecha) in Ntcheu district, where 300, 000 tonnes of the mineral exist (Table 2.1) (Kaphwiyo, 1965). The people of Dzing'anda village, in Ntcheu district, mine the deposits at small-scale artisan level and sell to Dedza pottery for use in the pottery and ceramic work.

2.3 Effects of Mining on the Environment

Effects of mining take place at all phases of mining: at the initiation of the project, during the operation stage of the mining project and even after closure (UNEP and WHO, 1998). Mining activities involve: (i) clearing of vegetation, (ii) total removal of top soil, (iii) drilling (iv) deposition of waste (overburden, chemicals and tailings), (v) blasting, (vi) use of vehicles, (Vii) crushing of mined raw materials, and (viii) excavations (Miller, 1993; UNEP and WHO, 1998; Singh, 2005). The affected parts of the environment include land, water, bio-ecology, air, society, economy and culture (Padmalal *et al*., 2004; Sarma, 2005; UNEP, 1994).

2.3.1 Effects of Mining on Bio-Ecological Environment

One of the very first parts of the environment to be affected by mining is the bio-ecological environment, through vegetation clearing, excavation and habitat disturbance (Chipofya *et al.*, 1999; Sarma, 2005; Weeks *et al.*, 2003). The bio-ecological environment consists of plant and animal communities together with microorganisms interacting with their natural non-living part of the physical environment, in a system called ecosystem (UNEP, 1994). The living part of the environment can be disturbed by mining and this could be directly, that is, by being physically destroyed, while indirectly, by disturbance of the environment or conditions that make its existence impossible (i.e. chemical or physical) (Weeks *et al.*, 2003).

Research findings on the effects of coal mining on vegetation by Sarma (2005), have shown that mining reduces the species diversity of tree and shrub species, while increasing the herbaceous species diversity. Herbaceous species have a better adaptive ability in the disturbed habitats than tree and shrub species (Sarma, 2005). On the part of fauna, Weeks *et*

al. (2003) found that river mining affected the riparian benthic microinvertebrate biodiversity, through the disturbance of the streambeds, which formed the important part of their habitats. It therefore, naturally follows that the destruction of vegetation and natural forests, which are natural habitats of larger animals, could negatively affect their biodiversity as well. The population of black howler monkeys, in Latin American tropical forests, have been greatly reduced by the destruction of the forests (Miller, 1993).

Changes brought about by mining onto an ecosystem, have the potential of inducing adverse effects on any other plant or animal species that depends directly or indirectly on the affected species, or habitats (Koziell and Omosa, 2003). This leads to extinction of some species, which is against the principles of sustainable development (Koziell and Omosa, 2003).

A diverse ecology has species with diverse genetic diversities too. Such an ecology is advantageous over the one that is less diverse, as the species of the former are less prone to extinction when habitats and conditions change than the latter (Kalindekafe, 2004). This is why species diversity is said to be an indicator of the health of an ecology (Selinus *et al.*, 2005). High diversity implies a healthy one, low diversity, implies an unhealthy one (Selinus *et al.*, 2005).

Sometimes effects of mining on the biodiversity originate from indirect activities related to mining or accidents. The failure of the tailings dam at Los Frailes in Spain in 1998, resulted in the loss of biodiversity in the aquatic species of the affected rivers, due to high water concentrations of zinc (Zn), lead (Pb), copper (Cu) and very low pHs (2-4) (Koziell and Omosa, 2003).

Plant communities are ecologically valuable in different ways. One of them is sustaining water availability in catchment areas. Mining disturbs catchment areas, through extensive removal of vegetation (Koziell and Omosa, 2003). The removal of diverse vegetation results in the shortage of water or reduced water flows down stream (Koziell and Omosa, 2003). This is because the ground water recharge system is disturbed, as the rainwater runs off without percolating into the ground (Froend *et al*., 2006)

The lack of vegetation cover aggravates siltation of rivers and streams, through erosion; the end result is changes in the river/stream regimes, affecting the ecology of the area through which the river/stream passes (Balkau, 1993).

2.3.2 Effects of Mining on Land and Water Quality

Mining affects land in a variety of ways; these could be chemical, biological or physical in nature (Sarma, 2005). Some of the mining activities, responsible for the effects, include total removal of the topsoil, drilling, deposition of waste, excavations and use of vehicles.

Total removal of topsoil takes with it the soil organic matter (SOM) (Padmalal *et al*., 2004). Lack of SOM has an effect on the physical as well as chemical nature of the affected soil. Physically, the structure, bulk density and water holding capacity of the soil are affected negatively, as these properties depend on the SOM (Brady and Weil, 1996; Stockings and Murnaghan, 2000). Sarma (2005) found that mining changed SOM, which in effect negatively affected the water holding capacity of the soils, through the removal of the fertile topsoils and dumping of infertile overburden.

Physical disturbance of the soil by the mining activities makes it prone to erosion by water and wind (UNEP, 1994). This is because the soil gets weakened through loosening (Brady and Weil, 1996). The loss of SOM and the weakening of the soil structure, also play a part in increasing the vulnerability of the land to erosion, as the soil particles attain reduced binding capabilities (Cooperband, 2002; Stockings and Murnaghan, 2000; Kandrika and Dwivedi, 2002). Removal of vegetation during mining also increases the rate of soil erosion by water (Kandrika and Dwivedi, 2002). Research findings by Kandrika and Dwivedi (2002) have shown that more sediment formed in mined areas as opposed to the unmined areas, indicating the negative effects of mining on soil by water.

Chemically, the soil fertility in the mining sites is reduced (Padmalal *et al.*, 2004). This is because the removal of the topsoil, together with the SOM, removes the source of the soil nutrients such as N, P and K, which originate from it by means of mineralization, after the decomposition process of dead animal and plant matter (Padmalal *et al.*, 2004). However, Padmalal *et al.* (2004), in their study on clay mining and related environmental problems in Chalakudy basin, found that for areas with subsoils richer than topsoils, the removal of topsoil is beneficial, as it exposes the fertile subsoil layer.

The buffering abilities of the soil against changes in metallic ion availability and mobility in the soils depend on colloid content (SOM and clay particles), through ion adsorption and complex formation (Altaher, 2001; Wild, 1993). The loss of SOM increases the availability

of the metal ions in the soils as there are limited surfaces on which the metal ions could adsorb or form complexes (Altaher, 2001; Wild, 1993).

In case of heavy metals, the effect could be an increase in the concentration of heavy metals in solution form, which threatens living things through poisoning, while in case of essential exchangeable cations, the effect could be an increase in the loss of these cations through leaching (Cooperband, 2002). Apart from buffering the metal ion concentration, the SOM also buffers against major changes in soil pH, through an increase or decrease in H^+ ions, counteracting the change, in so doing the soil pH is maintained within the neutral range or normal range for the area (Cooperband, 2002). The loss of SOM in mined areas would therefore imply a decrease in the soil pH buffering ability.

Drilling also affects the soil both physically and chemically. A research on the effects of drilling on wheat yield in Weld County, Colorado, indicated that soil salinity (sodicity) and pH increased following the drilling process (Bauder *et al*., 2005). The cause of the rise in sodicity was found to be the sodium ions (Na^+) contained in the drilling fluid components, while the rise in soil pH was attributed to the Ca^{2+} and Na^+, contained in the drilling fluid additives, constituting hydrated lime (Ca (OH_2). x H_2O) and sodium carbonate (Na_2CO_3) (Bauder *et al.,* 2005). Similar results on soil sodicity change arising from drilling have been reported elsewhere by other researchers (Miller and Persaran, 1980; Nelson *et al*., 1984; McFarland *et al.,* 1992). Drilling also damages the land through the dumping of drill cores and waste on land, creation of sinkholes in an area, which in effect encourage soil erosion, resulting in reduction of aesthetic values of the landscape (MMSDSA, 2001).

Haulage of raw materials causes soil compaction when vehicles tread on it (Hinds, 1999). At a bauxite mine in Western Australia the problem of soil compaction was reported emanating from treading by tractors (Hinds, 1999). The effect of soil compaction is reduction in water infiltration (Hinds, 1999).

The most notable and obvious effect of mining is the creation of pits (UNEP, 1994; Padmalal *et al*., 2004). This is a result of excavation. Pit formation reduces aesthetic values of the landscape (Singh, 2005; UNEP and WHO, 1998), reduces the productivity of the land, and increases the prevalence of accidents (Padmalal *et al*., 2004). Excavations at Nchanga copper mine in Zambia have resulted in the formation of large pits and waster rock materials piling around the pits, drastically affecting the aesthetic values of the land, and making it impossible

for other land uses (UNEP, 1994). The mining activities have also caused serious siltation problems on the Kafue river and its tributaries (Sikazwe, *pers. Comm.*,May 2008)

Notably, land and water are closely related, as such activities done on the land do affect water sources, such as wells, streams, rivers, lakes, dams etc (Singh, 2005). Water in rivers and streams gets polluted by the mining activities (Chiwona *et al.*, 2002; Weeks *et al.*, 2003). The by-products of mining, which include overburden, sediments and tailings, alter the chemical and physical characteristics of the water (UNEP, 1994; Bell, 1997; Singh, 2005). This could be through runoffs, wind blowing the dust from the mining sites into surface water sources, leaking of tailings and other poisonous chemicals into the underground water etc (UNEP; 1994; Singh, 2005; Bell, 1997).

Some of the water parameters affected by mining include: pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), turbidity, total suspended solids (TSS), solubility and concentration of cations, e.g. heavy metals (Pb, Cd, Mn, Hg, Cr, Ni, and Zn) and major elements such as Al, Ca, Fe, K, Mg, and Na (Borrego *et al*., 2002; Padmalal *et al*., 2004; Chiwona *et al.*, 2002; UNEP, 1994; Miller, 1993).

Heavy metal pollution has been reported in Zimbabwe's small-scale gold mines. Mercury levels as high as 2mg/L and 200 mg/g have been reported in the water and soil samples respectively (Maponga and Mutemererwa, 1995). Such levels are dangerous to the living environment in general (Alloway and Ayres, 1997).The accepted levels for mercury in the soils for agriculture, residential and industrial areas are 0.8- 1.0 µg/g, 2µg/g and 10 – 20 µg/g respectively (Alloway and Ayres, 1997), while that for drinking water is 1µg/L (Alloway and Ayres, 1997; WHO, 2004).

Runoff sediments from the cleared areas find their way into the nearby rivers, causing water pollution (i.e. increased turbidity) (Miller, 1993; Bell, 1997) and possibly siltation. An example of a mining area in Malawi with such effects is Mchenga coalmine in Rumphi (Chiona *et al*., 2002). Surface water pH levels and concentration of suspended solids were also affected at this site. Streams closer to the crushing site of the mine site were characterised by relatively lower pH (5.74) and higher suspended solids (37 mg/L) than those far away, possibly influenced by mining activities (Chiona *et al*., 2002). Chipofya et al., (1999), also observed similar trends at the site.

Underground hydrology or hydrogeology is also affected by mining. This could be through disturbances to the ground water recharge system by means of vegetation clearing (Froend *et al*., 2006), or by mining beyond the local water table (Padmalal *et al.*, 2004). A practical example is Chalakudy basin, where the water table dropped due to draining of water, which collected in the formed pools, owing to the mining beyond the local water table (Padmalal *et al.*, 2004). The draining of water was aimed at facilitating the clay mining process (Padmalal *et al.*, 2004). The effect of lowering of the water table was the drying up of water sources, especially in the dry season (Padmalal *et al*., 2004).

The major mining threat to ground water quality is metal ion leaching from overburden, wastes or tailings dams (UNEP, 1994; Islam *et al.,* 2000). Some metal ores and coal contain sulphides (Selinus *et al.,* 2005). During mining, these sulphides (eg FeS_2) are exposed to air and water to form acidic solutions (eg H_2SO_4). Equation 2.1 below shows the reaction.

$$FeSO_2\ (s) + 2H_2O\ (l) + 7O_2\ (g) \rightarrow 2FeSO_4\ (s) + 2H_2SO_4\ (aq) \quad [2.1]$$

These acidic solutions dissolve other metals (heavy metals) in the ores or waste leading to leaching of the metals polluting surface and ground water in due course (Harrison, 1999; Selinus *et al.,* 2005). This is called acid mine drainage (Harrison, 1999). At Mainamoti mining site in Bangladesh, ground water was contaminated with heavy metal ions due to leaching of mining by-products containing these ions (Islam *et al*., 2000). Available literature does not indicate any Malawian example of water contamination by leaching connected to mining, possibly due to little mining activities taking place in the country.

2.3.3 Effects of Mining on the Air Quality and Noise

Extraction activities at mining sites involving drilling, blasting, loading and hauling of raw materials from the mining sites to processing sites, and crushing of the mined raw materials, emit dust which pollutes the air (Singh, 2005; UNEP, 1994). The other important air pollutants include particulates and gases such as: methane (CH_4), sulphur oxides (SO_x,), nitrogen oxides (NO_x) and carbon oxides (CO and CO_2) (Singh, 2005; UNEP, 1994).

A lot of dust (609 mg/L) and particulate matter (300 HU) are produced at Mchenga coalmine in Malawi (Chipofya *et al*., 1999). High amount of dust causes visibility problems in the mining and surrounding areas (Singh, 2005). It also increases chances of respiratory and eye disorders among the miners, as well as, those living closer to the mining sites (Cecala and Timko, 1998; Jeyaratnam, 1999).

Respiratory problems caused by mining include silicosis, chronic bronchitis and pulmonary emphysema (Cecala and Timko, 1998; Jeyaratnam, 1999). Silicosis and mineral dust pneumoconiosis are said to be caused by exposure to dust with high silica content (Jeyaratnam, 1999; UNEP, 1991). At Quebec mines, 203 miners were found with silicosis and compensated between the years 1967 and 1977 (Azenwa, 1982). Reports also indicate a high rate of silicosis among the South African gold miners (Braun and Kisting, 2006). The most interesting part to the current study is that silicosis is directly linked to industries like ceramics, pottery, glass making, stone cutting and masonry (Cecala and Timko, 1998).

The problem of air pollution by mining differs with the type of mining method. Open cast mining has more severe impacts on air pollution than underground mining (Singh, 2005). Possibly, because the soils and overburden are loosened, as well as exposure to wind in open cast mining, as opposed to underground mining.

The effect of mining that has for a long time not been taken seriously is noise. Noise emanates from drilling machinery, vehicles, blasting etc (UNEP, 2000). The recommended levels of noise in the mining area are 45 decibels during the day and 55 decibels during the night (Chiona *et al*., 2002). Exposure to noises over 85 decibels for over eight hours is not recommended for workers as it would lead to deafness (GoM, 1997b).

Loud noise has different effects on the environment. It causes stress (increased release of adenocorticotropic hormone, elevation of corticosteroid levels, affecting the sympathetic section of the autonomic nervous system etc) (MBS, 2005). Loud noise also causes deafness in people (McBride, 2004; Chiona *et al*., 2002), affects animal's physiology and behaviour (Radle, 2007). Noise scares wild animals, and this was learnt from the mining noise simulations on elk calves, where it was found that the calves fled areas with the noise to distant places, and never returned, even after the sounds had stopped (Radle, 2007).

Noise in general has also been linked to disturbances of animal feeding efficiency. For instance, research has revealed a reduction of foraging efficiency of the bighorn sheep due to noise (Radle, 2007). Busnel and Fletcher (1978) reported possible disturbances to the health, growth and reproductive fitness of animals as a result of excessive stimulation of the nervous system due to stress, caused by noise.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This chapter describes the study area, as well as, provides its location. It also describes methods used in sampling, analysis of vegetation diversity, physicochemical and physiographic characteristics of the mining sites, to determine the effects of mining.

3.2 Description of the Study Area

3.2.1 Location and physiographic characteristics of the Study Area

The study area was Dedza-Ntcheu located in the central region of Malawi (Figure 3.1). Dedza had four sites, while Ntcheu had only one. Dedza, the main study area, lies between 33^{o} 35' E to 34^{o} 46' E, and 13^{o} 52' S to 14^{o} 38' S. It has a total land area of 3,624 sq. Km (GoM, 1999b).

Dedza district is divided into three topological areas. These are the Lilongwe plain (altitude 1100-1300 m above sea level), the Dedza highlands (1200-2200 m) and the Dedza escarpments (1000-1500 m). Topography varies from rolling slopes to plains (GoM, 1999b).

3.2.2 Geology and Soils

Dedza district lies on a geologic structure that forms a section of the Malawian basement complex, which is defined by charnockitic rocks (i.e. those of intermediate felsic and charnockitic granulites), granulites, paragneisses, marble and graphite-gneisses. The structure originated from isoclinical folding, producing major antiforms and syforms. The paragneisses originated from the metamerization of the perthic rocks mainly composed of quartz-synite and monzonites, with some granite and quartz-diorite (Thatcher, 1968).

In the north west of the district (Linthipe area), meta-arnothosite geology is encountered. This geology is a product of the metamorphosed pretectonic body of adirondack-type; within it are some amphibolites and few occurrences of meta-pyroxenite (Thatcher, 1968).

Dedza soils are generally deep and well-drained, brown to reddish in colour and coarse to fine textured (GoM, 1999b), and are grouped into Linthipe series and Bembeke series.

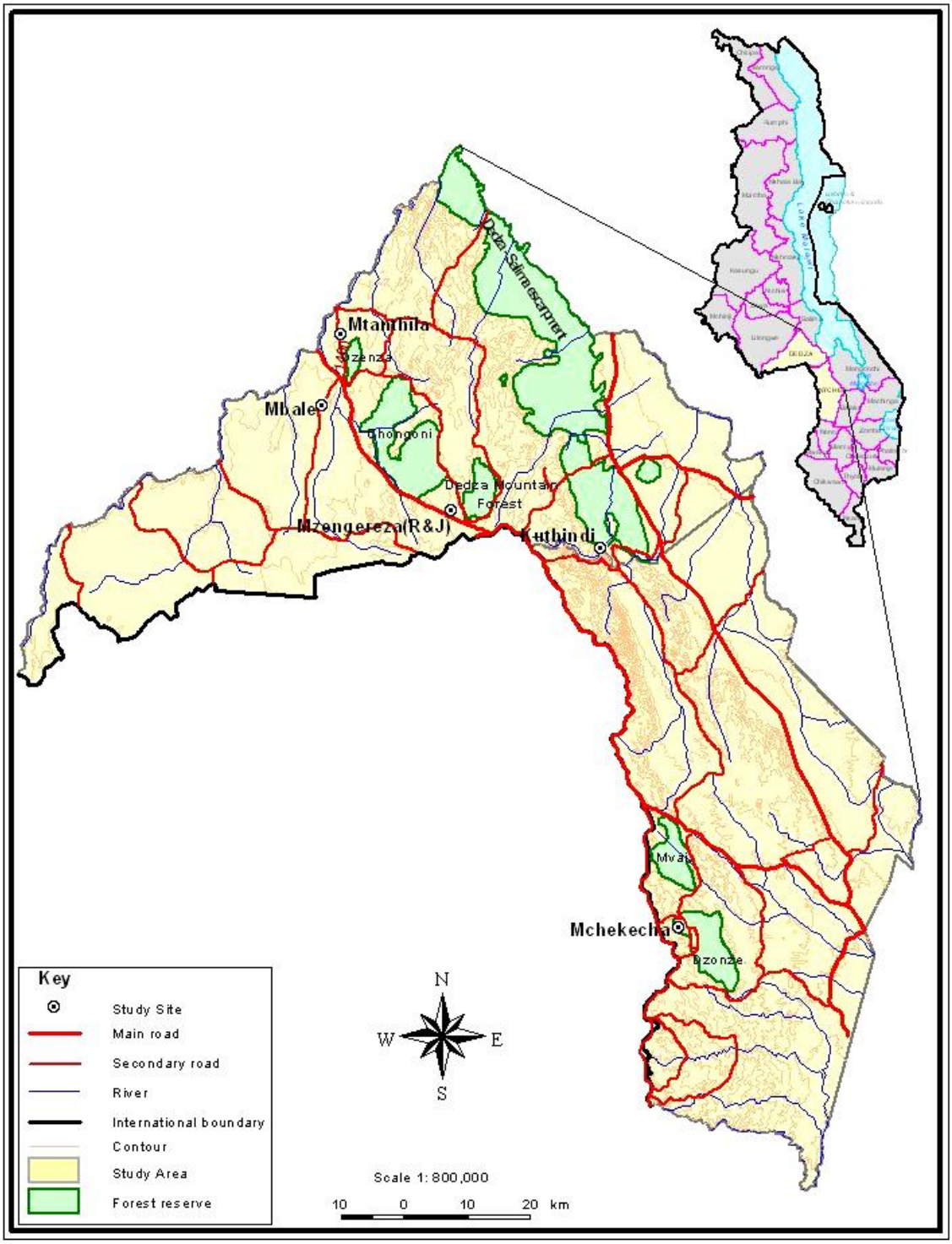

Figure 3.1: The study area and sites in Malawi.

The Linthipe series are ferruginous redbrown clay sandy soils, the Bembeke series are feralllic latosols with the top one being dark reddish brown sandy loam and just below is the kaolinitic sandy clay (Thatcher, 1968).

3.2.3 Climate and Vegetation

The district has variant types of climate due to variations in altitude, with the common one being the tropical continental climate. It has three types of seasons: cool (May-August), hot (September-November) and wet season (December-April). The mean rainfall for the district is 800-1200mm). Mean Temperatures in the district range from 17.5 to 25.5^{o}C. The minimum temperatures within the range 7.5 to 12.5^{o}C, are mostly experienced in the cool season. The relative humidity in the district varies between 60-80 % (GoM, 1999b).

Variations in the altitude, climate and topography cause variations in vegetation from one part of the district to the other. In hill areas, the brachystegia type and savannah woodland predominate, while in the lower slopes of the rift valley floor, mixed savannah woodland exists (Thatcher, 1968). The south Lilongwe plain mainly consisted of Brachystegia-Julbernadia savannah woodland in the past, today only patches of it are evident, while in the dambo lands treeless grassland is common with occasional tall grass (Thatcher, 1968).

3.2.4 Demographic and Socio-economic Characteristics

The population of Dedza district is 486, 682, and has 113, 544 household, according to the 1998 population census (Benson *et al*., 2002). The largest proportion of the population is found in the Traditional Authorities (TAs) Pemba (105,343) (Benson *et al*., 2002). The district is the second most populous district in the central region of Malawi (905,889) (GoM, 1999b).

Three main tribes are found in the district, these are: the Chewas, Yaos and Ngonis (GoM, 1999b). Their economic activities, range from small scale to large-scale enterprises. Small enterprises include bee keeping, farming, livestock keeping, while the large scale ones include Wood Industry Corporation (WICO) and Dedza Pottery (Paragon Ceramics) (GoM, 1999b). The only draw back with farming is the low percapita land holding size (0.4 Ha) (GoM, 1999b).

3.2.5 Location of the Study Sites

The main study area, Dedza district, had four study sites, and these included Mzengeleza (J and R), Kuthindi, Mtanthila (Kasina) and Mmbale (see Fig 3.1). J means greysoil site, and R stands for redsoils site. Ntcheu district had one site only (Mchekecha), where only vegetation was studied, as the researcher was faced with problems with the society. Despite going through the traditional leaders of the area, the society thought the researcher was a Satanist colluding with the local leaders. Attempts to kill the researcher were made, but leaders protected him. The data collection did not continue, as the situation was not conducive.

3.2.6 Partitioning of the Study Sites

Each study site was stratified into two, mined section (experiment) and unmined section containing the mineral deposits (control). The partition was based on similarities in the observed physiographic and edaphic features, to ensure that differences between the two sections were due to mining activities (Sarma, 2005).

3.3 Sampling and Sample Preparation

All samplaes were collected during the dry season (June – September), the mining season.

3.3.1 Vegetation Species Sampling

The study of vegetation involved the division of each site into mined section and unmined section (Sarma, 2005). For each section, stratified systematic sampling was employed (Lyne, 2003) to come up with the study strata due to differences in vegetation distribution within the sections. Each stratum was further divided into quadrats of size 5 m × 5 m each, using a measuring tape (Lyne, 2003). For a stratum with n quadrats, three random numbers between 1 and n were generated using the Moonstat statistical software (Lyne, 2003). Each stratum contributed three quadrats. Time spent on each quadrat was not fixed, but depended on finishing the counting and identification of species, to ensure equal effort, which has an effect on the correctness of the results. An expert from the National Herbarium was used in species identification and counting. The results were recorded on a data sheet (Appendix B -1). The average numbers per species per stratum were calculated, which were further used in calculating the averages per species of each section of the site. The process was carried out for both the mined, as well as the unmined sections, and the data were fed into the Ecosim 7.0 software to generate diversity indices as explained in section 3.5.

3.3.2 Soil Samples

Soil samples were collected from Mzengeleza (R), Mzengeleza (J), Kuthindi, Kanyentchera and Mmbale. Three randomly selected sampling points were identified in each section. A pair of samples, each 500 g, was collected from each sampling point, as follows: topsoil (0-30 cm) and subsoil (30-60 cm), with changes made depending on soil profile characteristics (Alloway and Ayres, 1997). All the soils from a particular section and profile formed one composite sample (1500.00 g). Each site contributed two sets of composite topsoil samples (one from mined section and the other from the unmined section), and one of subsoils from the unmined section. The composite soil samples, collected per site, were placed in black plastic bags (to prevent exposure to incident light) and transported in a cooler box to the laboratory. These samples were air dried at 27 ^{o}C while shielded from incident light, ground, sieved to ≤500 μm, and kept without preservatives under normal room conditions (25 ^{o}C), shielded from incident light, until analysis (UNECECLRTAP, 2003).

3.3.3 Rock Samples

Raw material samples were collected from Mchekecha (kyanite) and Mtanthila (quartz and feldspar) (Figure 3.1). For each rockmineral type and site, three samples, each 500.000 g, were randomly collected. The rock samples were, quartered, mixed, pulverised, and sieved to fine powder (< 180 μm) at the Geological Survey Department (GSD). The sieving to powder was done to increase the surface area of the raw materials for acid digestion (decomposition). The samples were stored at normal room temperatures protected from direct sunlight until digestion (UNECECLTAP, 2003).

3.3.4 Water Samples

Water samples for physicochemical analyses were collected in sealed bottles from the stream at Kuthindi only. The collection of water samples was undertaken at two occasions, before the mining season (control) and during mining season (experiment). At each occasion twelve samples each 500 mL were collected, four from the upper part of the stream (control), four at discharge point (experiment) and four after discharge point (experiment). The distance between sampling points was 50 m. Two of the four bottles per sampling point were treated with 2.5 mL of concentrated nitric acid (HNO_3) as a preservative for analysis of metals. The untreated ones were also taken to the laboratory for the analysis of suspended solids, conductivity and turbidity. All water samples were kept in a cooler box, containing ice and

transported to the laboratory, where they were stored at 4 ^{o}C before analysis (Walther *et al.*, 2003).

3.4 Analysis of Soil, Rock, and Water samples

3.4.1 Chemicals and Reagents

Analar and chemically pure grade chemicals and reagents were used. These were amyl alcohol, ammonium fluoride (NH_4F), ascorbic acid ($C_6H_8O_6$), cadmium (Cd), calcium carbonate ($CaCO_3$), calgon, copper (Cu), EDTA (ethylenediamine tetraacetic acid) ($[HO_2CCH_2]_2NCH_2CH_2N[CH_2CO_2H]_2$), ferrous ammonium sulphate $Fe[SO_4][NH_4]_2[SO_4]$ $6H_2O]$), hydrochloric acid (HCl), hydrofluoric acid (HF), hydrogen peroxide (H_2O_2), iron (Fe), lead nitrate (Pb $(NO_3)_2$), magnesium (Mg), manganese sulphate ($MnSO_4.H_2O$), nitric acid (HNO_3), pechloric acid ($HClO_4$), phosphoric acid (H_3PO_4), potassium chloride (KCl), potassium dichromate ($K_2Cr_2O_7$), potassium dihydrogen orthophosphate (KH_2PO_4), potassium nitrate (KNO_3), and sulphuric acid (H_2SO_4). The sources of the above listed chemicals were: Technlab, Lab Enterprise and Phamavelt, all in Blantyre city, Malawi.

3.4.2 Instrumentation

In the determination of the physicochemical parameters, different instruments were used. A glass electrode Sargent – Welch digital meter, model 500 was used in determining the on site water pH. To measure water conductivity, the WPA CM 35 conductivity meter with sensitivity up to 1 x 10^{-6} Siemens was used, a portable turbidimeter model DRT-15 CE with ± 1% fullscale repeatability was used to determine water turbidity. In the weighing of pulverised soil and rock samples, chemicals, and determining the total suspended solids (TSS) in water, the Mettler electronic balance with sensitivity 0.0000 g was used. To determine the soil pH, a pH meter Metroh Model 744, with sensitivity 0.01 pH was used, the Jenway UV/Vis spectrophotometer model 6405 was used to measure absorbance in the determination of available nitrogen (NO_3^-) and phosphorus (PO_3^{2-}), the Shimadzu spectrophotometer model UV-2201 was used in measuring the absorbance in the determination of silica content in rock raw materials. The atomic absorption spectrophotometer (AAS) Buck Scientific model No 200A was used to measure absorbance for the determination of exchangeable cations as well as heavy metals, the mechanical shaker model MK V was used for shaking mixtures in flasks.

3.4.3 Preparation of Solutions and Reagents

Cadmium (Cd) standard solutions

The standard stock solution was prepared by dissolving 1.000g cadmium metal in a medium of 1 + 1 HCL and diluting to 1000 mL in a volumetric flask to obtain a 1000 mg/L cadmium stock solution. The stock solution was used to prepare a 100 mg/L intermediate stock solution from which the working standard solutions were prepared. The standard solutions used in the final determination were 0.0, 0.5, 1.0, 2.0, 5.0 and 10.0 mg/L (APHA, 1989).

Copper (Cu) standard solutions

The standard stock solution was prepared by dissolving 1.000 g copper metal in 15 mL of 1 + 1 HNO_3 and diluting to 1000 mL in a volumetric flask to obtain a 1000 mg/L copper stock solution. The stock solution was used to prepare a 100 mg/L intermediate stock solution from which the working standard solutions were prepared. The standard solutions used in the final determination were 0.0, 0.5, 1.0, 2.0, 5.0 and 10.0 mg/L (APHA, 1989).

Lead (Pb) standard solutions

The standard stock solution was prepared by dissolving 1.598 g lead nitrate, $Pb(NO_3)_2$, in about 200 mL deionised water and adding 1.5 mL concentrated HNO_3 to complete solution. Diluting to 1000 mL in a volumetric flask a 1000 mg/L lead stock solution was made. The stock solution was used to prepare a 100 mg/L intermediate stock solution from which the working standard solutions were prepared. The standard solutions used in the final determination were 0.0, 0.5, 1.0, 2.0, 5.0 and 10.0 mg/L (APHA, 1989).

Iron (Fe) standard solutions

Standard Fe solution (1000 mg Fe/L) was prepared by dissolving 1.00 g of analytical grade Fe wire in 100 mL of 3.5 M sulphuric acid (H_2SO_4). The mixture was warmed, to completely dissolve it, and diluted to 1000 mL with distilled water. An intermediate Fe standard solution was prepared by taking 10mL of stock solution and diluting to 100mL with distilled water. Fe working standard solutions (0.0,1.0,2.0,4.0,6.0 and 8.0 mg) Fe/L were prepared by pipetting 0.0, 1.0, 2.0, 4.0, 6.0 and 8.0 mL of the intermediate stock solution into 100 mL volumetric flasks and diluted to volume with mehlich 3 extractant (Mweta, 2006).

Manganese (Mn) standard solutions

The standard stock solution was prepared by dissolving 3.076 g manganese sulphate ($MnSO_4.H_2O$) in about 200 mL water, adding 1.5 mL concentrated HNO_3, to complete solution. A 1000 mg/L manganese stock solution was made by diluting to 1000 mL in a volumetric flask. The stock solution was used to prepare a 100 mg/L intermediate stock solution from which the working standard solutions were prepared. The standard solutions used in the final determination were 0.0, 0.5, 1.0, 2.0, 5.0 and 10.0 mg/L (APHA, 1989).

Mixed standard calcium, magnesium and potassium solutions

Stock Standard solutions (2000 mg K/L, 1000 mg Mg/L and 10,000 mg Ca/L) were prepared by dissolving separately 1.000 g Mg ribbon in 50 mL concentrated HCl and transferring to a 1000 mL volumetric flask containing about 500 mL distilled water. To the solution, 24.972 g calcium carbonate ($CaCO_3$), and 3.815 g potassium Chloride (KCl) were added and dissolved. The resulting solution was diluted to 1000 mL with distilled water. Dilute stock standard solution (200 mg K/L, 100 mg Mg/L and 1000 mg Ca/L) was made by taking 10 mL of high stock standard solution to 100 mL volumetric flask and diluting to volume with distilled water. Working K, Ca, and Mg standard solutions were prepared by adding 0.0, 5.0, 10.0, 15.0, 20.0 and 25.0 mL of low stock standard solutions to 100 mL volumetric flasks and the solutions were brought to volume with mehlich 3 extractant. The solution contained the following concentrations 0.0, 10.0, 20.0, 30.0, 40.0 and 50.0 mg K/L, 0.0, 5.0, 10.0, 15.0, 20.0 and 25.0 mg Mg/L and 0.0, 50.0, 100.0,150.0, 200.0 and 250.0 mg Ca/L (Mweta, 2006).

Preparation of nitrate standard solutions

Nitrate stock solution (1000 mg/L) was prepared by dissolving potassium nitrate (KNO_3, 7223.000 g) previously dried in an oven at 105 ^oC for 1 hour. Distilled water was added and the solution was diluted to the 1 L mark in a volumetric flask. An intermediate stock solution (100 mg/L) was prepared from which the following standard working solutions were prepared; 0.0, 2.0, 4.0, 6.0,8.0 and 10.0 mg NO_3^-/L by pipetting 0.0, 2.0, 4.0, 6.0, 8.0 and 10.0 mL of the intermediate stock solution into 100 mL volumetric flasks and diluting to volume with distilled water (Chilimba, 1996).

Preparation of phosphorus (P) standard solutions

Phosphorus stock solution (1000 mg PO_4^{3-}/L) was made by dissolving 4.394 g potassium dihydrogen orthophosphate (KH_2PO_4), previously dried at 105 ^oC for 2 hours and cooled in a dissector, in 250 mL of deionised water and the solution was diluted to 1000 mL. Phosphorus intermediate stock solution (200 mg PO_4^{3-}/L) was prepared by taking stock solution and diluting to 100 mL with deionised water. Phosphorus (orthophosphate) working standard solutions (0.0,2.0,4.0,8.0 and 10.0 mg PO_4^{3-}/L) were prepared by pipetting 0.0, 1.0, 2.0, 3.0, 4.0 and 5.0 mL of intermediate stock solution into a 100 mL beaker and diluted to volume with mehlich 3 (Chilimba, 1996).

Preparation of the silica standard solutions

Silica (SiO_2) intermediate stock solution (100 mg/L) was prepared by pipetting 2.0 mL of the 1000 mg/L silica stock solution into a 20 mL volumetric flask and diluted to volume with distilled water. Using 10mL burette 0, 2, 4, 6 and 8 mL of the silica intermediate stock solution was each pipetted into 100 mL volumetric flasks, and diluted to volume with distilled water, forming standard SiO_2 solutions on 0, 2, 4, 6 and 8 mgL^{-1} (Matsudaira, 1992).

Preparation of potassium sulphate extractant (0.5M K_2SO_4)

Potassium sulphate extractant was prepared by dissolving potassium sulphate (K_2SO_4) (87.100g) in distilled water and diluting to 1 L in a volumetric flask using distilled water (AOAC, 1990).

Preparation of mehlich 3 extractant (0.2M CH_3COOH+0.25M NH_4F+ 0.013HNO_3 + 0.001M EDTA, pH 2.5)

Ammonium fluoride - EDTA stock solution was prepared by dissolving 138.900 g ammonium fluoride (NH_4F) and 73.500 g EDTA in 1000 mL deionised water. 23.0 mL of acetic acid was added to 40.000 g ammonium nitrate dissolved in 1500 mL deionised water, followed by 8.0 mL ammonium fluoride-EDTA reagent and 1.64 mL of concentrated nitric acid. The pH of the solution was adjusted to 2.5 ± 0.1 and diluted to 2000 mL deionised water (Mweta, 2006)

Preparation of the Murphy- Riley working solution

Murphy–Riley stock solution was prepared by dissolving 0.210 g of antimony potassium tatrate in 100 mL of distilled water. In a separate beaker, 12.000 g of antimony molybdate was dissolved in 200 mL distilled water. To a 2000 mL volumetric flask, 1000 mL distilled water was added followed by 140 mL of concentrated sulphuric acid, antimony potassium tartrate and ammonium molybdate solutions and the solution was made to the mark with distilled water. An aliquot of 100 mL of stock solution was mixed with 500 mL of distilled water and 0.526 g ascorbic acid and made to 1000 mL with distilled water to make the final Murphy- Riley working solution (Mweta, 2006).

Lanthanum diluting solution (2500mgLa/L)

To about 50 mL distilled water in a 100 mL volumetric flask, 14.75 g of lanthanum oxide (La_2O_3) were added and dissolved. The solution was placed in a cold-water bath and 25 mL of concentrated HCl was added while constantly swirling the flask and the solution was diluted to 5000 mL.

3.4.4 Analysis of Soil Samples

3.4.4.1 Determination of Soil pH

To a beaker containing 40.000 g of dried and sieved soil, 40.0 mL of distilled water was added, and slowly stirred, until complete mixing. This was repeated every 3 minutes for a total of five stirring and waiting cycles(i.e. five stirrings, each followed by a period of no stirring). The mixture was allowed to settle until a supernatant (clearer liquid above the settled soil) had formed (about 5 minutes). Calibration of the pH meter was done using pH 4 and 7 buffer solutions. The soil pH was measured by dipping the probe of the pH meter into the supernatant liquid (NSF and SSA, 2001).

3.4.4.2 Determination of Soil Moisture Content

Mass of a crucible (m_c) was recorded. A sample (10.000 g) of air dried soil was weighed and transferred into a crucible, this followed the weighing of the crucible with the air-dried soil sample together, and was recorded as m_1. The weighed samples were put in an oven to dry: organic layer at 60 ± 1^oC, while the subsoil at 105 ± 1 ^oC. The crucibles were cooled in a desiccator and weighed, and again heated in an oven, until a constant mass was reached. The

constant mass achieved was recorded as m_2 . The moisture content was calculated using the following equation:

$$Moisture(\%) = \frac{m_1 - m_2}{m_2 - m_c} \times 100 \qquad [3.1]$$

Where m_c is the mass of the empty crucible, m_1 is the mass of the crucible and air died soil and m_2 is the mass of the crucible and oven dried soil sample (UNECFECOLRTAP, 2003; Anderson and Ingram, 1989).

3.4.4.3 Analysis of Available Nitrogen in the Soil Samples

Extraction of available nitrogen in soil samples

A 10.000 g sample was weighed into an Erlenmeyer flask and potassium sulphate extractant (40 mL) was added and the mixture put on a mechanical shaker for 30 minutes. The sample was filtered using fine grade Whatman No. 42 filter paper, and the filtrate collected for determination of available nitrogen concentration, in form of nitrates (Chilimba, 1996).

Determination of available nitrogen

The colleted filtrate (0.5 mL) was pipetted into a 25 mL volumetric flask, and salicylic acid (0.8 mL, 5% w/v in concentrated sulphuric acid) added. The solution was left to cool for 30 minutes. An aqueous solution of sodium hydroxide (10 mL, 4 M) was added and the solution diluted to volume with sodium hydroxide (4 M). The solution was then left for 1 hour to develop a characteristic yellow colour, after which the solution was measured for the available nitrogen using UV/Vis Spectrophotometer at 410 nm (Chilimba, 1996).

3.4.4.4 Analysis of Available Phosphorus in the Soil Samples

Extraction of available phosphorus

A 2.500 g soil sample was weighed in 50 mL-extraction bottle, in triplicates and 25 mL mehlich 3 extractant was added. The mixtures were shaken on mechanical shaker for 10 minutes. The mixtures were filtered using Whatman No. 42 filter paper, and the filtrate was collected (Mweta, 2006).

Determination of available P in the extracts

To 1.00 mL of extract or working standard in triplicates, 9 mL of Murphy Riley working solution were added and mixed. The Absorbance of the standards and extracts were read at 880 nm after 15 minutes using UV/Vis Spectrophotometer (Mweta, 2006).

3.4.4.5 Determination of Organic Matter Content in the Soil

1.0 g of soil samples were weighed in 500 mL conical flasks, in triplicates. To the soil samples, 10 mL of 1.0 M potassium dichromate solution was added, followed by addition of 20 mL concentrated sulphuric acid. The mixtures were shaken for 1 minute and left to stand for 30 minutes to allow complete oxidation to take place. After 30 minute, about 200 mL distilled water and 10 mL of concentrated phosphoric acid were added and the solution was left to cool. To the resulting mixture, 1mL of diphenylamine indicator was added and the mixture was immediately titrated with 0.5 M ferrous ammonium sulphate until the colour changed from deep blue to dark green. A blank containing all the reagents but no soil was treated in the same way as the soil samples (Olsen and Sommers, 1982).

The amounts of carbon and organic matter were calculated from equations below:

$$\%\text{Total Organic Carbon} = 1.334 \times \frac{[V_B - V_S] \times 0.3 \times M}{m_S} \qquad [3.2]$$

$$\%\text{ Organic Matter} = 1.724 \times \%\text{ Total Organic Carbon} \qquad [3.3]$$

where: M is the molarity of ferrous ammonium sulphate solution; V_B is the volume of ammonium ferrous sulphate required to titrate blank (mL), V_S is the volume of ferrous ammonium sulphate required to titrate a sample (mL); m_s is mass of the soil sample and 0.3 equals $3 \times 10^{-3} \times 100$ where 3 is the equivalent mass of C.

3.4.4.6 Analysis of the Selected Heavy Metal Concentration in Soil Samples

Soil sample digestion

To pre-dried sieved soil (5 g) in a 250 mL beaker, concentrated nitric acid (10 mL) was added. The mixture was covered with a watch glass, refluxed for 45 minutes, the watch glass removed and the contents evaporated to dryness. The residue was treated with aqua regia (5

mL HCL + HNO_3) and suspension filtered. The filtrate was diluted to volume with distilled water in a 50 mL volumetric flask (Bamgbose *et al*., 1999).

Determination of heavy metal concentrations

The determination of heavy metals was done according to APHA (1989). Cadmium, copper, lead, and manganese on blanks, all standards and extracts were measured by AAS, at 228.8 nm, 324.8 nm, 283.3 nm and 279.5 nm respectively.

3.4.4.7 Analysis of Calcium (Ca), Magnesium (Mg), Potassium (K) and Iron (Fe)

Extraction procedure

2.500 g soil samples were weighed in 50 mL extraction bottle, in triplicates and 25 mL mehlich 3 extractant was added. The mixtures were shaken on a mechanical shaker for 10 minutes. The residue was filtered and the filtrate collected (Mweta, 2006).

Determination of K, Ca, Mg and Fe

In 25 mL volumetric flask, 3.0 mL aliquot of each working standard solution and all soil extracts was diluted to volume with lanthanum diluting solution, to control chemical interferences from other compounds, such as phosphate, when determining calcium (PerkinElmer, 2000). K^+, $Ca^{2+,}$ Mg^{2+} and Fe^{2+} on all standards and extracts were measured by atomic absorption spectrophometry at wavelengths of 766.5 nm, 285.2 nm, 422.7 nm and 248.3 nm respectively (Mweta, 2006).

3.4.4.8 Soil Grain Size Analysis and Determination of Soil Texture

The determination and analysis was based on the hydrometer method as described by Anderson and Ingram (1989), and the whole process was done at the Forestry Research Institute of Malawi (FRIM) soil science laboratory as follows:

Determination of the % composition of the soil grains

Soil sample (50.000g) was placed in a calibrated 250 mL heat resistant bottle with a screw top. Deionised water (100 mL) and 30% H_2O_2 (10 mL) were added to the soil and the bottle was swirled to mix the water and the soil. When the bubbles started overflowing, a drop of amyl alcohol was added. The bottle was heated for half an hour in a boiling water bath to destroy any unreacted peroxide. The bottle was removed and allowed to cool. Calgon (20

mL) was added and made up to 250 mL mark using deionised water. The bottle was shaken horizontally on mechanical shaker at 100 cycles per minute overnight. The contents of the bottle were transferred the following day (after 24 hrs) into a cylinder and made up to volume with deionised water. A blank cylinder was stirred vigorously then a drop of amyl alcohol was added to remove bubbles. The cylinder was placed on a level surface and a hydrometer dropped in and the readings recorded at 40 s and 5 hr for the soil and blank cylinders. Temperature was recorded at each time. The following calculations were used to determine soil grain percentages:

40 s (Corr.) = 2(40 s reading-40 s blank +T) [3.4]

5 hr (Corr.) = 2(5 hr reading – 5 hr blank + T) [3.5]

Where T = Temperature corrections, thus for every ^{o}C above 20 ^{o}C T= 0.3; for every ^{o}C below 20 ^{o}C T = -0.3.

Particle definition was Sand = 2 mm - 0.06 mm, Silt = 0.06 mm - 0.002 mm, and clay = < 0.002 mm

Textural analysis

Textural analysis was done based on the USDA classification using the texture triangle.

3.4.5 Analysis of Water Samples

3.4.5.1 Determination of the Suspended Solids in Water

Suspended solids were determined using the method by Grant and Tingle (2002). Through a dry fine grade Whatman No. 42 filter paper previously weighed (W_1), an aliquot of water samples (100 mL) was filtered. The filter paper containing the residue was placed in an oven (105 ^{o}C) for 1 hr, cooled in a desiccator and weighed. This process was repeated at least three times, until a constant weight (W_2) was achieved. Triplicates were used.

The concentration of the suspended solids in the water was calculated using the equation:

$$\mathrm{TSS(mg/L)} = \frac{W_2 - W_1}{V_w(\mathrm{ml})} \times 1000\mathrm{ml} \qquad [3.6]$$

Where V_w is the volume of the water (100 mL) used in the filtration process and TSS is the concentration of the suspended materials in mg/L

3.4.5.2 Determination of Turbidity of the Water Samples

Turbidimeter model DRT-15CE was used to determine the turbidity of the water samples collected. Measurements were carried out on the water samples collected before the mining and immediately after mining clay soil had started. Units of turbidity were in NTU.

3.4.5.3 Determination of the Water pH

Measurement of the pH was done at the site during water sampling. A calibrated pH Sergent Welch Model 500 pH meter was used. pH 4 and pH 7 buffer were used to calibrate the pH meter. Three sampling points were chosen, 50 m upstream, at the discharge point, and 50 m down stream. At each sampling point, three measurements were taken. Measurements of the pH were done at two occasions, before mining (control) and immediately after mining (experiment).

3.4.5.4 Determination of Heavy Metal Concentration in the Water Samples

The collected water samples were digested as described below.

Water sample digestion

Water samples were digested using concentrated nitric acid. The sample was thoroughly mixed by shaking, and a suitable volume (50 to 100 mL) was transferred to a beaker to which 5 mL concentrated HNO_3 was added. The sample was brought to a slow boil and evaporated on a hot plate to the lowest volume possible (about 15 to 20 mL) before precipitation or salting-out occurred. Another 5 mL concentrated HNO_3 was added and the sample was covered with a watch glass, and heated to obtain a gentle refluxing action. The heating was continued and addition of concentrated HNO_3 as necessary until digestion was complete as shown by a light-coloured, clear solution. The sample was not allowed to dry during digestion. To dissolve any remaining residue, 1 to 2 mL concentrated HNO_3 was added and the sample was warmed slightly. The sample was allowed to cool after which filtration was carried out. The filtrate was transferred to a 100 mL volumetric flask and diluted to the mark (APHA, 1985). Blanks were treated in the same way but without the sample. Heavy metal determination was done as in section 3.4.4.6

3.4.5.5 Determination of the Water Conductivity

To determine the conductivity of the water samples collected, a conductivity meter (model No. WPA CM 35) with accuracy up to 1×10^{-6} Siemens was used, following the method as described in AOAC (1990).

3.4.6 Analysis of Rock Samples.

3.4.6.1 Determination of Selected Heavy Metals in Rock Samples

Decomposition of rock samples

0.5 g of pulverized rock sample was put into a 100 mL beaker, and 5 mL of concentrated HNO_3 added. The mixture was boiled gently for 30 minutes on a hot plate. The beaker was cooled, 2 mL pechloric acid ($HClO_4$), 5 mL concentrated HNO_3, and 5 mL Hydrofluoric acid (HF) were added. The mixture formed was heated to near dryness. The corners and the walls of the beaker were washed with about 5mL double-distilled water, and the solution heated again until dense white fumes developed. The beaker was then cooled and 10 mL HNO_3 added to dissolve the salts. The solution formed was transferred into a 50 mL standard flask and diluted with double-distilled water. Using the same procedure blanks were prepared except that no sample was used. Triplicate samples were extracted, and then the solution was analysed by means of AAS at wavelengths as for heavy metals in the soil samples in section 3.4.4.6 (Fatoki and Mathabatha, 2001).

3.4.6.2 Determination of Silica (SiO_2) Content in the Rock Samples

The rock samples were analysed using the molybdenum-blue calorimetric method by Matsudaira (1992). The determination started with the digestion of the rock samples.

Decomposition of the silica in the rock samples

0.100 g of the pulverized sample was weighed into a clean nickel crucible and 2.000 g of NaOH added to the sample, and the mixture was thoroughly mixed. The resultant mixture was heated gently while increasing the heat intensity towards strong heating for 3 minutes. The heated mixture in a crucible was cooled and placed in a 500 mL polypyrene beaker, after which water was added to dissolve the melt, and the crucible was removed and rinsed with hot water. The resulting solution was transferred into a 250 mL volumetric flask and diluted

to the mark with distilled water. The contents of the volumetric flask were filtered into a 500 mL polypyrene beaker using fine grade Whatman No 42 filter paper (During the process the first 10 ~ 20 mL of the filtrate were discarded). The filtrate collected was the sample solution for the analysis. 1mL of the sample solution was pipetted into a 100 mL volumetric flask to which 1 drop of p-Nitrophenol indicator was added followed by drops of HCl (1+4), until the colour of the solution changed from yellow to colourless. About 50 mL of water was added to dilute the solution, after which 1mL of HCl (1+4) was added once again followed by Ammonium Molybdate solution (5% w/v, 4 mL) and mixed thoroughly. The solution was left to stand for 30 minutes. Tartaric acid (10% w/v, 5 mL) and ascorbic acid (5% w/v, 2 mL) were added to the mixture. The solution was diluted to the mark using distilled water and left to stand for 30 minutes.

Analysis of the silica on the UV/Vis spectrophotometer

Determination of decomposed samples and standards for silica was carried out using UV/Vis spectrophotometer (UV-2201 Shimadzu Model) at wavelength 650 nm against a blank.

3.5 Calculation of Some Parameters

Determination of diversity indices

Data obtained through the activity in 3.3.1 was fed into software called EcoSim700 to be rarefied (Gotelli and Entsminger, 2002). This was to ensure that estimates were not biased or influenced by abundances or sampling intensity (Gotelli and Colwell, 2001). The software was commanded to calculate and give out the following species diversities indices: Shannon Diversity Index (SDI), and Species Richness (SR) (Gotelli and Entsminger, 2002).

Conversion of concentration from mg/L to mg/g

Element/cations concentration was converted from mg/L to mg/g using equation [3.7] below by means of Microsoft excel:

$$\text{Conc.}(\text{mg/g}) = \frac{\text{Conc. in extracts}\,(\text{mg/L}) \times \text{Volume of extract(L)x df}}{\text{Mass of Soil sample (g)}} \quad [3.7]$$

Where *Conc.* stands for concentration and *df* dilution factor

3.6 Determination of Some Selected Physiographic Characteristics in the Sites

Direct observation was employed in this case and involved a systematic field survey guided by a carefully prepared matrix was used (Appendix B-2). The study took a qualitative approach due to the nature of the parameters and resources available. The following selected parameters were studied: erosion, riverbank stability (this was achieved by finding out evidences of erosion and bank failure), root exposures, nature of pits and steepness of the slope (Dejene *et al.*, 1997; Herron *et al*., 2001; Padmalal *et al*., 2004; Stocking and Murnaghan, 2000). Pictures were taken as well to aid interpretation of the collected data (Dejene *et al.*, 1997).

3.7 Determination of Peoples Views on the Effects of Mining the Sites.

3.7.1 Focus Group Discussions

Focus group discussions (FGD) were conducted with people at village committee level, to provide information on the effects of the project on the environment and suggested solutions to the problems (Appendix B-3).

Some discussion was also conducted for the employees (those involved in raw materials) to provide information on raw materials and effects of mining on the environment (Appendix B-4).

3.7.2 Interviews with Key Informant

This was carried out on one to one basis with the Acting District Environmental Officer, Dedza district.

3.8 Statistical Analysis of the Data Collected

Statistical analysis on the quantitative data involved the use of descriptive statistics (means, standard deviations, and ranges) to summarise parameter findings (Pallant, 2001).

One-way ANOVA was used to compare physicochemical parameters in the mined and unmined sections, while the independent t-test was used in comparing diversity indices in the mined and unmined sections (Pallant, 2001), to determine the effects of mining in the sites. For physicochemical parameters $p < 0.05$ was used, but for vegetation diversity $p < 0.1$, due to fewer data (Pallant, 2001). *Eta-squared* ($\acute{\eta}^2$) value (effect size) was used in determining the

proportion of the dependent variable explained by the independent variable (Pallant, 2001). According to Pallant (2001) $ή^2 = 0.01$ is small effect, $ή^2 = 0.06$, moderate effect, and $ή^2 = 0.14$ large effect. That is $0 < ή^2 < 0.06$ stands for small effect, $0.06 \leq ή^2 < 0.14$ is moderate effect, and $0.14 \leq ή^2$ means large effect. $ή^2 = 0.67$, implies that 67 % of the dependent variables are explained by the independent variable in a linear regression analysis.

Correlations were calculated to determine relationships and associations between parameters to investigate the causal - effects nature and sources. Significant levels of $p < 0.05$ were used, but where the level was greater than 0.05, r^2 was used to make decisions, and $r^2 > 0.2$ was counted as high for exploratory purposes on parameters, assisted with theory and literature on the concerned variables (Kleinbaum and Kupper, 1978).

Thematic analysis was carried out especially on the qualitative data generated from the field surveys, observations, pictures, focus group discussions, and consultations with key informants. Literature and observations were used to interpret the collected data.

HAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents, describes and discusses results of physiographic and vegetation characteristics, as well as, physicochemical characteristics of soils and water in the mining sites, and goes further discussing how and why mining activities affect them. Rock raw materials are also considered in the discussion; their selected chemical characteristics and possible effects on the environment, when mined, are suggested.

4.2 Physiographic features of the Study Sites

4.2.1 Topographical information of the mining sites

Table 4.1 shows qualitative field results on physiographic characteristics. The altitude and the red colour of the Kuthindi (1556 m) and Mzengeleza (R) soils (1600 m) suggest low pH and fertility status in the sites (Chiona *et al.*, 2002). On the other hand, the greyish-brown (grey soils) of Mmbale, Mtanthila and Mzengeleza (J) imply higher pHs, or nearly neutral, as light coloured soils (i.e. grey-white) are associated with high base cation content (Sanchez, 1976). The mottling observed in the upper layers of the grey soils, underlying the red-brown soils at Kuthindi, denotes poor drainage in the soils of the site, while the red spots are a resulting of oxidation reactions between oxygen and iron in soils producing the reddish iron (III) oxide (Thompson and Troeh, 1978).

4.2.2 Effects of Mining on the land in the Mining Sites

The study has shown that mining caused (i) the creation of pits and pools (encouraging water logging) (Figure 4.1), (ii) soil instability leading to bank failure and erosion (Figures 4.2 and 4.3). Pools were prevalent at Kuthindi and Mmbale sites (on average 1.5 m deep in each case), largely due to the mining of clay beyond the water table of the area (Padmalal *et al*., 2004). These sites (Mmbale and Kuthindi) have high water tables such that relatively shallow digging results in collection of water in the dug pits forming pools. The water tables of Kuthindi and Mmbale were 45 cm and 1.5 m respectively.

Creation of pits and pools (4 m- 60 m wide) constitutes threats to livestock and people (Padmalal *et al.,* 2004). The threat posed by pits and pools to people and livestock livestock was also mentioned during FGDs, in Mmbale and Kuthindi mining sites.

Table 4.1: Topographic features of the mining sites

Topographical Characteristics	Mining Site			
	Kuthindi	**Mmbale**	**Mtanthila**	**Mzengeleza**
	Situated at altitude 1556 m, in a river valley of average width 50 m, surrounded by highly weathered red soils. The valley has red topsoils (possibly eroded from the surrounding land), but deep down it has fine grey soils with mottling (mixed yellow and brown colour with some dark grey spots) and red spots on the upper layers and grey in the lower layers (It is this soil that is mined). Along the valley runs a perennial river, which provides the people with water for use in the gardens.	Located in Linthipe area at altitude 1186 m, it is flat with mainly grey soils. On the northwestern part there is a low-lying dambo area, while on the northeastern part there is a graveyard inhabited by thick forest of brachystegia type. The southern part has houses within a distance of 150 m.	Lies at altitude 1164 m, on a flat land gently sloping to the western direction, which forms part of the Linthipe area. The area has brown and grey- brown soils. A deep trench of length 100 m runs from the northwest to southeast, exposing the underlying rocks containing quartzo-felspathic rocks and partially weathered feldspar rocks.	Situated on the mountain foot at altitude 1600 m, with slopes ranging from 32 ^{o}- 35^{o}. A small depression naturally divides the site into two; eastern and western sections. The eastern part is lower with grey soils, while the western part is higher with red soils. On the lower southern part of the eastern part, there is a stretch of dambo land running along the depression down the mountain foot. It has aquifers that supply the water to the wells used by the villagers.

This possibly necessitated the pottery to cover up some of the pits and pools with waste and shelvings (At Kuthindi, Mmbale, and Mzengeleza).Since the rate of covering up the pits and pools was far much slower than the mining of the clay itself; this intervention was less significant and inconspicuous. Frequent cover up at the rate of clay mining is required. Physical characteristics of the land observed in the mining sites are shown in Table 4.2.

Soil erosion was also evident in all the mining sites. It was characterised by sediments, gullies, rills, and root exposures (Table 4.2). The most affected sites were Kuthindi and Mzengeleza, where significant levels of sedimentation, and rills, were encountered. At Mmbale and Mtanthila, there were some indications that mining was not directly responsible, as similar magnitudes were observed in the unmined sections. These sites lie in an area, which is highly vulnerable to soil erosion (Thatcher, 1968), possibly this was the cause.

However, mining played a part in causing erosion at Kuthindi and Mzengeleza. The activity probably induced physical disturbances of the soils and removal of vegetation cover, making the soils vulnerable to running water (UNEP, 1991). The loss of vegetation land cover, together with the sloping nature of the sites increased their susceptibility to erosion (Kuthindi lies on a mountain toe, while Mmbale lies on a mountain foot with slopes $32^{o} - 35^{o}$). At Mzengeleza the bare and hard surface left after mining (Figure 4.2), probably impeded efficient water infiltration into the ground, allowing more water to runoff causing more erosion in the lower sections of the slope.

Effects of mining activities on the riverbanks were also evident, particularly at Kuthindi, where the eastern bank had signs of failure due to instability (Figure 4.3). The undercutting and removal of vegetation cover possibly caused these bank failures.

Mining activities have further affected land availability for farming. The original land use types (e.g. farming, natural woodlot etc) were replaced by mining. It is believed that encroachment into some of these sites is probably a sign of the scarcity of arable land. This possibly confirms the statement by government, describing the district as having very low percapita land holding capacity (0.4 Hectare/ person) (GoM, 1999b).

Table 4.2: Physical characteristics of the land in the mining sites

Biophysical Characteristic	Mining Site			
	Kuthindi	**Mmbale**	**Mtanthila**	**Mzengeleza**
Rills/Gullies	Rills were seen running down the disturbed banks threatening the valley through siltation. (If left unattended may result into gullies due to the slope of the river valley).	Small rills were evident however no gullies were encountered in the site	Rills running along the large trench at the mining site	Evidences of erosion at large scale were seen in the old mining site. Some rills ran towards the depression and towards the lower part of the mining site
Pits/pools	Pools in old mining pits with an average depth 1.5 m. Making the site highly water logged.	Pits with water, forming artificial ponds (1.5 m deep on average)	One pit at the present mining site, however, old mining sites were left without remedy and numerous small pits were found in the area.	Two large uncovered pits of average depth 1.5 m, and 80 m by 60 m. Signs of pool formation in the pits during the rainy season were found
Plant /root / rock exposures in the vicinity	No evidences of root exposure were encountered	Only one instance was encountered, hence not significant at all	No evidence found	Evidences of rock and root exposures were encountered in the old mining site.
Siltation/sedimentation	Red silt and sediments in the river valley eroded from the banks and soils of the surrounding areas.	A few instances in the paths and road	Little found in the trench from the soil eroded in the surrounding area	Instances of sediments in channels formed by running water and deposited in the lower part of the slope were observed.
Bank Stability	Evidences of bank instability through bank failure	Not applicable	Not Applicable	Not Applicable
Ground surface after mining	Grey clay soils	Kaolinitic clay soil	Quartz rocks or Partially weathered felspathic rocks, forming white lime like substance, which is used by locals for liming their houses.	Hard- gravel in the mined parts with no loose soil left on it.

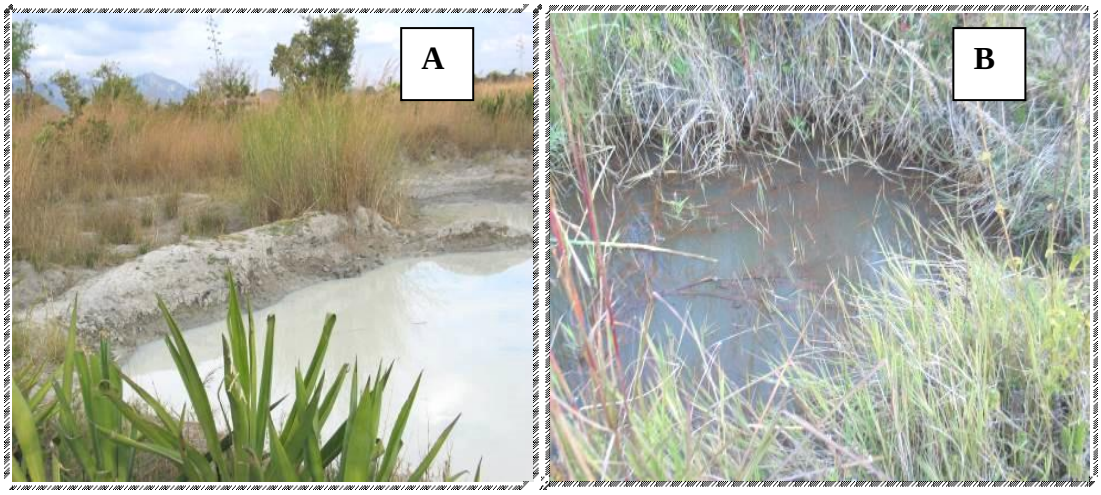

Figure 4.1: Some of the pools created by the mining of clay soils
Mmbale site (A) and Kuthindi site (B) taken during the dry season (September)

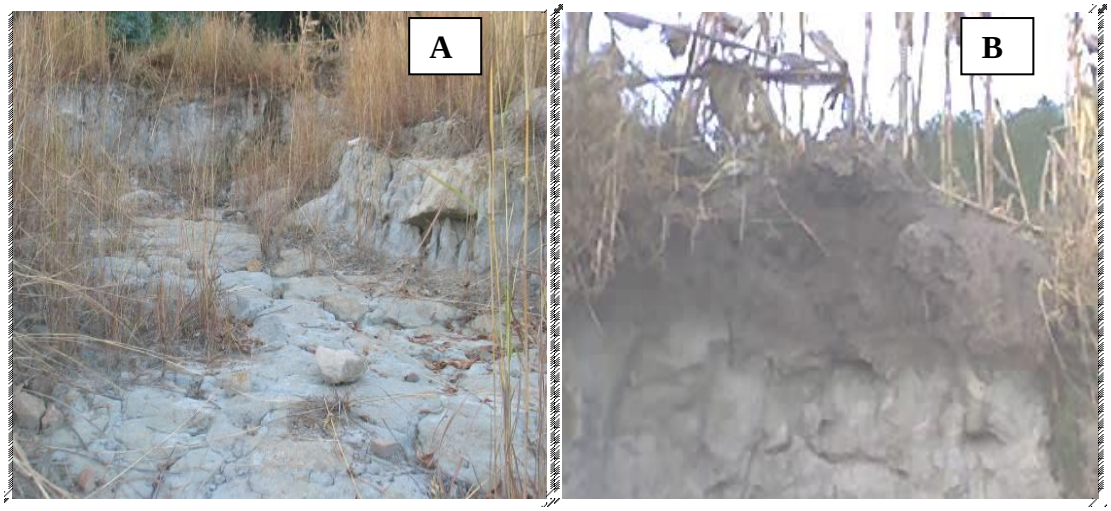

Figure 4.2: Part of the old pit (A) and a gully in a maize field (B) at Mzengeleza mining Site

Figure 4.3: Signs of bank failure at Kuthindi site

The area around the pottery had many of its anthills mined, as such, it is feared that mining of anthills for clay could be affecting the ecology of the area around the pottery, through the disruption of the ecological niche of the ants, which could affect other organisms in the ecological set up of the area (Koziell and Omosa, 2003; Miller, 1993) (Figure 4.4). Field study and informal interviews with employees at the pottery revealed that more than ten anthills were used for this purpose in the past three years.

Figure 4. 4: Mining of the anthill for its clay at Dedza Pottery (August, 2006)

4.3 Biodiversity Characteristics of the Vegetation in the Study Sites

4.3.1 Floristic Composition of the Study Sites

A total of 96 plant species, belonging to 80 genera, and 31 families were identified in this study. These were grouped into trees, shrubs and herbs. The studied species have been included in the Appendices (Appendix A–1 to A-3).

The average abundances of the three vegetation types showed a clear dominance of the herbaceous vegetation species in the mining sites (Figure 4.5). The high density of herbaceous species per quadrat, in the mined and unmined sections of the sites, seems to indicate their ability to withstand introduced disturbances (Woodwell, 2004). It is suggested that the general low tree and shrub densities, both in the mined and unmined sections of the sites, are exacerbated by high population and low growth rates of the indigenous vegetation types (GoM, 2002b).

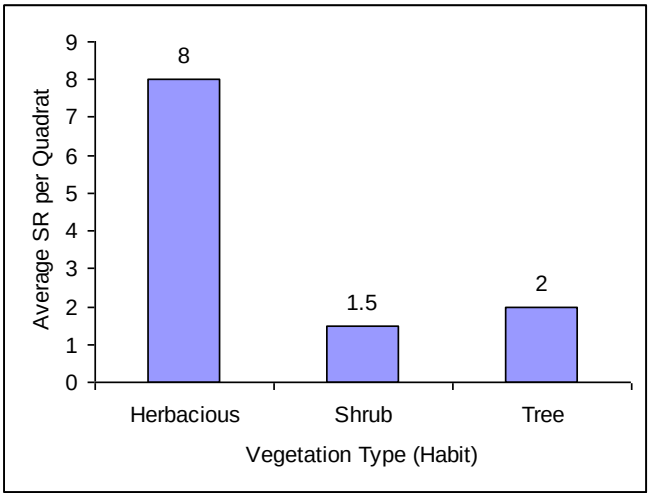

Figure 4.5: Comparative abundance of vegetation species types in the mining sites

4.3.2 Vegetation Diversity of the Study Sites

Vegetation diversity indices in the mined and unmined sections of the sites are shown in Table 4.3. The SR of the herbaceous species in the mined sections was generally lower than the unmined sections, except for Mchekecha. The decrease in the SR of the herbaceous species in the mined sections could be attributed to the high disturbances caused in the sites (Gotelli and Colwell, 2001; Woodwell, 2004). Mining affects the moisture content, OM, and availability of nutrients needed for plant growth (Sarma, 2005). These critical nutrients were negatively affected by mining (section 4.4 later).

Table 4.3: Herbaceous, Shrub and Tree Diversity Indices in Mining Sites

Diversity Index		Mining Site									
		Kuthindi		Mchekecha		Mmbale		Mtanthila		Mzengeleza	
		UNM	MN	UNM	MN	UNM	MN	UNM	MN	UNM	MN
Herbaceous Species	***SR***	20	11	12	14	11	6	17	12	17	9
	SDI	2.21	1.42	1.46	2.16	1.08	1.2	1.59	1.34	1.51	0.23
Shrub Species	***SR***	0	0	2	1	0	1	3	0	8	2
	SDI	-	-	-	0	-	0	-	-	1.74	0.38
Tree Species	***SR***	0	0	8	3	2	2	0	0	3	0
	SDI	-	-	1.34	0.89	0.33	0.44	-	-	1.01	-

(SR = Species Richness; SDI =Shannon Diversity Index; MN = Mined; UNM = unmined)

These effects were adverse to some species, allowing a few resistant ones to grow, hence causing a decrease in SR (Sarma, 2005).

The increase in SR of the herbaceous species in Mchekecha (from 12 to 14) is probably due to an intermediate disturbance introduced by mining on its natural forest, which was relatively better inhabited with trees (Teodorescu and Cogalniceanu, 2005). The disturbance possibly resulted in the creation of favourable conditions, allowing more species that were initially excluded at low disturbance to find a chance of growing (Teodorescu and Cogalniceanu, 2005).

It is interesting that at Kuthindi neither a shrub nor a tree species was registered within the boundaries of the study area. This is most likely because the site was previously a garden (FGD), as such trees might have been cut. Further, in this area careless and wanton cutting of trees is prevalent; some tree species were scarce or extinct (FGD).

The SR of the tree species was high at Mchekecha site (Table 4.3). This is probably because of the protection provided by the forest reserve, as the site is in Dzonze-Mvai forest reserve (Figure 3.1). Outside the reserve there were no trees.

Unlike the tree species, the shrub species had the highest SR at Mzengeleza, suggesting secondary ecological succession (Miller, 1993), and the presence of guava shrubs at the site probably supported the existence of past human activities at the site, from which the land was probably recovering. The higher values of the SR for the tree species in the unmined than in the mined section, at Mchekecha and Mzengeleza, as well as, that of shrub species at Mchekecha, Mtanthila, and Mzengeleza (Table 4.3), could imply that mining has an effect of reducing the number of tree and shrub species in the sites.

The use of SDI on the herbaceous species was not particularly valuable. Mchekecha and Mmbale gave higher SDI in the mined sections than unmined sections of the sites. This agrees with the findings of other researchers such as Das Gupta (1999) and Sarma (2005), who worked in similar studies. The increase in SDI in the mined section was caused by the creation of favourable conditions after mining, through elimination of competitive dominance prevalent at low disturbance (Teodorescu and Cogalniceanu, 2005). Kuthindi, Mtanthila and Mzengeleza gave higher values of the SDI in the unmined sections than mined sections of the sites, denoting a decrease. These results are at variance with expectations (Sarma, 2005). This

probably indicates the existence of high, frequent and chronic disturbances in the sites, making the growth of some herbs difficult, only allowing the growth of resistant species (Woodwell, 2004).

Table 4.4 shows a summary of the vegetation study (all vegetation types combined). The summarised data showed no significant differences in SDI between the mined and unmined sections ($p > 0.1$). However, the SR significantly decreased in the mined sections ($t = -2.17$; $p < 0.1$), concurring with Sarma (2005) in his study on the effects of coal mining on vegetation. The cause is stress originating from changes in soil moisture content, texture, nitrogen, organic matter etc in the mined sections (section 4.4. later) (Sarma, 2005).

Table 4.4: Summary of the vegetation indices in the mining sites

Species Diversity Index	**Section**	**Mining Site**				
		Kuthindi	**Mchekecha**	**Mmbale**	**Mtanthila**	**Mzengeleza**
No of Individuals	Mined	842	413	682	1635	2108
	Unmined	1478	1478	2930	1269	1705
Species Richness	Mined	19	19	10	11	12
	Unmined	21	21	12	16	28
Shannon Diversity Index	Mined	2.39	2.39	1.43	1.29	0.28
	Unmined	1.63	1.63	1.09	1.6	1.66

From this discussion (4.3.1), it could be concluded that the major effect of Dedza Pottery mining activities on vegetation diversity, is causing reduction in SR (number of vegetation species). This could be translated as a reduction in diversity, as species become less diverse due to reduction in species.

4.4 Physicochemical Parameters of the Soils

4.4.1 Particle Size Distribution and Texture of the Soil

The particle size distributions of the soils in the mining sites are presented in Table 4.5. The topsoils in the unmined sections of the sites are dominated by sand particles (53.3 ± 5 %.), while clay dominates the subsoils in unmined sections (46.1 ± 21 %), and topsoils of mined sections (42.0 ± 19 %). The fineness of the particles increased vertically (i.e. with increase in depth). This is because subsoils are older and fully weathered than topsoils, and that the clay in the topsoils is lost to the subsoils layer through leaching (Thompson and Troeh, 1978).

Table 4. 5: Percentage soil particle size distribution in the study sites

(Unmined top soils, subsoils and mined Soils) (Mean ± d; n = 15)

Aggregate	**Soil Sample Type**		
	Unmined topsoils (%)	**Mined Soils (%)**	**Subsoils (%)**
Clay	19.7 ± 6.0 (12.4 - 28.4)	42.0 ± 19.0 (20.4 – 66.4)	46.1 ± 21.0 (17.0 - 70.4)
Sand	53.3 ± 5 (47.6 – 57.6)	40.8 ± 1.0 (21.6 – 57.6)	35.6 ± 13.0 (17.6 – 50.2)
Silt	27.0 ± 7.0 (14.0 – 32.0)	17.2 ± 7.0 (8.0 – 24.0)	18.0 ± 10.0 (10.0 – 32.0)
Clay + Silt	46.7 ± 5.0 (42.4 – 52.4)	59.2 ± 14.0 (42.4 – 78.4)	64.3 ± 13.0 (49.8 – 82.4)

There is a significantly high correlation ($r = 0.98$; $r^2 = 0.96$; $p = 0.004$) between clays in the topsoils of mined, and the subsoils in the unmined sections of the sites and this suggests that the increased clay content in the topsoils of the mined sections, came from the clay soil dug from subsoils and later re-deposited on the surface during the mining process. This is probably the case for the high percentage of the finer soil particles (clay+ Silt) in the topsoils of the mined sections (59.2 ± 14%).

Table 4.6 shows soil textures of the three sample types in the mining sites. The results show that changes leaned towards the texture of the subsoils, particularly for Kuthindi Mmbale, Mzengeleza (R) and Mtanthila sites. Average textures of the soils changed from sandy clay loam (SCL) in topsoils of the unmined sections, to clay (C) in the topsoils of the mined sections (Table 4.6). This is probably because the waste in the mined sections were mainly subsoils, which mainly comprised clay (Table 4.6), and soil characteristics in mined areas are dependent on characteristics of subsoils (Sarma, 2005). It could be said therefore, that mining

has affected the texture of the soils in the mining sites. However, Mzengeleza (J) gave different results, possibly due to laboratory errors or an exchange of the samples with those of the Mtanthila mined section.

Arets *et al*. (2006) have recently reported changes in texture due to mining in South Africa. In their study, mined soils had low content of clay than the unmined ones (Arets *et al*., 2006). This is different from the results in the current study. The difference is due to the water flashing process, which removed the low density clay particles in the mined soils, leaving behind more sand (Arets *et al*., 2006).

`

Table 4. 6: Soil texture in the mining sites

*(*C- *Clay,* SL- *Sandy loam,* SCL-*Sandy clay Loam,* L- *Loam,* CL-*Clay loam)*

Mining Site	Texture of the Soil Sample Type		
	Unmined Topsoils	**Subsoils**	**Mined Soils**
Kuthindi	SL	C	C
Mmbale	L	C	C
Mtanthila	L	CL	SCL
Mzengeleza (J)	SL	SL	SCL
Mzengeleza (R)	SL	C	C
Average Texture (All Sites)	SCL	C	C

This discussion shows that mining changed the soil texture in the mining sites. The change was mainly from loamy textures to clay textures, possibly caused by the dumping of subsoils, rich in clay, onto the surface after mining.

4.4.2 Soil pH, Organic Matter and Moisture Content in the Mining sites

The average pHs for the samples of topsoils in the unmined sections, mined soils and subsoils in all sites were 5.70 ± 0.58, 5.71 ± 0.50, and 5.53 ± 1.10 respectively. The comparison between mined and unmined sections was found to be statistically insignificant (ANOVA, $F = 0.067$; $p = 0.9$), showing that the mining activity has insignificant effects on the soil pH characterising the mining sites. Site comparisons gave significant differences (ANOVA, $F = 6.38$; $p = 0.008$; $\acute{\eta}^2 = 0.01$), implying that the pH values of the soils are site specific, denoting geochemical differences between them. The pH values of the sites are shown in Figure 4.6.

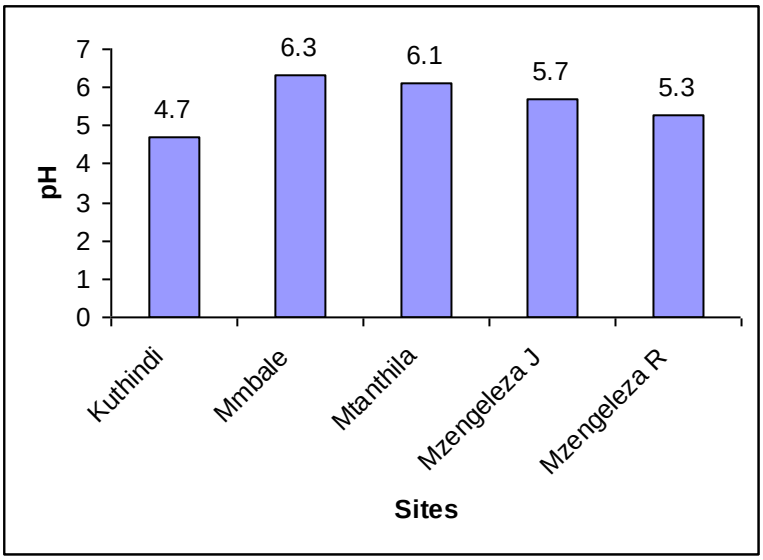

Figure 4.6: pH in the mining sites

The pH values of the soils in Figure 4.6 are typical of Dedza district, moderately acidic (pH 6.3 ± 0.6) to very acidic (4.7 ± 0.27) (Brown and Yonegh, 1965). Sites located in the Linthipe plains (Mtanthila and Mmbale) had higher pH values, than those in the highlands areas (Mzengeleza (J and R) and Kuthindi) (Figure 4.6). This is probably because of climatic differences between the areas (Thompson and Troeh, 1978), caused by variations in topology (Thatcher, 1968). The high areas of Dedza receive relatively higher rainfall than the low-lying Linthipe plains; with annual values being 1200 mm and 800 mm respectively (Macmillan Malawi, 2001).

The high pHs in the low rainfall areas of Dedza are due to less leaching of base cations (Ca, Mg, and K), increasing their concentration beyond that of the acid forming ions (H^+ and Al) (Brady and Weil, 1996; Thompson and Troeh, 1978; Wild, 1993). This process is called *alkalinization or hydrolysis (*Wild, 1993). The equation below illustrates the whole process.

$$(Ca, Mg, K)\,\text{Silicate} + H_2O \rightarrow Ca^{2+} + Mg^{2+} + K^{+} + Si(OH)_4 + OH^{-}$$

On the contrary, the soils in the high rainfall areas of Dedza had low pHs (acidic) because the base forming cations are leached, leaving behind acid forming cation (Brady and Weil, 1996; Thompson and Troeh, 1978; Wild, 1993), and also the oxidation of ferrous (II) sulphides (e.g. pyrite) in a reaction with water, producing more H^+, consequently increasing the acidity of the soils as shown in the equation below (Wild, 1993):

$$4FeS_2 + 15O_2 + 8H_2O \rightarrow 2FeO_3 + 16H^+ + 8SO_4^{2-}$$

The above equation implies that the more the iron in the soils, the higher the oxidation process, and the more the H^+ ions produced, consequently, the lower the pH. Red soils have high iron content (Bohn *et al*., 1985; Wild, 1993). The direct relationship between iron content and the acidity of soil probably explains why the highland areas of Dedza, predominantly comprised red soils, had acidic soils. The negative correlation between Iron (Fe) and pH (r = - 0.403; p = 0.1), though weak and insignificant, possibly supports the theory that iron has an effect of reducing the pH of the soils (i.e. increasing the acidity), through an increase in H^+ ions implying inverse relationship between soil pH and Fe content.

The relationship is inverse because at lower pHs Fe exists as ferrous iron (Fe^{2+}), which is relatively soluble, unlike at higher pHs where it takes the form of ferric iron (Fe^{3+}), which forms insoluble compounds with other elements, making it less available in free ionic form (Thompson and Troeh, 1978).

The strong and significant correlations found between the soil pH and the following elements: magnesium (Mg) (r = 0.765; p = 0.001), calcium (Ca) (r = 0.705; p = 0.003), and potassium (K) (r = 0.574; p = 0.025), probably indicate that concentrations of Mg, Ca and K in the soils of the mining sites are amongst the major factors determining the soil pH. The Pearson's correlation coefficient ("r") was highest in magnesium, possibly implying that Mg has more influence on the soil pH of the study sites.

The comparison of various sections for OM is shown in Table 4.7. It reveals significant differences among the three sample types (ANOVA, F = 5.8; p = 0.016; $\eta^2 = 0.5$).

Table 4. 7: Percentage OM of the soils from the three sections of the mining sites
(Mean ± d)

Sample Type	**Mean (%)**	**Maximum (%)**	**Minimum (%)**
Top soils	7.40 ± 2	10.42	4.60
Sub soils	3.64± 2	6.15	2.20
Mined soils	2.94 ± 3	7.01	1.16
Statistical significance	**	na	na

**** Stands for "Statistically significant at p< 0.05" while "na" stands not applicable since values are the maximum or minimum**

Topsoils gave a significantly higher OM (7.40 ± 2 %) than subsoils (3.64 ± 2 %) (Table 4.7). This is largely because more decomposition of the living matter occurs in this layer, due to better ventilation (Thompson and Troeh, 1978). The high effect size (0.5) described by the *eta-squared* value ($ή^2$) strongly strengthens the argument that sample types have different OM (Pallant, 2001).

The difference was also obtained between topsoils from unmined sections and mined soils ($p<0.05$), through Post-hoc analysis. This showed that mining clearly reduced the OM in the soils. The low value of the OM in mined soils could be due to reduction in organic litter (e.g. vegetation) content in these sections as compared to unmined sections (Sarma, 2005), and probably the dumping of the subsoils with low OM on the surface. The second reason is speculated because the subsoils had a lower OM value (3.64 ± 2 %) than topsoils (7.4 ± 2 %), and the comparison between subsoils and mined soils for OM gave no significant difference ($p = 0.869$), showing possible similarities in OM between them. This probably suggests an influence of the subsoils on the mined soils in mined sections, in terms of OM content.

However, site comparisons showed insignificant differences (ANOVA, $F= 0.959$; $p = 0.47$; $ή^2 = 0.28$), implying that site differences do not significantly affect the soil OM in the study sites. Figure 4.8 shows comparative values of the OM in the mining sites. Mtanthila exhibited the highest value (7.33 ± 1.3 %) of all the sites. This is likely due to deposition of litter into the area by a company (FGD), and upon decomposition, the litter increased the soil OM (Thompson and Troeh, 1978). Apart from causing an increase in OM at Mtanthila, mining generally caused reduction in the soil OM in sites, as found and discussed above.

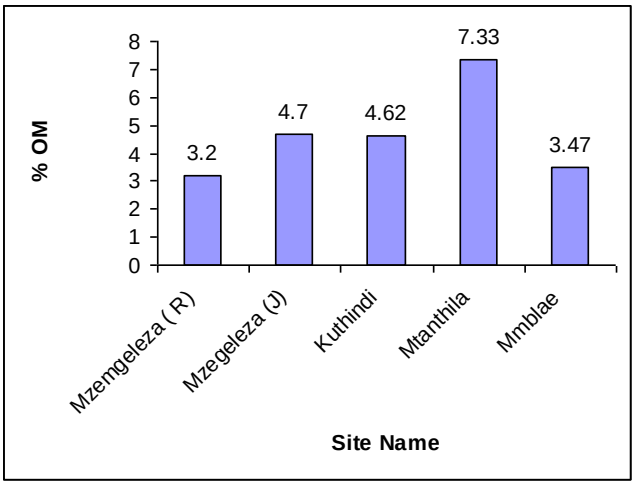

Figure 4.7: Percentage Organic Matter in the mining sites

Soil moisture contents of three sections studied, were significantly different (ANOVA, $F = 7.862$; $p = 0.007$; $\acute{\eta}^2 = 0.57$). The moisture contents were: top soils in the unmined sections 2.5 ± 2 %, subsoils in the unmined sections 3.6 ± 2 %, while for topsoils in the mined sections 7.5 ± 3 %. The higher moisture content in the mined sections was due to the high clay content in them (Orloff *et al*., 2003; Skrull *et al*., 2004; Thompson and Troeh, 1978). Clay soil holds more water due to large surface areas, resulting from their small pore spaces (Thompson and Troeh, 1978). Results of textural analysis showed that topsoils from the mined section had higher clay content (42.0 ± 19 %) than the topsoils of unmined sections (19.7 ± 6 %).

Topsoils in the unmined sections had low water holding capacity than subsoils. The low moisture content in topsoils of unmined sections was caused by the high proportion of sand in these sections (53.3 ± 5 %), causing a decrease in water holding capacities, consequently decreasing the soil moisture content (Thompson and Troeh; 1978). The subsoils of the unmined sections contained low proportion of sand (35.6 ± 13 %). Sand holds less water due to low surface area presented to water (Thompson and Troeh; 1978). Site comparisons did not show any significant differences in moisture content ($F= 0.284$; $p = 0.88$; $\acute{\eta}^2 = 0.1$).

It could be concluded that mining has no effect on the soil pH, however, it decreased the OM, and caused an increase in the water holding capacity of the soils in the mining sites, as discussed above.

4.4.3 Available Soil Nitrogen and Phosphorus

The comparison of mean available nitrogen and phosphorous in the mining sites, regardless of the soil soil sample type (Topsoils, minedsoils and unmined soils) is provided in Table 4.8.

Table 4. 8: Nitrogen and phosphorus content in the soils of the mining sites
(Mean ± sd; range)

Site	**Nitrogen (**mg/g**)**	**Phosphorus (**mg/g**)**
Mmbale	0.050 ± 0.004 (0.002 – 0.010)	0.011 ±0.020 (0.001 – 0.030)
Mtanthila	0.0069 ± 0.008 (0.002 – 0.020)	0.012 ± 0.020 (0.000 – 0.030)
Mzengeleza (J)	0.0053 ± 0.004 (0.003 – 0.010)	0.015 ± 0.010 (0.005 – 0.024)
Mzengeleza (R)	0.0017 ± 0.003 (0.001 – 0.010)	0.020 ± 0.030 (0.004 – 0.050)
Kuthindi	0.0019 ± 0.002 (0.0002- 0.001)	0.008 ± 0.007 (0.001 – 0.020)
Statistical Significance	X	X

Note: "X" means statistically insignificant at $p < 0.05$ when all sites were compared.

The data showed lack of significant differences in available nitrogen content between the sites (ANOVA, $F = 0.708$; $p = 0.605$), denoting independence of available nitrogen on the sites. The very low values at Kuthindi and Mzengeleza (R) (<0.002 mg/g), contradict with the readily abundant vegetation in the sites, which could be a source of nitrogen after mineralization and fixation process (Brady, 1984). This is probably due to low pHs in the sites (Kuthindi 4.7± 0.27) and Mzengeleza (R) (5.3 ± 0.7) and low presence of base forming cations (section 4.4.6 later) (Brady, 1984). The required pHs for nitrogen fixation and oxidation are those above 5.5 (Brady, 1984). Relatively higher values obtained at Mmbale (6.3 ± 0.6), Mtanthila (6.1 ± 0.2), and Mzengeleza (J) (5.7 ± 0.2), are probably caused by the high exchangeable bases and less acidic soil (higher pH > 5.5), which are necessary conditions for nitrogen fixation and oxidation (Brady, 1984).

Further comparisons between soil sample types (i.e. topsoils in mined sections, topsoils in unmined sections and subsoils in unmined sections), have shown that concentration of nitrogen is significantly different between the soil sample types (ANOVA, $F = 10.834$; $p < 0.01$). The mean values of the three sections were topsoils in the unmined section (0.0091 ± 0.005 mg/g), subsoils in unmined sections (0.0015 ± 0.001 mg/g) and soils from the mined

sections (0.0019 ± 0.001 mg/g). These results are in agreement with Padmalal *et al*. (2005) who found the topsoils being generally richer in nitrogen than subsoils. The higher nitrogen values in topsoils of the unmined section, as compared to topsoils of mined sections, denote a reduction in soil nitrogen, which could be attributed to the mining activity.

Pearson's correlation between nitrogen concentration and % OM was high and significant ($r = 0.682$; $p = 0.005$). This statistical result suggests that OM is the most probable source of available nitrogen in the mining sites, implying that it is mainly organic in form, concurring with Wells *et al.* (1997). Therefore, it could be argued that the low nitrogen content in the mined sections was caused by the low OM in the sections. Similar results were found by Padmalal *et al.* (2004) in their study on the clay mining and related environmental problems in the Chalakudy basin.

Site comparison for phosphorous (P) (see Table 4.8) revealed insignificant differences between them (ANOVA, $F = 0.225$; $p = 0.918$), suggesting similarities in the availability of the element in the soils of the studied sites. The mean value for all the sites, regardless of the sample type, was 0.013 ± 0.010 mg/g. This value could be classified as low (Chilimba, undated), while the sites range was 0.008 to 0.020 mg/g, being within low to medium content (Chilimba, undated). Table 4.8 shows the site means.

Low mean values for the sites are probably because the site averages took into account the subsoils, which had lower P content (Figure 4.8) (Thompson and Troeh, 1978). The low P value in the subsoils (0.005 ± 0.005 mg/g) is probably evidence to this, contrasting significantly with the high values of P in topsoils of the unmined sections (0.026 ± 0.020 mg/g; $p < 0.05$).

The high P value in the topsoils is in agreement with the existing knowledge, describing soils of Dedza having medium to high P content (Brown and Yonegh, 1965). Figure 4.9 shows the values of soil sample types (top soils from the unmined sections, top soils from mined sections, subsoils from unmined sections).

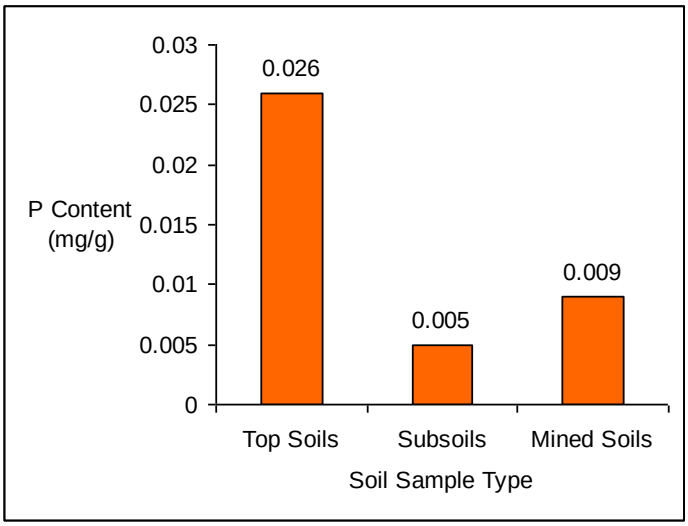

Figure 4.8: Phosphorus in the three mining sections in all sites

The higher P values in topsoils (unmined sections) than subsoils was due to the fact that in the topsoil layer the available P lost through leaching, is immediately replaced by that mineralised from the OM, unlike in subsoils where there is more leaching and absorption by plants than replacement (Thompson and Troeh, 1978). The result concurs with Padmalal *et al.* (2004). This result could mean that the main source of P is at the soil surface, most probably the decomposing organic substances (Padmalal *et al.*, 2004; Thompson and Troeh, 1978). The weak positive correlation between P and OM ($r = 0.3$; $p = 0.3$), probably supports this argument. The high values of available P in the topsoils of the unmined sections, as compared to the topsoils of mined sections, could have resulted from the high OM in the topsoils of the unmined sections, which contributed extra P, among other factors.

Contrary to the results shown on the graph above (Figure 4.9), comparison on the types of samples showed insignificant differences in available P between the topsoils from the unmined sections and topsoils from the mined sections (ANOVA, $F = 3.79$; $p = 0.053$; $\acute{\eta}^2 = 0.33$). This implies that mining has an insignificant effect on P content in the sites. However, having shown that P and OM are associated with each other, and that some P originates from the latter, it could be argued that mining indirectly reduces the available P, since mining has been found to cause negative effects on the OM. This suggestion could be supported by numerical differences in the value of P between the unmined sections and mined sections, which were 0.026 ± 0.02 mg/g and 0.009 ± 0.009 mg/g respectively (Figure 4.9).

Clay particles exhibited a moderate negative correlation with P (r = - 0.429; p = 0.1), though statistically insignificant, possibly due to little data used (Pallant, 2001). The negative correlation denotes the existence of sorptive effects between clay and the available P in the soils of the mining sites. Duffera and Robarge (1999) found strong correlation between the P sorbed and Clay, while Jackman *et al.*, (1997) found strong sorptive abilities of P on clay particles. It is therefore suggested that strong adsorption of P onto charged clay sites, might also have reduced the available P in soils from mined sections as their clay content was higher (42.0 ± 19 %) than those from unmined sections (19.7± 6 %).

Based on statistical results and the discussion, it has been found that mining significantly affects the available soil N content, but not the available soil P content in the mining sites.

4.4.4 The Exchangeable Soil Calcium, Magnesium, Potassium and Iron

The comparison of the soil cations as presented in Table 4.9, showed that the average concentration decreased as follows: Ca (1.06 mg/g)> Fe (0.19 mg/g) > Mg (0.14 mg/g) > K^+ (0.08 mg/g). The decreasing order of the exchangeable cations (Ca> Mg^{2+}>K^+) is consonant with typical productive soils (Bohn *et al.,* 1985). Therefore, this suggests that soils in the mining sites could be productive agriculturally.

Table 4. 9: Content of Major soil cation in the mining sites (mg/g)
(Mean ± d; range)

Cation	Unmined Topsoils	Subsoils	Mined Soils	Statistical Significance
Calcium (Ca)	1.9 ± 0.70 (0.34 – 2.16)	0.97 ± 0.70 (0.29 – 1.63)	1.01 ± 0.60 (0.43 – 1.92)	P >0.05
Magnesium (Mg)	0.14 ± 0.03 (0.09 – 0.18)	0.14 ± 0.04 (0.04 – 0.14)	0.14 ± 0.07 (0.11 – 0.18)	P > 0.05
Potassium (K)	0.10 ± 0.04 (0.03 – 0.12)	0.06 ± 0.03 (0.04 – 0.10)	0.08 ± .03 (0.04 – 0.10)	P > 0.05
Iron (Fe)	0.23 ± .06 (0.16 – 0.30)	0.10 ± 0.17 (0.06 – 0.31)	0.16 ± 0.07 (0.08 – 0.24)	P > 0.05

The calcium (Ca) content showed marked differences between sites (ANOVA, F = 15.686; p < 0.0005; $\acute{\eta}^2$ = 0.86). This difference is probably due to geological differences between the site locations (Thatcher, 1968), as the Ca content is defined by the geochemical nature of the

parent rocks from which the soils originate (SAI, undated). The variations could be seen in Figure 4.9.

Mtanthila and Mmbale sites (Linthipe area) gave out high values of Ca content, 1.9 ± 0.2 mg/g and 1.49 ± 0.1mg/g respectively. This area is underlain by kaolinitic clays, a product of the weathering of the labradorite plagioclase feldspars, of the anorthite type ($CaAl_2Si_2O_8$), forming the bedrock of the area (Piper, 1982).

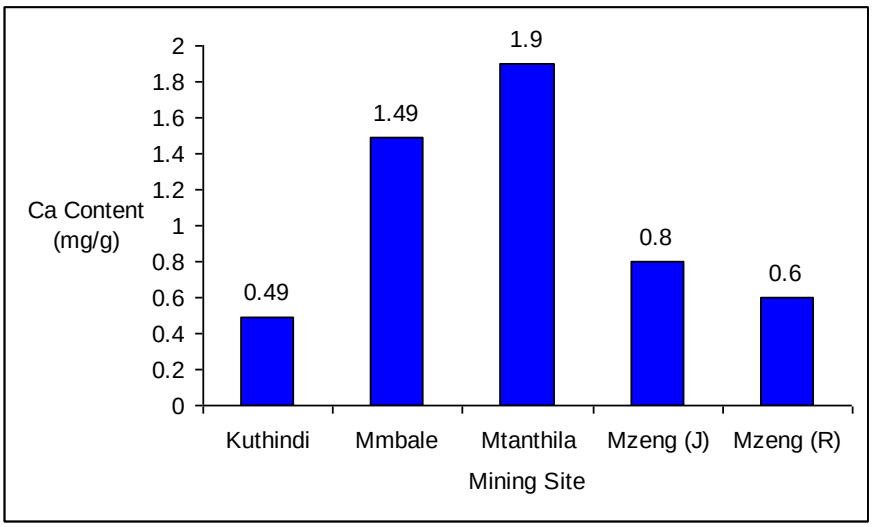

Figure 4.9: Calcium content in the mining sites

The high Ca content at Mtanthila and Mmbale sites, could also be due to the favourable pH values (6.0 < pH<7.2) existing in the soils of the sites (SAI, undated); Mtanthila and Mmbale had pH values of 6.1 ± 0.2 and 6.3 ± 0.6 respectively. Within this favourable pH range, Ca weakly adsorbs to colloidal particles, thereby increasing the content of free Ca, making it more available (SAI, undated). The lower values of Ca at Mzengeleza (R and J), and Kuthindi are probably due to the lower pH values (< 6.0), which were 5.30 ± 0.70, 5.70 ± 0.20 and 4.70 ± 0.27 respectively (SAI, undated). The lower pH values might have increased the solubilities of Fe and Al, and consequently reacting with the free Ca (SAI, undated). The resulting compounds of the reactions are relatively insoluble, causing a reduction in the exchangeable soil Ca (SAI, undated).

The effect of site pHs on the exchangeable Ca as discussed above, is probably confirmed by the significant correlation between pH and Ca ($r = 0.705$; $p = 0.003$), while the formation of insoluble compounds between Ca and Fe at lower pHs, is possibly supported by the negative correlation between Fe and Ca, though weak and insignificant ($r = -0.22$; $p = 0.4$).

The Ca data from the three mining sections revealed insignificant differences in content (ANOVA, F = 0.160; p = 0.854; $\acute{\eta}^2$ = 0.02). This indicated that calcium content in the three soil sample types of the mining sections (i.e. the topsoils from the mined sections, topsoils from the unmined sections, and the subsoils from the unmined sections) is insignificantly different. The lack of significant differences between the mined and unmined sections of the sites implies that mining has insignificantly affected the Ca content in the mining sites.

The magnesium content (Figure 4.11) in the soil samples significantly differed from one site to the other (ANOVA, F = 4.13; p = 0.031; $\acute{\eta}^2$ = 0.67).

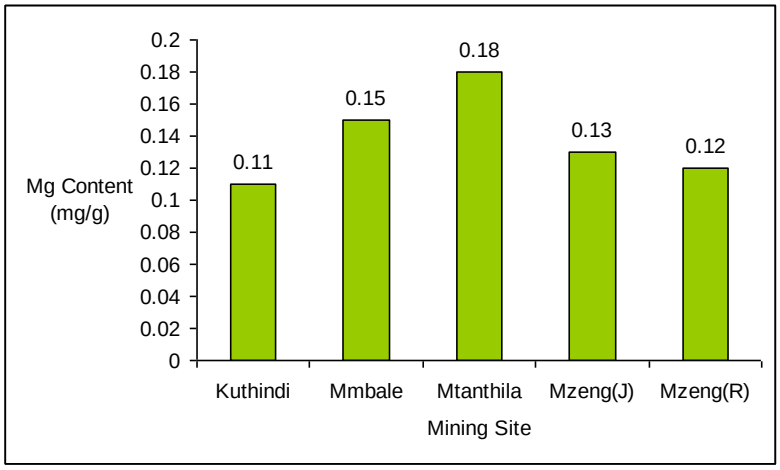

Figure 4.10: Magnesium Content in the mining sites

The major source of Mg is geological, through the chemical weathering of Mg containing minerals which include dolomite ($CaCO_3MgCO_3$), biotite [$K_2Al_2(Fe_{11}Mg)_6O_{20}(OH)_4$], chloriterite ($Al_2Mg_5Si_3O_{10}(OH)_8$, and brucite ($Mg(OH)_2$) (Miller and Gardiner, 1998). The significant differences could imply geochemical differences of the area in terms of Mg content (Alloway and Ayres, 1997).

Mtanthila and Mmbale recorded the highest values of exchangeable Mg (Figure 4.11). This was probably due to their high soil pH values, which were 6.30 ± 0.60 and 6.10 ± 0.20 respectively, as Mg and pH are directly related (Bohn *et al.*, 1985). This study also found a significant correlation between pH and Mg (r = 0.765; r^2 = 0.59; p = 0.001), possibly supporting the argument raised on the said relationship. It could be said therefore, that the low Mg content at Mzengeleza (J and R) and Kuthindi is due to low pH values, which were 5.70 ± 0.20, 5.30 ± 0.70 and 4.70 ± 0.27 respectively (Bohn *et al.*, 1985).

However, comparison between the means of soil sample types revealed no significant difference in content of Mg (ANOVA, F = 0.014; p = 0.99) clearly showing that mining has not affected the exchangeable Mg content.

The content of exchangeable potassium (K) in the sites (Figure 4.12) has not been affected by mining activities (ANOVA, F = 1.84; p = 0.2; p = 0.2; $\acute{\eta}^2 = 0.44$). However, it was revealed that soils at Mmbale and Mtanthila had the highest K values, while those at Kuthindi were the lowest. The high values at Mtanthila and Mmbale are probably due to the presence of K-feldspar which provided the source of K after weathering, as the Linthipe area, where the sites are located, has this kind of feldspar as well (Gwosdz *et al*., 1996). On the other hand, the low levels of the exchangeable K at Kuthindi and Mzengeleza (R and J) could be a result of leaching and erosion taking place in these places (Thompson and Troeh, 1978; Yuan *et al*., 2003). These sites lie in an area with relatively high rainfall, hilly and sloping terrain compared with the Linthipe area (Agnew and Stubbs, 1972; Macmillan- Malawi, 2001).

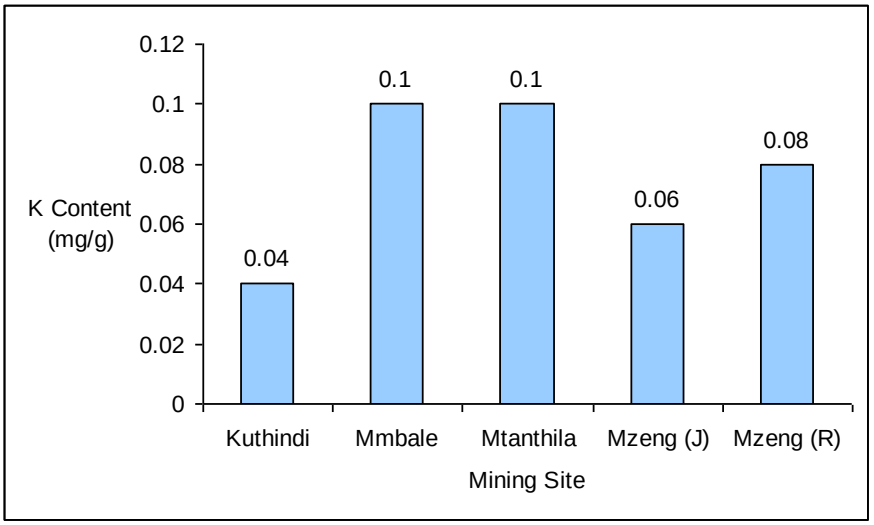

Figure 4.11: Comparative content of potassium in the soils of the mining sites

The data for K in the three soil sample types (mining sections) (Table 4.9) revealed that the levels are not significantly different (ANOVA, F = 2.39; p = 0.13; $\acute{\eta}^2 = 0.25$). This implies that mining activities are insignificantly affecting the exchangeable soil K in the sites.

It was found that high values of exchangeable K were registered in sites with higher pHs (Mtanthila and Mmbale), as opposed to sites with lower pHs (Figure 4.12). This relationship was probably shown by a significant correlation between pH and K (r = 0.58; p = 0.03; r^2 = 0.33). The high values at Mmbale and Mtanthila could be due to their higher pHs which are

favourable to K, as this element is also a base forming cation, unlike Mzengeleza (R and J) and Kuthindi which had lower pHs (Gustfsson *et al.*, 2005; Thompson and Troeh, 1978; Wild, 1993). This correlation could be a pointer to the fact that site differences could affect the K availability, since pH was found to be site dependent ($p = 0.008$). Possibly, the statistical insignificances in the differences found here, could have resulted from the small sample size ($n = 15$) (Pallant, 2001)

The results for iron (Fe) showed no difference between sites (ANOVA, $F = 2.933$; $p = 0.076$; $\acute{\eta}^2 = 0.53$), suggesting lack of significant differences in the geochemical natures of the mining sites. This was also the case when the content of Fe in the different soil types were compared (ANOVA, $F= 0.994$; $p = 0.4$; $\acute{\eta}^2 = 0.15$), probably indicating that mining has not affected the content of Fe in the soils of the mining sites.

However, generally, topsoils in the mined sections gave the highest Fe content (0.23mg/g) (Figure 4.13); this is probably due to the adsorption of Fe onto OM reducing its loss through leaching (Alloway and Ayres, 1997). On the other hand, the low value in the mined soils (0.16 mg/g) is due to the leaching of Fe, caused by the low OM content in the mined sections (Alloway and Ayres, 1997). It has been reported that Fe adsorbs to OM and can be exchangeable (Ussiri and Johnson, 2004). Topsoils of the unmined sections had shown high OM content (7.4 ± 2 %) as opposed to the topsoils of mined sections (2.94 ± 3 %).

The relatively higher values of exchangeable Fe in subsoils of the unmined sections, as compared to topsoils of unmined sections (Figure 4.13), could have resulted from the leaching of the element in the topsoils, and accumulating in the subsoil layer (Thompson and Troeh, 1978).

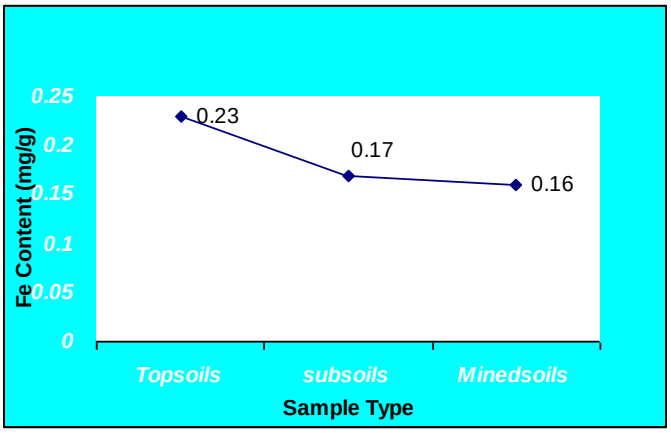

Figure 4.12: Iron content trend in the three mining sections of the sites

This section therefore, clearly shows that mining does not have significant effects on the soil exchangeable cation content in the mining sites. The agriculturally productive order of the exchangeable cations in the soils also remains unaffected.

4.4.5 Heavy Metal (Cu, Cd, Mn and Pb) Content in the Soils of the Mining Sites

The contents and site comparisons of the heavy metals in the soils are presented in Table 4.10. The data revealed that copper (Cu) in the soil was site dependent (ANOVA, $F = 6.88$; $p = 0.006$; $\acute{\eta}^2 = 0.73$). This is probably because of the differences in composition of the element in the parent rocks (Alloway and Ayres, 1997). The highest value was recorded in the Mtanthila soil samples (10.7 ± 1.5 µg/g), while the Mmbale samples gave the lowest (2.0 ± 0.3 µg/g).

The results on soil sample types (mining sections), revealed that the content of Cu in the topsoils, subsoils and mined soils ranged from 1.00 - 11.0 µg/g (5.9 ± 4 µg/g), 1.70 – 9.70 µg/g (5.9 ± 3 µg/g), and 2.00- 12.50 µg/g (6.5 ± 4 µg/g) respectively. The Cu content was independent of the sample types (ANOVA, $F = 1.409$; $p = 0.963$; $\acute{\eta}2 = 0.006$), indicating that mining insignificantly affected the soil Cu content. Since all the values of Cu content in the sites were much lower than critical content for Cu (60.0 µg/g) (Alloway, 1995), it implied that the contents were within acceptable levels (< 60.0 µg/g), and that Cu poses no danger to life and the environment.

The Cadmium (Cd) levels in the mining sites seemed to be independent of the mining site (ANOVA, $F = 0.99$; $p = 0.456$; $\acute{\eta}^2 = 0.28$). This seems to indicate the lack of significant differences in the Cd composition of the parent rocks in the sites from which the soils were derived (Alloway and Ayres, 1997). The mean values and ranges are shown in Table 4.10. The highest value was registered at Mzengeleza (J) (6.1 ± 0.7 µg/g) while the lowest at Kuthindi (0.78 ± 0.7 µg/g).

Further, comparisons between the soil sample types showed no evidences of differences in Cd content (ANOVA, $F = 0.987$; $p = 0.4$; $\acute{\eta}^2 = 0.4$), denoting that the vertical content of the Cd in the soils of the sites is the same, and that mining has not significantly changed the content of soil Cd. Figure 4.14 shows a comparative presentation of the Cd in the soil sample types studied. The levels of soil Cd were within acceptable levels, below the critical content (3.0 µg/g) (Alloway, 1995). This suggests that mining has caused insignificant changes on soils Cd levels.

Table 4.10: Heavy metal content in the soils of the mining sites

Site	Heavy Metal Content (µg/g)			
	Cd	**Cu**	**Mn**	**Pb**
Kuthindi	0.78 ± 0.7 (0.28 – 1.9)	9.2 ± 3 (5.6 – 11.0)	8.7 ± 9 (2- 20)	7.3 ± 3.8 (3.0 – 10.0)
Mmbale	0.82 ± 0.9 (0.28 – 1.9)	2.0 ± 0.3 (1.7 – 2.2)	43.3 ± 25.1 (20 – 70)	3.3 ± 0.2 (3.0 – 3.4)
Mtanthila	1.73 ± 0.2 (1.6 – 1.9)	10.7 ± 1.5 (9.7 – 12.5)	96.7 ± 23 (70 – 100)	6.8 ± 0.7 (6.3 – 7.6)
Mzengeleza (J)	6.1 ± 0.7 (1.8 – 14.0)	3.7 ± 1.6 (2.2 – 5.3)	30.0 ± 34 (30 – 40)	8.3 ±3 (5.0 – 11)
Mzengeleza (R)	0.9 ± 0.7 (0.19 – 1.6)	5.0 ± 4 (1.0 – 8.9)	36.3 ± 5.8 (30 – 40)	6.3 ± 3.2 (4.2 – 10.0)
Statistical Significance	X	**	**	X

Note: "" Stands for "Statistically significant at p< 0.05", "X" means statistically insignificant at p < 0.05.**

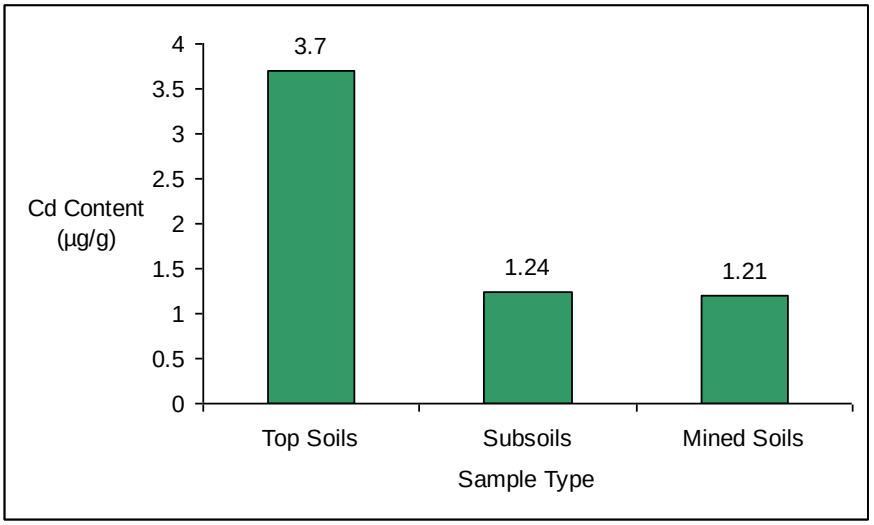

Figure 4.13: Cadmium metal content in the three sections of the mining sites

The correlation between Cd and OM was statistically significant ($r = 0.54$; $r^2 = 0.29$; $p = 0.038$), suggesting that Cd is associated with OM. The presence of OM facilitates adsorption of Cd in soils resulting in the formation of complexes (Skrull *et al.*, 2004). The higher Cd values in the topsoils of the unmined sections could be strongly associated with the relatively higher OM in them (Alloway and Ayres, 1997; Skrull *et al.*, 2004).

Contrary to Cd, results of Manganese (Mn) revealed that it strongly depended on the site (ANOVA, $F = 6.5$; $p = 0.008$; $\acute{\eta}^2 = 0.71$) Table 4.10. This is suggestive of the geochemical differences affecting Mn content in the sites (Alloway and Ayres, 1997). The highest Mn value was registered at Mtanthila (96.7 ± 23 µg/g), indicating that soils are relatively enriched in the element. Some Mn might have been probably derived by weathering of Mn bearing carbonate rocks. However, the metal content in feldspar and quartz minerals was lower than in the soils (96.7 ± 23 µg/g), denoting the existence of an unknown source within the area, much richer in the metal than these rock minerals.

The content ranges of Mn in topsoils, mined soils, and subsoil were 20 – 110 µg/g (62 ± 34 µg/g), 4 – 110 µg/g (38.0 ± 42 µg/g), and 2- 70 µg/g (28.0 ± 27 µg/g) respectively. The topsoils had the highest mean (62.0 ± 34 µg/g). This denotes extra sources at the surface, probably from atmospheric deposition, animal and plant excreta and release from the decomposition of dead animal and plant matter (Howe *et a*l., 2004), but also adsorption and

complex formation with OM, which was higher in the topsoils (Alloway and Ayres, 1997; Skrull *et al.*, 2004).

However, insignificant differences existed between the three sample types (ANOVA, $F = 1.040$; $p = 0.38$; $\acute{\eta}^2 = 0.17$). The values in the sites and soil sample types were lower than the critical value for soil Mn (1500 µg/g) (Alloway, 1995). This implies that mining has insignificantly affected the levels of Mn in the soils of the mining sites.

Unlike Mn, lead (Pb) content revealed no notable differences in the mining sites ($F = 1.67$; $p = 0.23$; $\acute{\eta}^2 = 0.4$), showing similarities in the geochemistry of parent rocks in relation to Pb in the sites (Alloway and Ares, 1997). The content and ranges of Pb in topsoils, subsoils, and mined soils were 3-9 µg/g (6.28 ± 2.7 µg/g), 3-11 µg/g (5.84 ± 3.4 µg/g), and 3.4 -10 µg/g (6.96 ± 3 µg/g), respectively. The subsoils had the highest value (6.96 µg/g). However, insignificant differences were found amongst the sample types (ANOVA, $F = 0.17$; $p = 0.85$; $\acute{\eta}^2 = 0.028$), suggesting the lack of mining effects on the content of Pb in the sites. The levels of Pb both in the sites and in sample types were below the critical level of causing danger (100µg/g) (Alloway, 1995). This shows that Pb contamination does not exist in the mined sections..

It could be concluded that mining has no adverse effects on the environment of the mining sites. All the heavy metals were lower than the critical values in the soils and did not pose any of potential danger.

4.5 Characteristics of Selected Chemical Parameters in Raw Materials

Table 4.11 shows the content of some selected heavy metals (cadmium, copper, manganese and lead) and silica in the raw materials (kyanite, quartz and feldspar), used at Dedza Pottery.

Table 4.11: Heavy metal and silica content in raw materials

(<dl stands for below the detection limit; Mean ± d; n = 15)

Raw material Sample	**Heavy metal Concentration (µg/g)**				**SiO_2 (%)**
	Cd	Cu	Mn	Pb	
Quartz	4.3 ±1	<dl	13.67 ± 2	<dl	94.23 ± 0.4
Kyanite	5.3 ±1	<dl	9.57 ±2	59.07±7	60.22 ± 2
Feldspar	1.9 ±1	<dl	13.67 ± 2	<dl	49.73 ± 2
Statistical Significance	**	X	X	**	**

"" Stands for statistically significant at p< 0.05; "X" Means Statistically insignificant at p<0.05 when rock samples were compared**

Not all raw materials were equally important sources of cadmium (Cd) (ANOVA, $F = 7.67$; $p = 0.022$; $\acute{\eta}^2 = 0.72$), but kyanite and quartz. These two had the contents above the critical level (3 µg/g), raising fears of environmental contamination (Table 4.11) (Alloway, 1995). The potential dangers would be more probable if the raw materials were taken to the pottery, and deposited there as waste after use, due to the acidic nature of the soils of the place (Brown and Yonegh, 1965). Low pHs increase the dissolution of Cd complexes making the metal more available in solution form (Altaher, 2001; Wild, 1993). Some precautions are therefore needed in the mining, use and disposal of the raw material wastes to protect the environment and people.

The content of Mn in the raw materials was found to be insignificantly different (ANOVA, $F = 3.0$; $p = 0.125$; $\acute{\eta}^2 = 0.50$), denoting similarities in the content of the element in the rock raw materials. However, the threat of Mn to the environment, as a result of rock raw material mining, was remote. This is because the contents of the element in the rocks studied were lower than the critical level to trigger concerns (1500 µg/g) (Alloway, 1995).

Unlike Cd and Mn, the Pb content depended on the raw material type, as shown by the significant differences between them (ANOVA, $F = 194.68$; $p < 0.0005$; $\acute{\eta}^2 = 0.98$). Failure to

detect Pb in quartz and feldspar indicated that the element was either absent or existed in insignificantly low contents in these raw materials, but in kyanite it did exist (Table 4.11). However, its content was lower than the critical level of danger (100 µg/g) (Alloway, 1995). This strongly suggests that mining of kyanite, feldspar, and quartz has insignificant effects on Mn content, and no threats to the environment and living organisms.

All raw materials studied were found to be siliceous. The order of silica content was observed to be Quartz > Kyanite > Feldspar, and the values were 94.23 ± 0.4 %, 60.22 ± 2 % and 49.73 ± 2 % respectively (Table 4.10). Values of SiO_2 in quartz approximates 100%, depending on the purity of the mineral (Deer *et al.*, 1966). The slightly lower value obtained in this study could be due to natural impurities reducing the purity of the raw material type in the site. The outcome possibly implies that unprotected exposure of employees to dust from these raw materials would make them run risk of silicosis (UNEP, 1991; Jeyaratnam, 1999). Discussion with employees handling raw materials, revealed high occurrence of chest pains and coughing, these could be suggestive of toxicity signs due to silicosis (Jeyaratnam, 1999; Miller, 1993).

In conclusion, this section has showed that Cd content in quartz and kyanite is a potential danger to the environment and people, as its contents were above the safe limit. The danger is exacerbated by the explored possibility of dissolution in the acidic areas of Dedza Pottery. Threats of silicosis amongst the workers seem highly probable, since silica content was higher in the rock raw materials.

4.6 Physicochemical Characteristics of Water in the Study Sites

The physicochemical characteristics (pH, TSS, turbidity, conductivity, and heavy metal concentration) of water were studied at Kuthindi, the only site where mining was done close to a surface water resource.

4.6.1 pH, TSS, Turbidity and Conductivity of the Stream Water

The mean pH value before the mining season, for all the three sampling points, was 6.38 ± 0.05. This value is below the recommended range of the WHO standards (6.5 – 8.5) (WHO, 2004), but is within that by Malawi Bureau of Standards (5.0 – 9.5) (MBS, 2005) and the Department of Water (DW) Standards (6.0 – 9.5) (CWL, 2001), i.e. for drinking. During the mining season, the mean pH for all the three sampling points declined (5.99 ± 0.04), which is below the recommended levels by the DW and WHO. This meant that during the mining season, water was not suitable and safe for drinking by the people in the area.

The decrease might have also affected the existence of aquatic organisms (Harrison, 1999). Normally, pH values below 6.0 cause acidic stress on aquatic organisms, resulting in the death of some organisms such as fish, zooplankton, benthic macro-invertebrates, amphibian species etc (Harrison, 1999). Possibly this could be happening in the Kuthindi stream, especially during the mining season, due to the water pH decrease experienced.

The water pH from all the three sampling points, were not significantly different before the mining season ($p > 0.05$). However, during the mining season, the pH of the stream water declined significantly between the upper sampling point (6.36 ± 0.02) and the discharge point (5.98) (ANOVA, $F = 42.27$; $p < 0.005$; $\acute{\eta}^2 = 0.94$) (Table 4.12) This difference strongly suggests that clay mining was the most probable agent. The drop in pH described here, could have been caused by the effects of the acidic muddy water draining into the stream from the ponds created during the mining process. The soil analysis results from this area indicated that the soils were acidic (pH 4.71 ± 0.27). Possibly, contact with this soil made the water acidic as well.

Prior to the mining season, a lot of red precipitates were observed, possibly, solid iron oxide precipitates, some suspended in the water, while others coated the river vegetation. These are

Table 4.12: Physicochemical characteristics of water at Kuthindi stream

Selected Water Characteristics		Before Mining Started				After Mining started			
		Upper	**Discharge point**	**Lower**	**Statistical Significance**	**Upper**	**Discharge point**	**Lower**	**Statistical Significance**
Physicochemical Characteristics	Conductivity (µS/cm)	4.53± 10	450± 10	450± 10	X	433± 10	483 ± 6	476± 15	X
	pH	6.36± 0.02	6.44± 0.1	6.44± 0.1	X	6.35± 0.05	5.98 ±0.04	6.0± .04	**
	TSS (mg/L)	158± 18	156.3± 14	156.3± 14	X	158.7± 20	1215 ± 21	1168± 16	**
	Turbidity (NTU)	4.8± 0.3	4.7± 0.3	4.7± 0.3	X	4.9± 0.3	160 ± 4	133.7± 5	**
Heavy Metal Characteristics (mg/L)	Cd	<dl	<dl	<dl	-	<dl	<dl	<dl	-
	Cu	<dl	<dl	<dl	X	<dl	0.04 ± 0.02	0.03±0.02	**
	Mn	<dl	<dl	<dl	X	<dl	0.23 ±0.03	0.18±0.06	**
	Pb	<dl	<dl	<dl	-	<dl	0.13 ± 0	0.13 ± 0	**

Note: "" Stands for "Statistically significant at p< 0.05", "X" means statistically insignificant at p < 0.05, < dl means below detection limit.**

possibly caused by the low pH values of water and soils at the site, allowing iron to react with oxygen forming iron (III) oxide precipitates, which manifest themselves as red suspensions in water (O'Neill, 1993).

The total suspended solids (TSS) of the water samples were not significantly different before mining ($p > 0.05$), and varied between 152.3 – 158.0 mg/L (155.5 ± 15 mg/L), which is higher than that recommended by WHO (30 mg/L) for surface water (Chiona *et al*., 2002), possibly due to the solid precipitates of iron (III) oxide in the water, and physical disturbances caused to the water by farmers, as the stream is also used for irrigation. Table 4.12 shows details of the results. GoM (1999b) published higher values of TSS for Dedza rivers and streams than recommended by WHO and attributed this to farming activities, loosening of soils, which are eventually carried into rivers by runoffs during the rainy season.

Mining significantly aggravated the TSS as indicated by the significant differences between the three sampling points (ANOVA, $F = 2909.9$; $p < 0.0005$; $\acute{\eta}^2 = 0.999$). Turkey's Post hoc test revealed that these differences existed between the upper water samples and those at discharge point ($p < 0.0005$), while that between the discharge point and lower part, was insignificantly different ($p > 0.05$), implying that the concentration of TSS changed at the discharge point, and the state continued as the water flowed down the stream to the lower sampling point. Since the change came during mining, it could be attributed to the mining activities. Mining therefore increased the TSS of the stream water, and consequently affecting the water quality.

The mean TSS values during mining were 1215 ± 21 mg/L and 1168 ± 16 mg/L at the discharge point and lower sampling point respectively. Such high values (> 500 mg/L) gradually kill aquatic organisms, if they persist for some time (Earth Force Green, undated), and enhance the multiplication of bacteria (Chiona *et al*., 2002; WHO, 2004). However, very high TSSs (> 20,000 mg/L) induce immediate deaths of aquatic life (Lee and Taylor, 1995). Therefore, precautionary measures are required to reduce and avoid aggravation of the effects at the site to protect the aquatic organisms.

The mean turbidity of the stream water before the mining was 4.73 ± 0.3 NTU (4.7- 4.9 NTU), this is within the recommended limit of 5 NTU (WHO, 2004) and that of surface water, as required by WD (25 NTU) (CWL, 2001), but not for the MBS drinking water standards (0.1- 1.0 NTU) (MBS, 2004). Thus, the surface water is within acceptable levels of

WHO, WD, but higher for MBS. The turbidity of the water did not vary significantly ($p>0.05$), indicating insignificant changes in the turbidity along the course of the stream, i.e. between the studied points.

However, during mining season, the situation was different; the three sampling points were found to be statistically different (ANOVA, $F = 2353.7$; $p < 0.0005$; $ή2 = 0.999$). The upper sampling point had a lower value of turbidity (4.9 ± 0.3 NTU), as opposed to that at discharge point (160 ± 4 NTU) and lower sampling point (133.7 ± 5 NTU). Denoting that more suspended solids were introduced at the discharge point, where clay was mined, showing that mining increased the turbidity of the stream water. Mol and Ouboter (2003) found that mining increased the turbidity of water in their study of the impacts of small-scale gold mining on the in stream habitat and fish community of a small neotropical rainforest stream.

The positive mean difference between the discharge point and the lower sampling points (mean difference = 26.43; $p < 0.0005$), implies a decreasing trend in levels of turbidity as the water flowed down stream (the average rate of decrease was calculated to be -0. 53 NTU/m). The turbidity problem caused by clay mining at Kuthindi could be more serious than it appears. This is because the effects could persist, as it takes longer for suspended clay particles to settle down completely, due to their high surface areas and repulsive forces between them, caused by positive charges that develop around them (Hargreaves, 1999).

The electric conductivity of the water samples between the three sampling points was insignificantly different before ($p> 0.05$), and even after the mining had started (ANOVA, $F = 3.092$; $p = 0.051$; $ή^2 = 0.56$) (Table 4.12). The lack of significant differences between sampling points denotes the absence of the effect of the mining activity on the salinity of water.

This discussion therefore, shows that mining increased the TSS and turbidity of water, decreased the pH, but had no effect on the conductivity of the stream water. Some of these changes affected the water quality as discussed above.

4.6.2 Heavy Metal Concentration in the Stream water

The concentrations of heavy metals in stream water are shown in Table 4.12. These results indicate that before and after mining, the Cd concentration of the water samples were negligible, and below the limits of the WHO (3 µg/L) (WHO, 2004), finaly MBS (3-5 µg/L)

(MBS, 2005) for drinking water. Therefore, the stream water is largely free from Cd contamination.

The levels of Cu increased above the detection limit in the water samples during the mining season unlike before. Water samples at the discharge point gave appreciable levels (0.04 ± 0.02 mg/L), while the upper and lower sampling points were 0.00 mg/L and 0.03 ± 0.02 mg/L respectively. These differences were highly significant (ANOVA, $F= 7.175$; $p = 0.003$, $\eta 2 = 0.67$). Cu in water was probably derived from clay mud draining into the stream. Soil samples of the site contained reasonable concentration of Cu (9.2 ± 3µg/g) (section 4.4.7). However, the Cu values obtained during the mining season were much lower than the limit of 2 mg/L (WHO, 2004; CWL, 2001), and 1 mg/L (MBS, 2005), for drinking water, and for irrigation purposes (10 mg/L) (Lee and Tayler, 1995).

Therefore, clay mining does not cause threats to human and aquatic life, as the values of Cu are within acceptable levels for the standards. Maintaining low concentration of Cu is necessary though, as high levels of the element in water are toxic to fish (Lee and Taylor, 1995).

Mn and Pb could not be detected in the samples collected before the mining season (Table 4.12). The failure to have Mn and Pb detected would infer 0.0 mg/L, or very low concentrations of Mn and Pb in the water samples under no mining activity.

Mn levels increased during the mining season particularly for the discharge point (0.23 ± 0.03 mg/L). The lower point had 0.18 ± 0.06 mg/L, while the upper regime was still below the detection limit (< dl). The differences between the upper regime and discharge point were very significant ($t = - 14.0$; $p = 0.005$). Mining activities significantly raised the Mn levels above MBS (0.05 – 0.1 mg/L) (MBS, 2005), and yet within the WHO (0.1- 0.4 mg/L) (WHO, 2004) and DW (< 1.5 mg/L) (CWL, 2001) for drinking purposes. The Mn levels were also below the standard for irrigation purposes (10 mg/L) (Lee and Taylor, 1995). Therefore, it could be said that the change in Mn levels brought about by mining, insignificantly affects the quality of the water.

Similarly, the Pb concentration during the mining season increased at the discharge and lower sampling point, where the values were 0.13 ± 0.0 mg/L each, while in the upper sampling point Pb remained undetected (< dl). The values during mining were above 0.05 mg/L (MBS,

2005; CWL, 2001), but below 0.4 mg/L (WHO, 2004) for drinking and 10 mg/L for irrigation purposes (Lee and Taylor, 1995). The fact that the Pb level was below the irrigation and WHO standards probably denotes that mining insignificantly affects the quality of water.

There is therefore evidence that mining had no effects on Cd concentration, but increased the concentrations of Cu, Mn and Pb. The increase in the concentration of Cu, Mn, and Pb had insignificant effects on the quality of water for drinking and irrigation, as the values were within safe range. This shows how insignificant the effects of mining are on the heavy metal content in the stream water.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This study examined the following elements of the environment, soil, water, pottery raw materials, and vegetation in the mining sites of Dedza Pottery. Major effects of mining identified were reduction of vegetation SR, increase in soil erosion, formation of pools and pits, threats to existence of ants, causing changes in soil texture, increasing the water holding capacity of the soils, and reduction in N and OM. Cd was found to be high in kyanite and quartz raw materials. The water quality was affected through a decrease in pH, and increase in TSS and turbidity. Section 5.2 fully concludes the findings.

5.2 Conclusions

The land in the mining sites was significantly affected in several ways: through (i) the creation of pits and pools, and (ii) encouragement of soil erosion. Pits were predominant at Mmbale and Mzengeleza, while creation of pools was a problem of Kuthindi and Mmbale. The cause of pool formation was the mining of clay beyond the water table of the sites. Pools and pits were found to be a serious threat to people's lives and livestock by either drowning of falling into them respectively. Efforts of land remediation were evident, but taking place at a pace much slower than the mining activity itself. At the Kuthindi and Mmbale sites, the pit and pool creation brought about reductions in farming land, further increasing the problem of farming land, already existent in Dedza district.

The probability of a direct link between soil erosion and mining activities, at Mzengeleza and Kuthindi, is very high. These two sites lie on slopes, such that disturbances caused to the land, and removal of vegetation encouraged the erosion of soil. It is feared that in the absence of immediate intervention, the problem would aggravate. However, mining was not the major causative factor of soil erosion at Mmbale and Mtanthila, as similar magnitudes of erosion were observed in unmined sections (areas). The nature of the soils, reported to be highly vulnerable to erosion by water, were found to be responsible. Bank failures were observed at Kuthindi site, and clay mining was responsible, through undercutting of the bank in the course of mining.

Effects on the ecology of the area have been identified, through mining of anthills. This is seriously threatening the existence of ants in Dedza. The activity would drive the ants into extinction in the area, a condition that may affect the ecosystem balance.

The vegetation of the mining sites was dominated by herbaceous plants, followed by trees and finally shrubs. The frequency of the occurrence of trees and shrubs was almost the same. Mining activities caused a reduction in the species richness (SR) of vegetation in the sites, probably through changes introduced on the critical soils nutrients, and physical characteristics (soil texture, water-holding capacity etc). There was also evidence of chronic vegetation disturbance in the sites, which may finally result into total plant growth failure if nothing is done to reduce these disturbances.

The physical and chemical aspects of the soils were also affected. Mining affected the soil particle distribution in the mining sites, by increasing the proportion of clay, consequently, changing the texture of the topsoils in the mined sections of the sites. The average texture of the sites changed from sandy clay loam (SCL) to clay, implying that the change in texture was from loamy textures, in unmined sections, to clay textures in mined sections. The change has been attributed to the dumping of the subsoils rich in clay onto ground surfaces in the mining sites.

The soil pH was insignificantly affected by mining in the sites ($p > 0.05$), but the amount of OM was significantly affected ($p< 0.05$). The OM content in the unmined section was higher (7.2 ± 2 %) than that in the mined sections (2.94 ± 3 %). The cause was probably the dumping of the subsoil containing little OM onto the ground surface, and the reduction of vegetation, which is a source of OM after decomposition. Mining increased the water holding capacity of the soils in the sites. Topsoils in the mined sections had higher moisture content (7.5 ± 3 %) than topsoils in the unmined sections (3.6 ± 2%) ($p< 0.05$). The cause was found to be the increase in clay content in the mined soils. The clay content in the unmined sections was 19.7 ± 6 %, while that in the mined sections was 42.3 ± 19 %.

Mining caused a reduction in the nitrogen content of soils in the mining sites. Mined sections had lower contents of nitrogen (0.0019 ± 0.001 mg/g) than the unmined sections (0.0091 ± 0.005 mg/g) ($p < 0.05$). High and significant relationships existed between nitrogen and OM ($r = 0.69$; $p< 0.05$), suggesting that most of the available nitrogen was organic in origin. This meant that the reduction of the element in the mined section was due to the reduction in OM

content in these sections. However, available phosphorus was not affected by the mining activities ($p > 0.05$).

The study on the major cations showed that Ca, K, Mg, and Fe were not affected by mining ($p > 0.05$), but were generally higher in the topsoils of the unmined sections. It has been suggested that the high values in the topsoils of unmined sections were caused by the adsorption of the metals onto surfaces of the organic matter. K and Fe correlated moderately with OM ($r > 0.4$), probably indicating that these metals were associated with OM.

The comparative analysis for Cu, Cd, Mn, and Pb, between mined sections and unmined sections, showed no significant differences ($p > 0.05$), and the levels of all the metals in soils were below the critical limits for intoxication (Alloway, 1995). This was enough evidence that the heavy metal content in the soils of the mining sites remained unaffected by the mining activity. Generally, topsoils in the unmined sections showed higher values of the metals, suggesting adsorption to OM. Mn concentration was the highest at Mtanthila (96.7± 23 µg/g), the source of quartz and feldspar. The Mn content of feldspar and quartz was relatively higher (13.67 ± 2 µg/g each) than kyanite (9.57± 2 µg/g) but lower than the soils. The lower levels of the metal in the raw materials, than the soils (96.7± 23 µg/g) at Mtanthila site, prompted a suggestion of attributing the high soil Mn content to the weathering of other sources richer in Mn.

Quartz, kyanite, and feldspar were found to be sources of heavy metals. Quartz and kyanite had the highest content of Cd, but Cu was none existent in all (quartz, kyanite, and feldspar), while Mn was prevalent in almost similar quantities ($p < 0.05$). Lead (Pb) was only found in kyanite. The contents of Cu, Mn, and Pb were below the levels to trigger health concerns. However, high Cd levels were identified especially in quartz and kyanite, where the values were above the critical limit (3µg/g). Precautions are therefore, required in the use and disposal of the waste from these raw materials, especially in Dedza proper where the soils are acidic. This is because heavy metal dissolution and mobility requires acidic conditions.

Silica was found in all the raw materials. It was the highest in quartz (94.23 ± 0.4%), seconded by kyanite (60.22 ± 2%), and finally feldspar (49.73±2). Therefore, all have a potential to cause silicosis to workers, if not protected from the dust generated during crushing.

The water analysis showed that mining significantly affected the quality of water at Kuthindi as indicated by the significant changes in pH, TSS, and turbidity ($p < 0.05$). The pH value dropped to values below the acceptable range by WHO and DW, but was within the range for MBS. This showed that the effect on drinking was minimal, but the potential danger to aquatic life was quite high, as the pH was below 6.0, a threshold for survival of the most sensitive organisms. The decrease in pH was attributed to the draining of the acidic muddy water into the stream. It has been suggested that the water became acidic through contact with the deep acidic clay soils of the site.

The TSS value during mining was above the WHO standards (30 mg/L). The prevailing TSS values (average = 1191.5 mg/L) during the mining season were higher than that recommended for the survival of fish and aquatic organisms (>500 mg/L). Indicating a possibility of death of aquatic organisms during the mining season. The increase in TSS levels during mining season was caused by draining of the dirty and muddy water from the pools created by the mining activities. However, mining had no significant effects on water conductivity, indicating that the salinity of the water is not affected.

Mining activities exhibited significant effects on increasing the concentration of heavy metals in stream water at Kuthindi. These included Cu, Mn, and Pb contents and their increases were > detection limit (dl) to 0.04 mg/L, > dl to 0.23 mg/L, and > dl to 0.13 mg/L, respectively. The changes were highly significant during the mining season ($p < 0.05$), but not before ($p > 0.05$). However, their levels were below the WHO standards, both for drinking and irrigation purposes. This meant that heavy metal concentrations posed no danger to the people and environment, despite their increase during the mining seasons.

5.3 Recommendations and Further Research

In order to improve safety and the state of the environment in the mining sites, the following are recommended:

- Regular monitoring (quarterly during the mining season) of the mining sites should be carried out by the Environmental Affairs Department (EAD), through the Environmental District Officer (EDO), to regulate the mining activities within the environmentally acceptable standards;

- immediate rehabilitation (covering pits and pools) of the degraded land at Kuthindi, Mzengeleza and Mmbale. Mzengeleza could have some grass and trees planted, preferably, indigenous ones from the district (if exotic, then the pinus species), to reduce soil erosion since the site is on a mountain foot;
- the topsoils removed during mining should be retained and subsequently used for land restoration as soon as possible to retain the OM, reduce textural changes, and protect the sites vegetation seed bank;
- precautionary measures against soil erosion, bank failures, and water pollution are required at the Kuthindi site (i.e. terracing, avoiding undercutting the banks, and avoiding draining muddy water into the stream, respectively), or closure of the Kuthindi mining sites, and an alternative mining site be identified, far from important water sources, and not on a steep slope;
- precautionary measures against soil erosion are required at Mmbale and Mtanthila when mining raw materials to avoid induction of erosion since the area is known to have vulnerable soils. This should involve quick covering of pits and planting of vegetation cover, such as grass and trees;
- continued dumping of sawdust at the same rate with mining, to restore the lost OM. The sawdust should be mixed with soil to avoid being carried a way by water during the rainy season. Organic waste from Dedza Market could also be used;
- staff should be trained in the disposal of kyanite and quartz, to avoid Cd poisoning and contamination, at the pottery. Possibly, application of lime around the storage area and waste disposal sites to precipitate the Cd;
- sensitisation of the workers, to always use protective gear during working, and increase ventilation in the workplaces, to avoid potential dangers of silicosis; and
- the pottery should come up with an environmental management system (EMS), clearly defining its environmental policies, objectives, roles of personnel, staff trainings, monitoring schedules, and effective reporting methods.

Further studies are required to:

- determine the social-economic effects of the mining activities at the pottery and the sites;
- determine the effects of acidic soils on the dissolution and mobility of the Cd in quartz and kyanite in Dedza Highland Areas; and

- investigate employee exposure to occupational dust, and the associated epidemiological effects.

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APPENDICES

APPENDIX A-1: Tree Species studied in the mining Sites (UMN = Unmined, MN= Mined)

Vegetation Attributes			Mining Site									
Habit	Species	Family	Kuthindi		Mchekecha		Mmbale		Mtanthila		Mzengeleza	
			UMN	MN	UMN	MN	UMN	MN	UNM	MN	UMN	MN
Tree	*Brachystegia Longifolia*	Caesalpinioiodeae	0	0	4	0	0	0	0	0	0	0
	Brachystegia Speciformis	Caesalpinioiodeae	0	0	25	16	0	0	0	0	0	0
	Brachystegia Stipulata	Caesalpinioiodeae	0	0	0	0	9	0	0	0	0	0
	Combretum Adegonium	Combretaceae	0	0	0	0	1	0	0	0	0	0
	Combretum Molle	Combretaceae	0	0	0	0	0	0	0	0	3	0
	Cussonia Aborea	Araliaceae	0	0	2	0	0	0	0	0	0	0
	Dalbegia Nitidula	Papilionoideae	0	0	0	0	0	0	0	0	0	0
	Diospyros Kirkii	Ebenaceae	0	0	0	0	0	3	0	0	0	0
	Diospyros Lycioides	Ebenaceae	0	0	0	0	0	0	0	0	2	0
	Ekerbergia Benguellensis	Meliaceae	0	0	2	0	0	0	0	0	0	0
	Eleusine Indica	Poaceae	0	0	0	0	0	0	0	0	0	0
	Julbernadia globilata	Caesapinioideae	0	0	5	0	0	0	0	0	0	0
	Maesa Lauceolata	Myrsinaceae	0	0	0	0	0	0	0	0	1	0
	Maytenus Senegalensis	Celastracea	0	0	0	0	0	16	0	0	0	0
	Ochna Shwin Furthiana	Ochnaceae	0	0	7	0	0	0	0	0	0	0
	Osyris Compressa	Olacaecea	0	0	80	0	0	0	0	0	0	0
	Parinali Curatellifolia	Chrysobalanaceae	0	0	10	23	0	0	0	0	0	0
	Protea Madiensis	Proteaceae	0	0	0	3	0	0	0	0	0	0
	Protea Welwitschii	Proteaceae	0	0	0	0	0	0	0	0	0	0

APPENDIX A-2: Shrub species studied in the mining sites (UMN = unmined, MN = mined)

Vegetation Attributes			**Mining Sites**									
Habit	**Species**	**Family**	**Kuthindi**		**Mchekecha**		**Mmbale**		**Mtanthila**		**Mzengeleza**	
			UMN	**MN**	**UMN**	**MN**	**UMN**	**MN**	**UMN**	**MN**	**UMN**	**MN**
Shrub	*Crotalaria Natalitia*	Papilionoideae	0	0	1	0	0	0	1	0	0	0
	Entada Rheedii	Mimosoideae	0	0	0	0	0	0	1	0	0	0
	Eriosema Ellipticum	Papilionoideae	0	0	0	0	0	0	0	0	0	0
	Flemingia Grahamiana	Papilionoideae	0	0	0	0	0	0	0	0	10	2
	Pseudarthria Hookeri	Papilionoideae	0	0	0	0	0	0	0	0	9	0
	Indigofera Emarginella	Papilionoideae	0	0	0	0	0	0	0	0	0	0
	Lippia Javanica	Verbenaceae	0	0	0	0	0	0	0	0	4	0
	Merremia Tridentata	Convolvulaceae	0	0	0	0	0	5	0	0	0	0
	Psidium Guajava	Myrtaceae	0	0	0	0	0	0	0	0	2	0
	Psorospermum Febrifugum	Clusiaceae	0	0	1	0	0	0	0	0	0	0
	Rhoicissus Tridentata	Vitaceae	0	0	0	0	0	0	0	0	1	0
	Rhus Longipes	Anacardiaceae	0	0	0	0	0	0	0	0	3	0
	Tithonia Diversifolia	Asteraceae	0	0	0	0	0	0	0	0	0	0
	Vernonia Glabra	Asteraceae	0	0	0	0	0	0	2	0	0	0

Appendix: A-3: Herbaceous species studied in the mining sites (UMN = unmined, MN = mined)

Vegetation Attributes			Mining Site									
Habit	**Species**	**Family**	**Kuthindi**		**Mchekecha**		**Mmbale**		**Mtanthila**		**Mzengeleza**	
			UMN	**MN**	**UMN**	**MN**	**UMN**	**MN**	**UMN**	**MN**	**UMN**	**MN**
Herb	*Agerantum Conyzoides*	Asteraceae	7	3	0	0	0	0	0	0	600	0
	Achemilla Cryptantha	Rosaceae	45	10	0	0	0	0	0	0	0	0
	Amaranthus Hybridus	Amaranthaceae	0	0	0	0	0	0	2	0	0	0
	Anthrospermum Globosum	Rubiaceae	0	0	0	0	3	0	0	0	0	0
	Asparagus Africanus	Asparagaceae	0	0	0	0	0	0	0	0	1	0
	Asparagus Asetaceus	Asparagaceae	0	0	0	0	0	0	0	1	0	0
	Aspilia Mossambicensis	Asteraceae	0	0	2	0	0	0	0	0	0	0
	Becium Grandiflorum	Lamiaceae	0	0	0	13	4	0	0	0	0	0
	Berkheya Zeyheri	Asteraceae	0	0	0	7	0	0	0	0	0	0
	Bidens Steppia	Asteraceae	34	27	0	0	0	0	0	0	0	0
	Bidens Pilosa	Asteraceae	0	0	0	0	0	300	67	98	25	20
	Blumea Brevipes	Asteraceae	0	0	0	3	0	0	0	0	2	2
	Bothriocline Longipes	Asteraceae	0	0	0	0	0	0	0	23	0	0
	Coccinea Adoensis	Asteraceae	7	2	0	0	0	0	0	0	0	0
	Crossocephalum Rubens	Asteraceae	4	0	0	0	0	0	0	0	0	0
	Cynodon Dactylon	Poaceae	0	0	0	0	0	0	0	1000	20	0
	Dicoma Sessilifolia	Asteraceae	0	0	0	5	0	0	0	0	0	0
	Dolichos Trinervatus	Papilionoideae	0	0	0	9	0	0	0	0	0	0
	Elephantopus Scaber	Asteraceae	0	0	7	11	0	0	7	0	0	0
	Eleusine Indica	Poaceae	25	0	0	0	0	0	45	0	0	0
	Emilia Abyssinica	Asteraceae	0	0	0	0	0	0	0	0	0	2
	Eragrostis Aspera	Poaceae	0	0	600	0	0	0	29	80	73	0
	Eragrostis Ciliaris	Poaceae	0	0	0	0	0	0	0	21	0	3

Appendix A-3 (Continued)

Vegetation Attributes			Mining Site									
Habit	**Species**	**Family**	**Kuthindi**		**Mchekecha**		**Mmbale**		**Mtanthila**		**Mzengeleza**	
			UMN	**MN**	**UMN**	**MN**	**UMN**	**MN**	**UMN**	**MN**	**UMN**	**MN**
Herb	*Fadoja Stenophylla*	Rubiaceae	0	0	5	4	0	0	5	0	7	0
	Gerbera Alata	Asteraceae	0	0	0	0	0	0	0	0	0	14
	Guizotia Scabra	Asteraceae	20	0	0	0	0	0	0	0	0	0
	Haumanniastrum Callianthum	Lamiaceae	0	0	0	0	0	0	0	0	71	56
	Helichrysum Kirkii	Asteraceae	0	0	0	30	0	0	0	0	0	0
	Heteropogon Controtus	Poaceae	0	0	100	0	0	0	0	0	0	0
	Hibiscus Acetocella	Malvaceae	0	0	0	0	0	0	2	0	0	0
	Hibiscus Cannabinus	Malvaceae	1	0	0	0	0	0	0	0	0	0
	Hyparrhenia Cymbaria	Poaceae	60	30	0	0	0	0	15	0	700	2000
	Hyparrhenia Filipendula	Poacea	70	0	0	0	0	0	0	0	0	0
	Hyperthelia Dissoluta	Poaceae	0	0	0	0	1800	200	600	0	0	0
	Hypoestes Forskaoli	Acanthaceae	0	0	0	0	0	0	0	0	3	0
	Indigofera Fulvopilosa	Papilionoideae	0	0	0	0	0	0	0	0	0	0
	Inula Glomerata	Asteraceae	0	0	1	10	0	0	0	0	2	0
	Justicia Striata	Acanthaceae	0	0	0	0	75	0	0	0	0	0
	Leersia Hexandra	Poaceae	275	50	0	0	0	0	0	0	0	0
	Leucas Martinicensis	Lamiaceae	0	0	0	0	0	0	0	7	0	0
	Melinis Ambigua	Poaceae	0	0	500	60	7	0	0	0	0	2
	Melinis Repens	Poaceae	140	50	0	0	55	0	300	300	14	0
	Nephrolespis Undulata	Polypodiaceae	0	0	60	0	0	0	0	0	0	0
	Nicandra Physaloides	Solanaceae	0	0	0	0	0	0	5	0	12	0
	Nidorella Spartioides	Asteraceae	32	200	0	0	0	0	1	0	4	0
	Pennisetum Polystachyum	Poaceae	0	0	0	0	0	0	0	0	0	0

Appendix A-3 (Continued)

Vegetation Attributes			Mining Sites									
Habit	**Species**	**Family**	**Kuthindi**		**Mchekecha**		**Mmbale**		**Mtanthila**		**Mzengeleza**	
			UMN	**MN**	**UMN**	**MN**	**UMN**	**MN**	**UMN**	**MN**	**UMN**	**MN**
Herb	*Pennisetum Purpureum*	Poaceae	200	50	0	0	0	0	0	0	0	0
	Phragmites Mauritianus	Poaceau	500	400	0	0	0	0	0	0	0	0
	Plectranthus Spp	Lamiaceae	0	0	0	0	0	0	0	0	0	0
	Plectranthus Elegans	Lamiaceae	0	0	90	0	0	0	0	0	0	0
	Rottboellia Cochinchinensis	Poaceae	0	0	0	0	0	0	150	10	0	0
	Sida Acuta	Malvaceae	0	0	0	0	0	9	0	0	0	0
	Spermacoce Dibrachiata	Rubiaceae	0	0	8	0	0	0	0	0	0	0
	Spolobolum Pyramidalis	Poaceae	150	0	0	0	0	0	3	0	14	3
	Sorghum Sorghoides	Poaceae	0	0	0	0	0	0	0	23	0	0
	Targetes Minuta	Asteraceae	0	0	0	0	0	0	0	0	1	0
	Themeda Triandra	Poaceae	0	0	60	72	800	0	0	0	0	0
	Tithonia Diversifolia	Asteraceae	55	20	0	0	0	0	0	0	0	0
	Trichodesma Zeylanicum	Boraginaceae	0	0	0	0	60	43	17	86	1	0
	Tridax Procumbens	Asteracea	0	0	0	0	0	0	0	7	0	0
	Trimfetta Pilosa	Tiliaceae	10	0	0	0	106	0	0	0	72	3
	Vernonia Cinerea	Asteraceae	0	0	0	0	10	0	9	0	48	0
	Vernonia Poskeana	Asteraceae	0	0	0	0	2	0	0	0	0	0
	Vernonia ugandensis	Asteraceae	0	0	5	0	0	0	0	0	0	0

APPENDIX B-1: Vegetation Species Record Form

VEGETATION SPECIES RECORD FORM

Form No _____*Quadrant No*_____ *Date* _____

*Research site*_____

*Location of study site*_____

Description of study site

_____
_____
_____

Weather Conditions During The Sampling Process

_____
_____
_____

Species name	**Family name**	**Total no of the species members**	**Average height**

Appendix B-2: Biophysical indicator variable's matrix

BIOPHYSICAL INDICATOR VARIABLES FOR THE ASSESSMENT OF THE LAND DEGRADATION

Form No _____*Date* _____
Study site_____

Indicator variables	**Data source**	**Observations**
Rills		
Gully		
Pits		
Pedestals		
Plant / tree root exposure		
Water falls & soil loss		
Rock exposure		
Consistency		
Slope/steepness		
Sedimentation in drains/ sediments in river banks (Siltation)		

Appendix B-3: Focus Group Discussion Guide for Villagers

A. INFORMATION ON POTTERY ACTIVITIES IN THE SITES

1. What activities does the pottery company do in your area?
2. When are these activities mainly carried out?
3. How are the activities done by the pottery company?

B. IMPACTS OF THE POTTERY ACTIVITIES ON THE ENVIRONMENT

4. If you compare now and before the company started their work in the area, what change do you notice in the following:
    - Land
    - Vegetation
    - Water quality

C. CAUSES OF THE IMPACTS

5. What is causing the changes that you have noticed in the environment?

D. MITIGATION MEASURES

6. What do you think should be done to improve on the positive impacts so that the impacts are more successful?
7. What should be done to stop/reduce the negative impacts the pottery has on the environment?
8. What have you done in attempt to reduce the negative impacts on the environment?
9. What has the company done to reduce the negative impacts on the environment?

End of Group Discussions. Thank you for your participation

Appendix B-4: Focus Group Discussion Guide for Raw Material Employees

A. INFORMATION ON POTTERY ACTIVITIES IN THE SITES

1. How many sites does the pottery have?
2. What is mined from each site?
3. How much of each mineral is mined, and its function in the pottery work?
4. At which part of the year is mining mainly done?
5. How is the mining done?

B. EFFECTS OF THE POTTERY ACTIVITIES ON THE ENVIRONMENT

6. What are the effects of the mining activities on the following:
    - Land
    - Vegetation
    - Water quality
7. Have the people in the mining sites complained about the way the activities are done?
8. Which diseases are common amongst the raw material employees, what could be the causes?

C. CAUSES OF THE IMPACTS

9. What is causing each of the effects that you have mentioned?

D. MITIGATION MEASURES

10. What do you think should be done to improve on the positive effects so that the impacts are more successful?
11. What should be done to stop/reduce the negative effects the pottery has on the environment?
12. What have you done in attempt to reduce the negative effects on the environment?
13. What has the company done to reduce the negative effects on the environment?

End of Group Discussions. Thank you for your participation

Appendix C- 1: One-way ANOVA test for soil pH, % OM, Nitrogen and Phosphorus the Sites

Section = Sample Type

Source of Variation	Sum of Squares	df	Mean Square	F-Ratio	Significance level
Site pH	6.375	4	1.265	6.375	0.008
Section pH	0.073	2	0.037	0.067	0.936
Site %OM	31.904	4	7.976	0.959	0.471
Section %OM	54.556	2	27.278	5.816	0.016
Site %Moisture Content	12.30	4	3.075	0.284	0.882
Section %Moisture content	68.410	2	34.205	7.862	0.007

Appendix C- 2: One-way ANOVA Test for available nitrogen and phosphorus in the Sites

Source of Variation	Sum of Squares	df	Mean Square	F-Ratio	Significance level
Site N	0.000	4	0.000	0.408	0.605
Section N	0.000	12	0.000	10.834	0.002
Site P	0.000	4	0.000	0.225	0..918
Section P	0.001	2	0.001	3.790	0.53

Appendix C-3: One-way ANOVA Test for Ca, Fe, Mg and K in the Sites

Source of Variation	Sum of Squares	df	Mean Square	F-Ratio	Significance level
Site Ca	4.521	4	1.130	15.686	0.000
Section Ca	0.136	2	0.068	0.160	0.854
Site Fe	0.055	4	0.014	2.933	0.076
Section Fe	0.015	2	0.007	0.994	0.399
Site Mg	0.008	4	0.002	4.132	0.031
Section Mg	0.000	2	0.000	0.014	0.986
Site K	0.007	4	0.002	1.839	0.198
Section K	0.004	2	0.002	2.387	0.134

Appendix C-4: One-way ANOVA Test for Ca, Fe, Mg and K in the Sites

Source of Variation	Sum of Squares	df	Mean Square	F-Ratio	Significance level
Site Cd	0.264	4	0.066	0.990	0.456
Section Cd	0.131	2	0.066	0.987	0.401
Site Cu	0.000	4	0.000	6.881	0.006
Section Cu	0.000	2	0.000	0.038	0.963
Site Mn	0.013	4	0.003	6.465	0.008
Section Mn	0.003	2	0.001	1.040	0.383
Site Pb	46.089	4	11.522	1.666	0.233
Section Pb	3.184	2	1.592	0.17	0.845

Appendix D-1: One-way ANOVA Test for the heavy metals and silicates in rock raw materials.

Source of Variation	Sum of Squares	df	Mean Square	F-Ratio	Significance level
Rock Cd	18.416	2	9.208	7.666	0.022
Rock Mn	33.620	2	16.810	3.000	0.125
Rock Pb	6977.742	2	3488.871	194.679	0.000
Silicates	82841.237	2	16409.244	2354.782	0.000

Appendix E-1: One-way ANOVA Test for the heavy metals in stream water

Source of Variation	Sum of Squares	df	Mean Square	F-Ratio	Significance level
Cd	0.000	5	0.000	-	-
Cu	0.004	5	0.001	7.175	0.003
Mn	0.267	5	0.053	9.366	0.001
Pb	0.065	5	0.013	-	-

Appendix E-2: One-way ANOVA Test for physical parameters in stream water

Source of Variation	Sum of Squares	df	Mean Square	F-Ratio	Significance level
Electric conductivity	5066.667	5	1013.333	3.092	0.051
pH	0.615	5	0.123	42.274	0.000
Total Suspended Solids	4289.666	5	857933.2256	2909.892	0.000
Turbidity	81846.227	5	16369.245	2353.782	0.000

Appendix F-1: Independent t-Test for the vegetation diversities between the mined and unmined sections in the mining sites

	Levenes Test of Variances		t- Test for Equality of means						
								95% Confidence Interval Difference	
	F	sig	t	df	Sig (2-tail)	Mean difference	Std error	Lower	Upper
Shannon Diversity Index	0.892	0.372	- 0.628	8	0.547	-0.24	0.38190	-1.12066	0.64066
Species Richness	0.881	0.375	-2.170	8	0.062	-6.800	3.13369	-14.02630	0.42630

Equal Variances assumed since the Levenes Test of Variances had p > 0.05

Appendix F-2: Independent t-Test for Mn in the water between the upper sampling point and intervention point at kuthindi

	Levenes Test of Variances		t- Test for Equality of means						
								95% Confidence Interval Difference	
	F	sig	t	df	Sig (2-tail)	Mean difference	Std error	Lower	Upper
Mn	16.000	0.016	- 14. 000	2.000	0.005	- 0.2333	0.01667	-0.30504	0.16162

Equal Variances not assumed since the Levenes Test of Variances had p < 0.05