AN INVESTIGATION OF THE LEVEL OF SELECTED TRACE METALS IN PLANT SPECIES WITHIN THE VICINITY OF TANTALUM MINING AREA IN GATUMBA, NGORORERO DISTRICT, RWANDA

by

FRANÇOIS GAKWERERE

submitted in accordance with the requirements
for the degree of

MASTER OF SCIENCE

in the subject

ENVIRONMENTAL SCIENCES

at the

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR: PROF. P. NDABANEZE

NOVEMBER 2012

DECLARATION

I, François GAKWERERE sincerely and solemnly declare that ‘AN INVESTIGATION OF THE LEVEL OF SELECTED TRACE METALS IN PLANT SPECIES WITHIN THE VICINITY OF TANTALUM MINING IN GATUMBA, NGORORERO DISTRICT, RWANDA’ is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

ACKNOWLEDGEMENT

My sincere gratitude goes to the Volkswagen Foundation, a Germany company, which supported this dissertation through the Coltan Environmental Management Project.

I would like to express my profound thanks to Prof. Pontien Ndabaneze, who kindly accepted to supervise my research project. Without his help, guidance, advice and constructive criticisms this work would not have been completed. I appreciate all the effort he has provided despite his heavy responsibilities.

I would also like to thank Prof. Omotayo Rafiu Awofolu for his continuous support and scientific guidance during the process of writing this dissertation. His support all along my postgraduate studies is highly appreciated and has made it possible to accomplish this study. I am also greatful to Prof. Lehmann, Prof. Nielder, Prof. Naramabuye, Prof Owor, Dr Habarugira Ildephonse, Mr. Ndoli Alain, Mrs. Inga, Mr. Tobias, Prof. Peter White, Mr. Rutegwa Marcelin, Mrs. Muhongere Candide, Mr. Nsanganwimana Florien, Mrs. Mukamwambari Concilie and Mr. Karasira Gilles, for scientific and technical support during the carrying out of this study. Special thanks are forwarded to the staff of the University of South Africa, particularly the members of the Department of Environmental Sciences who provided me with intellectual knowledge and skills during my studies for Honors and Masters programs.

ABSTRACT

Due to mining activities, the natural vegetation cover in Gatumba area was removed and replaced either by crops or bare wasteland with reduced available arable land. The main aim of the study was to assess the impact of the mining activities on the plant mineral uptake and the dynamics of the vegetation. The vegetation in this area under investigation was diversified and heterogeneous. Trace element concentrations in soils were similar to those in plant parts but some elements were highly concentrated in soils than in plants. According to the bioaccumulation factors of the analyzed trace elements in plant parts, two categories of plants were identified, and these are excluders and accumulators. No toxic levels of the evaluated trace elements were found in the analyzed plant samples. As a recommendation for the adaptation of plants to Gatumba mining environment, the most useful plant species for the revegetation/restitution of the technosols should be *Sesbania sesban*, *Crotalaria dewildemaniana* and *Tithonia diversifolia* subject to further experiments on trace elements bioaccumulation and organic matter production.

KEYWORDS: Soil and plant trace elements, Transect, Similarity, and Performance index, Tolerance, Bioaccummulation factors, Translocation factors, Excluders, Absorption, Plant community.

DEDICATION

To my late parents

To my wife

To my children

To my nephew

To my brother and sisters

To my friends

TABLE OF CONTENTS

Pages

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ABREVIATIONS AND ACRONYMS

ASM: artisanal and small-scale mining
BCF: bioaccumulation factors
CASM: Communities and artisanal & small-scale mining
DR Congo: Democratic Republic of Congo
DVWK: Deutscher Verband für Wasserwirtschaft und Kulturbau (German Association for Water and Wastewater)
DW: Dry Weight
FAOSTAT: Food and Agriculture Organization based statistics
GDP: Growth Domestic Product
ISS: Institute for Security Studies
MINAGRI: Ministry of Agriculture
MINITERE: Ministry of Land and Environment Management
MVSP: Multivariate statistical package
NSI: National Statistic Institute

REDEMI: Régie d'Exploitation et de Développement des Mines (Mine exploitation and development agency)

REMA: Rwanda Environment Management Authority

SOM: Soil Organic Matter

SOMIRWA: Société minière du Rwanda (Rwandan Mining Company).

USAID: United States Agency for International Development

WRB: World reference base for soil resources

CHAPTER 1: INTRODUCTION

1.1 Background on Coltan tantalum

This study investigates the level of selected trace metals in plant species within the vicinity of tantalum mining area in Gatumba, located in Ngororero district, Western Province of Rwanda. Tantalite is part of elements that form coltan. In fact, coltan is the colloquial African name for columbite-tantalite, a metallic ore which produces Niobium (Nb) and Tantalum (Ta) elements. Ta occurs in complex oxides combined with Nb, Ti, lanthanides, and other metals. Columbite and tantalite are conveniently described by the formula (Fe, Mn) $(Nb, Ta)_2O_6$ and are frequently made up of columbite and tantalite compounds of iron and manganese. Nb has strong geochemical relations with Ta, and its association with Fe has been recognized. Minerals that contain tantalum (atomic number 73) are usually referred to as tantalite (Wickens, 2004). Columbite minerals contain the element columbium (atomic number 41), which is another name for Niobium. Tantalum mineralization has been reported in 17 African countries (Fetherston, 2004). Ta is believed to be less mobile than Nb during weathering because of its lower solubility and the slight stability of organic complexes. Thus, the Nb to Ta ratio varies depending on environmental conditions (Kabata-Pendias, 2001). The niobium-dominant mineral in coltan is called columbite, and the tantalum-dominant mineral is known as tantalite (Reetsch, 2008). Coltan is used primarily for the production of tantalum capacitors, which are used in many electronic devices. Several sources mention the importance of coltan in the production of cell phones, but this is an over-simplification since tantalum capacitors are used in almost every kind of electronic device (Reetsch, 2008).

The increased demand for coltan shot prices up higher than normal in 2011 in part because there wasn't as much available in world metals markets. Tantalum price dropped during 2012 first quarter. Starting June, tantalite price experienced a significant increase impacting Tantalum price for the second half of 2012. Coltan prices are expected to remain stable during 2012 with modest rises entering 2013 as consumer electronics units sales are expected to grow. The global economic crisis of the preceding years had forced the closing of columbite-tantalite mines in several countries. Unfortunately, mining operations in the Democratic Republic of Congo and

other conflict areas continued to supply the ore, but at higher than normal cost. Coltan price is based on Tantalite (Ta_2O_5) concentration (Magma Coltan, 2012).

With regard to the effect of coltan excavation in Gatumba mining, it could be observed that the environmental damage has extended from animals, plants, and trees to the land itself. Mining has caused significant land erosion and severe pollution of rivers and lakes surrounding the area. Some coltan composites are toxic and the lack of standards in its excavation and production has seriously increased the damage to the local environment. The irony, of course, is that a lack of sustainability inevitably lead to a depletion of coltan and the destruction of other natural resources. Such natural resources include inorganic nutrients that are considered to be essential to plants, such as calcium, chloride, magnesium, manganese, molybdenum, phosphate, potassium, selenium, sodium, sulfate, copper and zinc. They also include some inorganic substances that are not essential to the higher plants such as lead, caesium, arsenic, etc. More details on coltan are provided in chapter 2.

1.2 Problem Statement

The increase in price of Coltan Tantalum in the international market has resulted in an overexploitation of Gatumba mining zone located in Ngororero (Figure 3.2). People abandoned their subsistence agriculture and got involved in the artisanal mining activities in order to improve their welfare. As a consequence, natural vegetation cover was removed and top soil washed away, exposing bare soil or rock which reduced available land for cultivation in a highly populated region (Byiringiro and Biryabarema, 2007). Mineralised pegmatites extracted from Gatumba mines are washed with water in order to separate coltan mineral from other raw materials. Site observations indicated that the mudflows from the mining area accumulate in Nyabarongo and other small valleys located in Birambo site. This mechanical process mobilises mine-derived elements that get deposited within the surrounding soil environment.

Normally, the soil which is washed away by mining activities contains inorganic substances that are required by autotrophic plants for their growth and development with the presence of sunlight. Some inorganic substances are not essential for plant life and are categorized into macro and micro-elements (Sinha, 2004). Plants uptake these minerals from soils and accumulate

them in their tissues. These elements are finally released in the ecosystem to influence the trophic chain.

Ndabaneze *et al.* (2008) showed that native vegetation had disappeared in the mining area and has been replaced by other local and exotic plant species such as *Lantana camara L*. In the area under investigation, the vegetation cover is not fully identified; mineral concentration in plants and soil are not yet fully identified and mineral translocation in Gatumba plants is not yet known. Therefore, this study focuses on investigating the changes in the spatial variability of vegetation and plant uptake of trace elements from Gatumba mining soil. It also proposes strategies for re-vegetation of Gatumba mining area.

1.3 Research hypotheses

This study verifies the following hypotheses:

i) Plant communities in Gatumba mining area are characteristic and related to the soil mineral composition.

ii) Trace elements uptake depends on the type of soil and plant species.

iii) The vegetation of Gatumba mine site has natural sensitivity to the accumulated trace elements.

1.4 The aim and objectives of the study

1.4.1 The aim

The main aim of the study is to investigate the plant community, the level of selected trace metals in plant species and to identify the impact of the mining activities on the dynamics of the vegetation in Gatumba mining area.

1.4.2 Specific Objectives

The research project was guided by the following specific objectives:

- To identify plant communities in Gatumba mining area;
- To analyse plant and soil trace element concentrations;

- To analyse the relationship between plants and soils by using bioaccumulation and translocation factors of trace elements;
- To identify the plant tolerance to trace elements in Gatumba mining soil.

1.4.3 Research questions

This research attempts to answer the following questions:

- What are the plant communities that are present in Gatumba mining area?
- What trace elements are contained in Gatumba mining soil and plants on it?
- Is spatial variability in plant communities induced by trace element concentration of soils?
- Is there any bioaccumulation of trace elements by plant uptake in Gatumba mining area?

1.4.4 Rationale of the study

The findings from this study will help researchers to understand the relationship between mining soils and plant community dynamics in Gatumba mining area. They also be used to plan for rehabilitation/ restitution of the mining wastelands. Furthermore, local mining communities were informed about the effect of some trace elements on their welfare and livelihoods. They will inform decision makers in terms of sustainable environment management and mining wasteland rehabilitation.

1.4.5 Research Concept

Trace elements need to come into contact with the plant-roots in order to enter into the roots (Adriano, 2001). However, nutrient uptake and plant growth are influenced by conditions prevailing at the soil-root interface. These conditions vary according to sites and plant species. In the case of this study, all the investigated sites were influenced by mining activities and the resulting water flow. The investigated plants grow in natural conditions and the observed interactions between mining sites and plant uptake are represented in Figure 1.1. As the release of trace elements to soil occurs when plant parts die and decompose, such a phenomenon

provides a possible pathway between soil solution/concentration and plant uptake of nutritional elements. This process is described as follows:

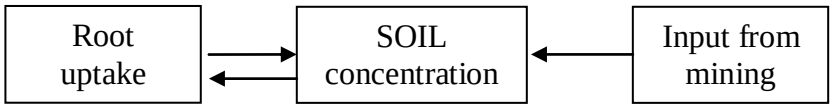

Figure 1. 1: Model showing absorption by roots in a mining zone (Adriano, 2001).

1.4.6 The scope of the study

The study investigates the plant communities that can thrive within the Gatumba mining area under conditions of trace elemental uptake. This study is limited to four sites of Gatumba mining area, namely Ruhanga, Mpare, Rwasare and Birambo. The research process involved mapping the spatial variability of plant communities specifically plant sociability, and identifying the relationships between soil and plant trace element uptake. As plant species were numerous, seventeen dominant plants were investigated and their trace element concentrations were analysed.

1.5 Chapter Layout

The present study is divided into five chapters. Chapter one includes the introduction, objectives, hypotheses, significance and scope of the study. Chapter two comprises the Literature review, while Chapter three deals with the methodology. Chapter four presents the research findings, while Chapter five discusses the results and provides with conclusion and recommendations.

1.6 Conclusion

The present chapter states the background of the problem, hypotheses and objectives. A brief research concept has also been presented as well as the scope of this study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The chapter gives a review of previous works which show the relationship between plants and soils. This review provides information which helps to understand the relative efficiency with which plants take up minerals from soils and how efficient mineral absorption depends partially on the interrelationships between plant and soil physical factors (Cataldo and Wildung, 1978). It also displays plant physiological processes that facilitate the understanding and interpretation of data collected during the present survey.

2.2 Regional geology

Central Africa, where Rwanda is partially located, hosts one of the important tantalum ore of the world. Tantalum ore deposits in this region are mostly pegmatite-based (Varlamoff, 1968, 1972 and Pohl, 1994). A pegmatite is an intrusive igneous rock mainly composed of quartz, feldspar and mica. The ore mineral is tantalite (a variety of columbite), which contains about 52 to 86% by weight of Ta_2O_5 and which has a density of 6.2-8.0 g/cm^3. Tantalum pegmatites are part of the Li-Cs-Ta-rare-metal-group of pegmatites and granites (Martin and Cerny, 1992). Cassiterite, lithium (Li) and Caesium (Cs) minerals, and feldspar or kaolinite are frequent co-products. Tantalite is extremely resistant to surficial alteration and becomes enriched in residual soil and proximal fluvial placers (Pohl, 1994). Minor and trace minerals associated with tantalite include pyrite, arsenopyrite, bismuth sulfides, sulfosalts (like Pb and Zn), as well as uraniferous minerals. Therefore, deleterious elements which may be present in primary or placer deposits of tantalum include S, As, Bi, U, and toxic base metals (Pohl, 1994). Tantalum ores have typically contents of around 300 g/t of Ta_2O_5. Therefore, large masses of rocks have to be treated for mineral recovery. This leaves a heritage of spoils, tailings, and sediments resulting from hydraulic mining or manual panning of soft rock or of placers (Pohl, 1994).

In Gatumba area of Western Rwanda, several but generally small deposits of this type of Tantalum are common and are originated from Late Proterozoic (~1000 Ma) tin granite magmatism of the Kibara orogen (Pohl, 1994). Gatumba area is a typical mining site in Central

Africa, in terms of social conditions, climate, geology, topography and vegetation. Thus, it is a very proper example for hundreds, possibly thousands of similar tantalum mining sites in Burundi, Democratic Republic of Congo (Kivu), Rwanda and Uganda (Lehmann *et al.*, 2008).

In Africa, traditional sources of tantalum are mainly found in Rwanda, Democratic Republic of Congo, Uganda, Burundi, Ethiopia and Nigeria, and these countries have supplied the minerals for half a century in variable quantities (Zogbi, 2005). Coltan is limited to pegmatites and does not occur in higher concentrations in hydrothermal alteration zones (Reetsch, 2008). This limitation can be explained by the low solubility of niobium and tantalum in aqueous solutions (Dewaele, 2007).

The map below shows the location of Gatumba mining area within the region.

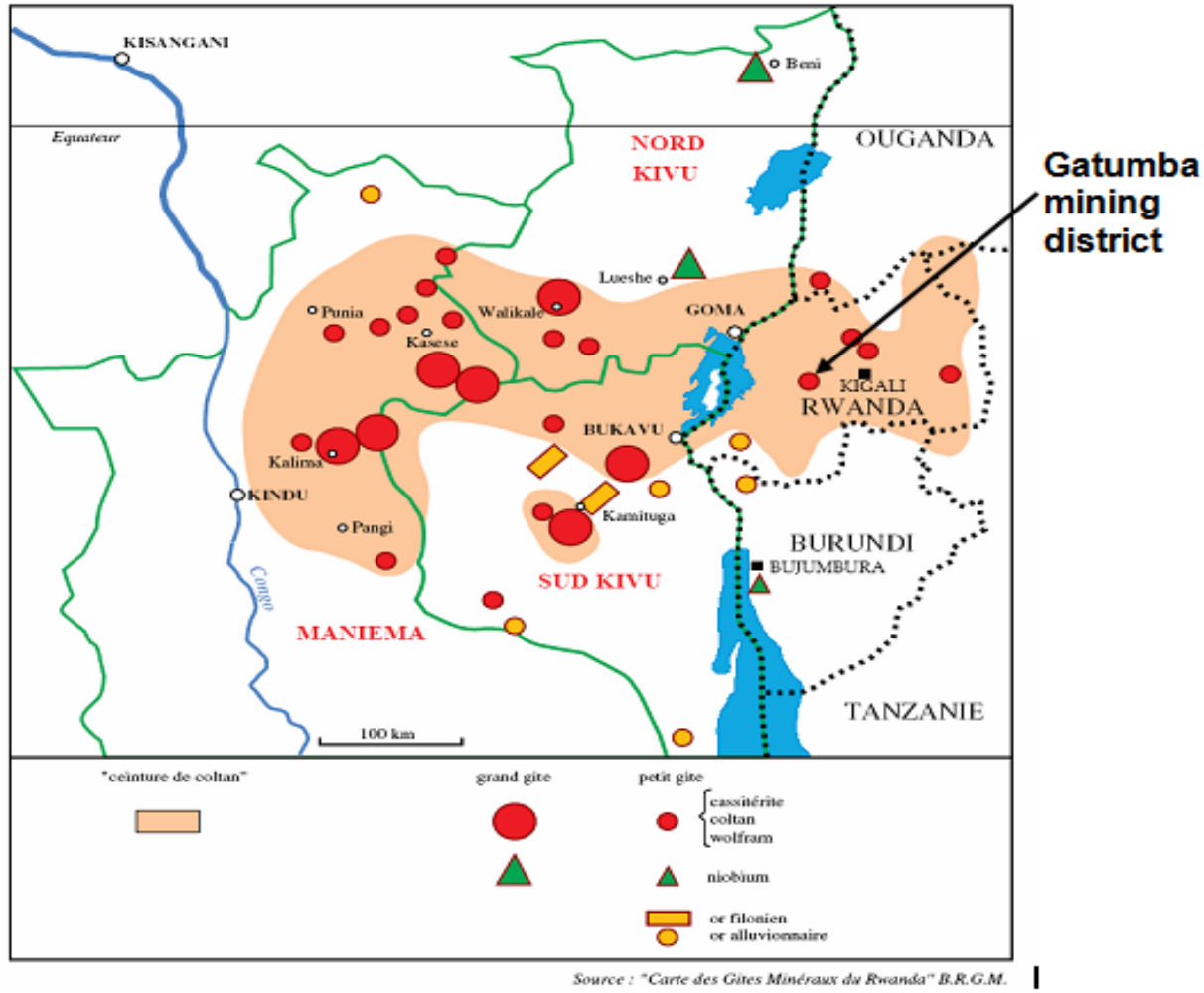

Figure 2. 1: Location of the Gatumba mining district within the Central African Tin-tungsten-tantalum (Pohl, 1994).

2.3 Mining background in the Rwandan context

In Rwanda, mining activities started around 1920 by colonial companies up to 1971. However, artisanal exploitation took place during that period and it was driven by high tantalum and tin prices. In 1973, the Rwandan government established its own mining company called "Société minière du Rwanda (SOMIRWA)", a Rwandan mining company. This company operated for about 15 years. Then, in 1985, SOMIRWA was replaced by another mining company: the Mining and Mines Development Authority or "Régie d'Exploitation et de Développement des

Mines (REDEMI)" in French. This company is still operating in the Gatumba mining area today. The main minerals found in Rwanda are Cassiterite, Wolfram and Colombotantalite (Bucagu, 2007). However, the largest tantalum mines are located in Australia which produces more than 50 % of the global demand (Wickens, 2004).

Recently, in the 2006–2007 fiscal year, the Rwandan mining sector experienced intensive privatization that led to the growth of the national economy. Currently, REDEMI which has been under the Rwandan government management is undergoing privatization with 17 out of a total of 20 concessions already under private ownership. Mining minerals is a non-renewable resource activity with great potential. Even if mining activities occupy a small area of the land in Rwanda, they can have significant and often irreversible environmental impact (REMA, 2009).

2.4 Soil formation

According to Adriano (2001), soil development is the disintegration and alteration of rocks and minerals by physical, biological, and chemical processes or by physico-biogeochemical processes, with climate being the most important factor in these processes. Table 2.1 shows the mineral composition of parent rocks of different types of soils.

Table 2. 1: Concentration of metals in igneous and sedimentary rocks (mg/kg) (Zhenli *et al.*, 2005)

Elements	Basaltic igneous	Granitic igneous	Shales and Clays	Limestones	Sandstone
As	0.2-10	0.2-13.8	1-17	0.1-8.1	0.6
Cd	0.006-0.6	0.003-0.18	0-11	0.05	0.05
Cr	40-600	2-90	30-590	10	35
Co	24-90	1-15	5-25	0.1	0.3
Cu	30-160	4-30	18-120	4	2
Hg	0.002-0.5	0.005-0.06	0.005-0.51	0.01-0.22	0.001-0.3
Pb	2-18	6-30	16-50	9	<1.31
Mo	0.9-7	1-6	2-5	0.4	0.2
Ni	45-410	2-20	20-250	20	2
Se	0.05-0.11	0.05-0.06	-	0.08	0.05
Zn	48-240	5-140	18-180	20	2-41

Generally, the earth's crust is made up of 95% of igneous rocks and 5% of sedimentary rocks of which the latter has about 80% of shales, 15% of sandstones and 5% of limestones (Zhenli *et al.*, 2005). However, sediments are more common at the ground surface as they tend to overlie the igneous rocks from which they were derived. Brady *et al.* (2002) noted that igneous rocks contain more trace elements (like Cr, Co, Mn, Cu, Zn, Cd and Pb) than sedimentary rocks. Soils developed from these parent materials tend to reflect their chemical composition, although pedogenetic processes may modify this relationship (Zhenli *et al.*, 2005). During soil development, Cu, Zn and Cd tend to concentrate in Mn oxides, whereas Pb is more likely to be enriched in the oxides and hydroxides of Fe. The rate and extend of solubilization are governed by physico-chemical properties of the deposited material, soil processes and soil properties (Cataldo and Wildung, 1978). Soil pH determines the distribution of several elements where for example a pH of 6.5-7.5 provides an optimal concentration of N, K, Ca, P, S, B, Cu, Zn and Mo in the soils (Figure 2.2**)** adapted from Jones and Jacobsen (2001) obtained from Reetsch (2008).

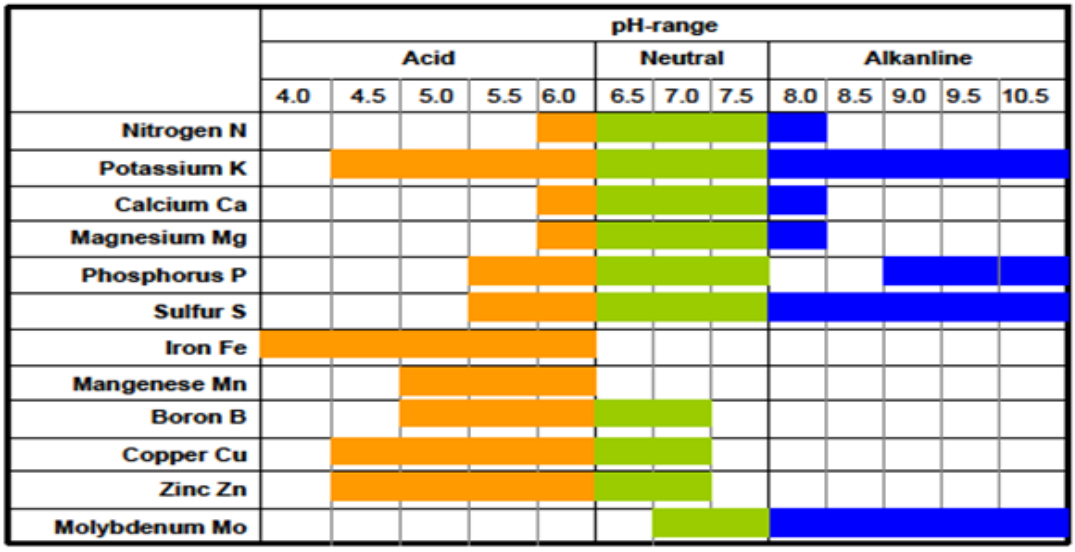

Figure 2. 2: Distribution of minerals in relation with pH (adapted from Jones and Jacobsen, 2001) obtained from Reetsch (2008).

Typical Soil Reference Groups of the tropical highlands of Rwanda are lixisols, nitisols, cambisols, gleysols, and umbrisols (WRB, 2006). In general, soil degradation caused by erosion and acidification is strongly linked to the population density and inadequate farming methods (Roose, 1996). The erosion risks in Rwanda vary greatly between the volcanic zones in the north,

the areas surrounding the Kivu Lake in the West, and the Congo-Nile-Watershed (Reetsch, 2008). Tillage in Rwanda is done manually with hoes. There is no mechanization that could cause compaction of soil horizons. Increasing agricultural use at the slope bottom is observed in western Rwanda. Different forms of erosion that occur in the highlands of Rwanda are the dry mechanical erosion, sheet erosion, linear erosion, mass movement and wind erosion (REMA, 2009). The topsoil horizons are quickly eroded by linear erosion, dry mechanical erosion following multiple tillage procedures (Reetsch, 2008). The soil cover on the hilltops is often shallow and rocks appear (Roose, 1996). Soils developed on the Rwandan mine spoils are shallow and contain low Soil Organic Matter (SOM), nutrients and some trace elements. As the soils developed become relatively young substrates, they may be enriched in toxic elements like arsenic and cadmium (Reetsch, 2008).

2.5 Trace elements and plants

The term trace element has different meanings according to various disciplines. It often designates a group of elements that occur in natural systems in low concentrations. It can also be defined as elements used by organisms in small quantities but are believed to be essential to their nutrition (Adriano, 2001). The trace elements in soils are derived from both parent materials and anthropogenic inputs (Zhenli *et al*., 2005). Some trace elements, including Cu, Zn, Mn, Fe, Mo, and B are essential for plant growth and are called micronutrients. Except for B, these elements are heavy metals, and can be toxic to plants at high concentrations. Some trace elements such as Co and Se are not essential to plant growth but are required by animals and humans. Other trace elements such as Cd, Pb, Cr, Ni, Hg and As have toxic effects on living organisms and are often considered as contaminants. Soil contamination by trace elements derived from parent materials or point sources often occur in limited areas. The trace metal contents of soils are highly dependent on the rocks from which the soil parent material was derived and on the process of weathering that the soil-forming materials have been subjected to. Thus, the older the soil, the less likely is the influence of parent rocks (Adriano, 2001). Table 2.2 below shows normal concentrations of some trace elements in soils as well as concentrations at which these elements become toxic (Ross, 1994).

Table 2. 2: Trace elements in soils and associated mineral concentrations (adapted by Ross, 1994).

Elements	Normal range in soil (total)(μgg^{-1} dry weight)	Concentration in soil considered toxic (total) (μgg^{-1} dry weight)
Cr	5-1000	75-100
Mn	200-2000	1500-3000
Co	1-70	25-50
Ni	10-1000	100
Cu	2-100	60-125
Zn	10-300	70-400
Cd	0.01-7	3-8
Sn	<5	50
Hg	0.02-0.2	0.3-5
Pb	2-200	100-400

Toxic trace elements can be released in gaseous (aerosols), liquid or solid form, depending on the source. These trace elements can emanate from mining and dust released by mining activities. Tolerance to heavy metals in plants may be defined as the ability to survive in a soil that is toxic to other plants, and is shown by an interaction between a genotype and its environment (Macnair *et al*., 2000). Natural tolerance of plants to metal accumulation depends on plant species and genotypes. According to Adriano (2001), plants uptake can be divided into three groups according to their sensitivity to metal accumulation, and these are:

i) Excluders which are non-tolerant plants to uptake and accumulation of potentially toxic elements;

ii) Indicators which are plants whose trace element concentrations in tissues are related to availability of trace elements in soils; and

iii) Accumulators which are plants that accumulate higher concentrations of elements in their tissues according to their increase in soils. There are also extreme accumulators called "hyperaccumulators" that can live and thrive on contaminated soils and accumulate extremely high concentrations of trace elements (Baker, 1987).

Below is Figure 2.3 that indicates the above-mentioned categories of tolerant plants:

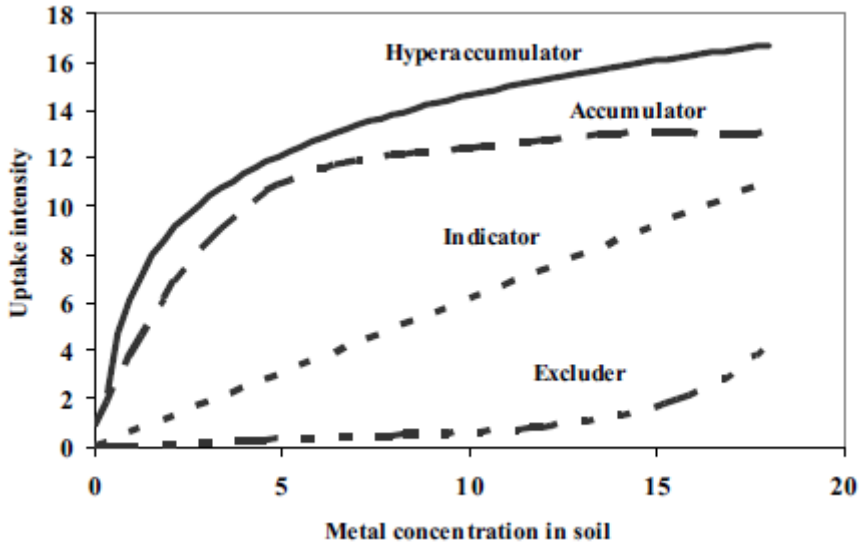

Figure 2. 3: Model of Relative uptake and bioaccumulation potential among plant species (Adriano, 2001).

With regard to correlation between plant mineral concentration and soil solution concentration of individual heavy metals, it is apparent that the higher the bioavailability in solution of elements (e.g. Cd, Zn, Cu and Pb) in the soils, the more the uptake by plants (Kabata-Pendias and Pendias, 1986). Trace elements uptake by plants have three patterns: (a) true exclusion in which trace elements are restricted from entering the plant, (b) shoot exclusion in which metals are accumulated in the root but translocation to the shoot is restricted, and (c) accumulation where metals are concentrated in all plant parts (Baker, 1981 and Kamal *et al*., 2003). Hyperaccumulators can tolerate, uptake, and translocate high concentrations of certain heavy metals that would be toxic to most organisms. For example, a Cd uptaken by a plant becomes toxic when its concentration in plant tissues is >100 mg/kg of dry matter for Cd, or when >1000 mg/kg for Ni and Cu, or when >10,000 mg/kg for Zn and Mn, in case they are grown in metal-rich soils (Kamal *et al*., 2003 and Zavoda *et al*., 2010).

Figure 2.4 below shows a correlation between plant concentration and soil solution concentration of individual heavy metals.

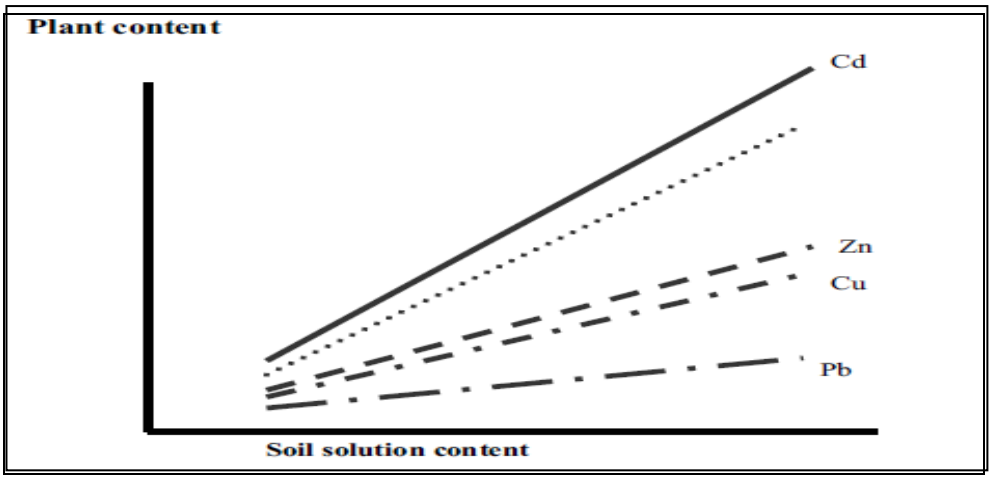

Figure 2. 4: Correlation of plant uptake of heavy metals and their concentration in soils (Source: Kabata-Pendias and Pendias, 1986).

Still on correlation between plant and soil concentration, Alloway (1990) indicates that Cr, Pb and Hg are weakly mobilised; but Ni, Co and Cu are intermediate mobilised; while Cd, Mn, Mo and Zn are readily mobilised within plants. In addition, Tlustoŝ *et al*. (2006) show that the accumulation of mineral elements in plants does not depend only on the plant species and mineral elements behaviour but it also depends on other internal and external factors of the plant. As illustrative example, Brown *et al*. (1994) show that many plant species mainly from Brassicaceae family have the ability to accumulate Cd up to 0.2% in their tissues; while Brooks (1998) indicates that the same tissue concentrate >1% for Zn and Ni.

In food biochemical and biomedical research, trace elements are considered to be those that ordinarily present in plant or animal tissues in concentration which is below < 0.01% of the organism (Adriano, 2001). That is why Adriano (2001) states that trace elements refer to elements that occur in natural and disturbed environments in small amounts and that they become toxic to living organisms when they are present in sufficient concentrations.

As for bioaccumulation factors (BCF), Mingorance *et al*. (2007, in Ye *et al*., 2008) state that the value of bioaccumulation factors is a soil-plant element transfer index that may favor the understanding of the trace elements uptake characteristics. Based on bioaccumulation factors (BCF) values, metallophytes could be classified into two types, namely excluders which are

plants with BCF values that are lower than 1; and accumulators whose BCF values are equal or higher than 1 (Baker, 1981). As a special type of accumulator, some plants may contain unusual large concentrations of certain elements in aerial parts on a dry mass basis and they are called hyperaccumulators (Boyd, 2004 and Ye *et al.,* 2008).

As heavy metals include a great number of minerals, the salient one in this study are copper, cadmium, lead, cadimium, zinc, arsenic, uranium, rubidium, caesium, lithium to name but a few.

2.5.1 Copper and plants relationship

Copper (Cu) can be released into the environment by both natural sources and human activities. Examples of natural sources are wind-blown dust, decaying vegetation, forest and fires. As copper is released both naturally and through human activity, it is very widespread in the environment (Marschner, 1995 and Raven *et al.,* 1999). Since copper does not break down in the environment, it can accumulate in plants and animals when it is found in soils. Copper is an essential redox-active transition metal that is involved in many physiological processes in plants because it can exist in multiple oxidation states plants. Under physiological conditions, Cu exists as Cu^{2+} and Cu^{+}. Its role in plant tissue is that it acts as a structural element in regulatory proteins and participates in photosynthetic electron transport, mitochondrial respiration, oxidative stress responses, cell wall metabolism and hormone signaling (Marschner, 1995 and Raven *et al.,* 1999). Plants require Cu as an essential micronutrient for normal growth and development. When this ion is not available in the soil, plants develop specific deficiency symptoms, most of which affect young leaves and reproductive organs (Raven *et al.,* 1999). Furthermore, Copper is not more mobile in soils than Zinc and it is attracted to soil organic matter and clay minerals as illustrated in Figure 2.4.

Copper deficiency in plant is characterized by withering of tips of young leaves and causes exanthema in some trees (Raven *et al.,* 1999). Typical symptoms of Cu deficiency in plants appear first at the tips of young leaves and then extend downwards along the leaf margins. The leaves may also be twisted or malformed and show chlorosis or even necrosis (Marschner, 1995). In addition, high nitrogen concentrations in plants delay translocation of copper from older

leaves to the growing parts of the plant (young leaves), significantly enhancing copper deficiency (Marschner, 1995). Plant composition shows dynamic changes as soil Cu increases. Malaisse *et al. (*1999) and Strandberg *et al*. (2006) stress that plant community composition varies with the severity of soil mineral contents such as Cu contamination. As a consequence, dwarf shrubs become less frequent and trees disappear towards the pollution source (Koptsik *et al*., 2003).

Moreover, the study of plant species and biomass on Cu-contaminated soils or other heavy metals is important to identify metal-tolerant species with either accumulator or excluder phenotypes (Wong, 2003). These plants could be used in phytoremediation processes to restore plant cover and contribute to increased organic matter supply to soils and to decrease metal dispersion (Koptsik *et al.*, 2003).

2.5.2 Cadmium and plants relationship

Cadmium is a mobile trace element in the soil and is taken up by plants through the roots and is transported in aerial parts (Kabata-Pendias and Pendias, 1986**)**. According to them, factors influencing Cd transfers into plants are cadmium concentration in soils, soil pH values, and humus content in soils. There is a high risk of accumulation, even at low soil concentration of Cd which is inferior to 1 mg/kg, and with pH values under 6.5 (DVWK, 1988) due to its mobility in the soils. Plant contaminated can sometimes be identified directly according to soil conditions on which it grows. Accumulation rates differ according to plant parts. Smolders (2001) rates them as follows: roots > tubers > leaves >shoots > fruits > seeds.

2.5.3 Lead and plants relationship

According to Subhuti (2007), lead is the heaviest of the non-radioactive metals (atomic number 82; atomic weight 207) that naturally occur in substantial quantities (ppm) on the earth's surface. Natural soils usually contain less than 50 ppm of lead but are never lead free. Thus, terretrial plants tend to absorb lead from the soil and retain small content in their roots, due to the nature of the soil (DVWK, 1988). Lead from the atmosphere has low mobility on the soil and tends to stay on the top surface of the soil. Therefore, superficially rooted plants, such as grasses and common vegetables, are particularly vulnerable to uptake lead contamination that originates from

the atmosphere (Greene, 1993). Calcium and phosphorus application may reduce lead uptake by roots (Greene, 1993).

2.5.4 Zinc and plants relationship

Zinc is the most abundant element in the Earth's crust (Zhenli *et al.*, 2005). The world's zinc production is still increasing. This basically means that there are a lot of zincs emitted into the environment. Finally, zinc can interrupt microbiological activity in soils through its negative influence on microrganisms and earthworms, leading to a serious breakdown of organic matter (Marschner, 1995). Uptake of zinc is also negatively affected by high levels of available phosphorus and iron in soils. It is an essential component of various enzymes for energy production, protein synthesis, and growth regulation in plants. It is poorly mobile in plants, suggesting the need for a constant supply of available zinc in the soil for optimum growth (Marschner, 1995). The most visible zinc deficiency symptoms are short internodes and a decrease in leaf size. Delayed maturity also is a symptom of zinc-deficient plants and Zn deficiency also reduces organic matter in soils (Sinha, 2004).

2.5.5 Arsenic and plants relationship

Chemically, arsenic is a metalloid, which is an intermediate element possessing properties of both metals and non-metals. In soils, arsenic is mainly present in inorganic forms as arsenite and arsenate. Arsenate is the dominant form of arsenic in the soil solution (Porter and Peterson, 1977), thus tolerant plants take up arsenic in the form of arsenate (Asherc and Reay, 1979). In order for plant uptake process to proceed, arsenic must be bioavailable, ready to be absorbed by roots. The availability of arsenic forms is determined by the soil conditions. Arsenic contaminated sites usually have adverse soil conditions that include poor soil structure, low organic content, and inadequate N and P. Therefore, plants have to adapt to those hostile soil conditions as well as to the metal contents (Asherc and Reay, 1979). Only plants that are pre-adapted to these conditions will develop tolerance. Arsenic phytotoxicity is not directly linked to total concentration of arsenic in soil since much of the soil arsenic is not directly available to plants (Sadiq, 1986). Phytotoxicity of arsenic is dependent on available arsenic concentration in

plant (Deuel and Swoboda, 1972). Plants normally take up inorganic forms, arsenate and arsenite, which are the most toxic forms naturally occurring in the biosphere. Plants tolerance to arsenic is variable according to arsenic concentration. For example, potatoes, cabbage, tomatoes, carrots, tobacco, and Sudan grass are tolerant, while onions, cucumbers and legumes have low tolerance (Leo *et al*., 1977).

2.5.6 Uranium and plants relationship

Uranium (U) and thorium (Th) are natural radioactive elements which are widely distributed in lithosphere, as well as in Stratosphere. Uranium uptake is highly dependent on soil pH (Ebbs *et al.,*1998) and organic compounds content in soil due to their influence on uranium mobility in soil (Bednar *et al*. 2007). Fungal mycelium probably can help in translocating uranium as uranyl cations into roots through fungal tissues (Weiersbye *et al*. 1999 and Rufyikiri *et al*. 2002). The uranium concentration varies in different parts of the plant and it has been observed that the uranium uptake in plant depends on the nature and age of the plant. Plant growth is affected by increase in concentration of uranium in the soil (Kovalevskii, 2007).

2.5.7 Rubidium and plants relationship

No minerals of rubidium (Rb) are known, but rubidium is present in significant amounts in other minerals such as lepodite (1.5%), pollucite and carnallite. Rubidium has no known biological role (Läuchli and Epstein, 1970). Rubidium and potassium are found together in minerals and soils, although potassium is much more abundant than rubidium. Plant will absorb rubidium faster. Some plants with potassium deficiency will respond positively to rubidium (Läuchli and Epstein, 1970). High Rb concentrations are toxic especially to the growth of tuber roots. Sodium or Rb has been shown to enhance the growth of beet plants under either low or high K conditions.

2.5.8 Caesium and plants relationship

Caesium (Cs) is an alkali metal and has physical and chemical properties similar to those of rubidium and potassium. Cs released by weathering in soils is strongly adsorbed, but there is

very little information on the Cs status of soils. It is present in soil solution as monovalent Cs cation. Cs apparently is not an essential component of plant tissues, and there are few data on its occurrence in plants. Souty *et al*. (1975) and Yudintseva *et al*. (1979) report that Cs is relatively easily taken up by plants, although its absorption by roots appeared not to parallel K absorption. Its role for Cs in plant nutrition is not well known, but excessive Cs can be toxic to plants (Babula *et al.*, 2008). However, its threshold was not found in the existing literature. Furthermore, plants take up caesium via cation transporters which cannot discriminate between radioactive and non radioactive caesium (^{133}Cs).

2.5.9 Lithium and plants relationship

Lithium (Li) is widely distributed throughout the earth's crust and is likely to be concentrated in acidic igneous rocks and sedimentary aluminosilicates. Earth's crust ranges from 25 to 40 ppm. Li is very mobile in geochemical processes and preferably enters silicate minerals rather than sulfide minerals. It is also readily absorbed by clay minerals. During weathering, Li is released from the primary minerals relatively easily in oxidizing and acid media and then is incorporated in clay minerals. It is also slightly fixed by organic matter, and is fixed by Mn-oxides and accumulated in phosphate rocks. Thus, the Li content of soils is more controlled by conditions of soil formation than by its initial content in parent rocks. The Li distribution in soil profiles follows the general trends of soil solution circulation, even if it may be highly irregular (Wells and Whitton, 1972). In the arid climatic zones, Li follows the upward movement of the soil solution and may precipitate at top horizons along with easily soluble salts of chlorites, sulfates, and borates. However, as Shakuri (1976) reported, water soluble forms of Li in the soil profile reach up to about 5% of the total soil content and therefore Li is likely to occur in ground waters of areas having elevated Li contents in rocks and soils. Exchangeable soil Li is reported to be strongly associated with Ca and Mg (Davey and Wheeler, 1980). The soluble Li in soils is readily available to plants. Therefore, the plant content of this element is believed to be a good guide to the Li status of the soil (Farrah and Pickering, 1978). Some plants of the family of Rosaceae, Polygonaceae and Solanaceae accumulate more than 1000 ppm Li when grown in an aridic climatic zone (Sievers and Cannon, 1973). Li appears to share the K transport carrier and is therefore easily transported in plants, being located mainly in leaf tissues. However, a higher

Li content is very often reported in roots. Lithium is easily absorbed by plants and the amount of lithium in plants varies widely, reaching 30 ppm in some cases (Bingham, *et al*., 1964).
Usually, plants observed to be lithium-tolerant, such as cotton, red beets, and Rhodes grass, accumulate larger amounts of lithium (Bingham, *et al*., 1964). Lithium toxicity symptoms are not distinct and are difficult to recognize on the plant growth and development but its threshold in the existing literature was not found.

2.5.10 Bismuth and plants relationship

Claude Geoffroy (1753) cited by Calvin and Hamilton (2008) discovered that Bismuth (Bi) is a metalloid that shares similar chemical properties with arsenic and antimony. They showed that those trace elements are different. Bismuth is non-toxic (not poisonous), unlike lead and most other heavy metals (Babula *et al.*, 2008). Natural bismuth metal is rare in nature, and does not occur in sufficient quantities to be mined as a source of bismuth. pH seems to be a very important factor for bismuth uptake from contaminated soils (Li and Thornton, 1993). The mechanisms of bismuth transport in plants are still unknown and the bismuth compounds generally have very low solubility and they are not considered to be toxic to plants (Babula *et al.*, 2008).

2.5.11 Antimony and plants relationship

Antimony (Sb) is a very rare element, but it is very common in sulphides and salts of sulphur (Babula *et al.*, 2008). Soluble antimony forms are quite mobile into water while less soluble antimony species are adsorbed onto soil particles and they are mainly bound to iron and aluminium (Babula, *et al.*, 2008). Bioavailability of Sb is very low because of very limited bioavailability of this element (Casado *et al*. 2007). Antimony emissions into living environment are exclusively caused by human activities (Babula *et al*., 2008). According to Babula *et al*. (2008), toxicity of antimony is not well known, but Sb (III) elements are usually more toxic than Sb (V) elements and are comparable in its biochemical behavior with arsenic and bismuth. It seems to be probable that algae and plants with high ability to accumulate As and Bi are also able to accumulate antimony (Babula *et al*., 2008).

2.6 Deficiency and Toxicity

This section introduces the threshold of some essential minerals for plant nutrition. It briefly describes their deficiency and sufficient levels in plants. Table 2.3 below shows deficient, normal and excessive concentrations of trace element concentrations in dried weight (DW) mature leaves (Kabata-Pendias and Pendias, 1986). Micronutrients deficiency occurs when the plant cannot acquire sufficient amounts of them. An excessive supply of trace elements in the soil results into toxicity on plant (Zhenli *et al*., 2005). Mineral deficiencies in plants can often be detected by specific symptoms such as chlorosis, necrosis, anthocyanin formation and stunted shape (Levetin and McMahon, 1999). Minerals such as Ca can be present in low concentrations and consequently unavailable to plants. Manganese deficiency occurs in plants that are grown in organic, alkaline, calcareous, poorly drained and slightly acid soils (Martens and Westermann, 1991). Mn deficiency is characterized by chlorosis followed by necrosis of leaves. Boron deficiency leads to physiological diseases such as folding of leaves of potatoes, or cork formation in apples (Sinha, 2004). Increased pH due to liming, high clay, P supply and low soil temperatures promote Zn deficiency (Marschner, 1995). High levels of phosphorous, zinc, iron, manganese and aluminum may also restrict copper absorption by cereal roots. Molbdenum deficiency is widespread in legumes and maize grown in acidic mineral soils containing high amounts of Fe oxides and hydroxides (Miltmore, 1971). Molybdenum deficiency leads to the mottling of lower leaves followed by necrosis of margins (Sinha, 2004). According to Van Assche and Clijsters (1990), toxicity of trace elements may result from the binding of metals to sulphydryl groups in proteins, leading to an inhibition of activity or disruption of structure, or from the displacing of an essential element resulting in deficiency. Some plant species, however, have developed tolerant species that can survive and thrive on metalliferous soils, probably by adapting mechanisms that may also be involved in the general homeostasis, and constitutive tolerance to essential metal ions as found in all plants (Dietz *et al*., 1999). Plants have a range of potential mechanisms at the cellular level that might be involved in the detoxification and thus tolerance to heavy metal stress (Dietz *et al*., 1999). In mine tailings with high metal concentrations and low fertility, grasses dominate the vegetation (Shu *et al.*, 2005).

Table 2. 3 : Approximate concentration of trace elements in mature leave tissues (ppm DW) (Kabata-Pendias and Pendias, 1986).

Elements	Deficient (ppm)	Sufficient or normal (ppm)	Excessive or toxic (ppm)
As	-	1-1.7	5-20
Be	-	<1-7	10-50
Cd	-	0.05-0.2	5-20
Co	-	0.02-1	15-50
Cr	-	0.1-0.5	5-30
Cu	2.5	5-20	20-100
Hg	-	-	1-3
Mn	15-25	20-300	300-500
Mo	0.1-0.3	0.2-1	10-50
Ni	-	0.1-5	10-100
Pb	-	5-10	30-300
Zn	10-20	27-150	100-400

With regard to details on metals concentrations in soils, there is a broad range depending on their origin and usage, their chemical forms, their ability and availability to the plant as well as plant–soil interactions, as illustrated in Table 2.4 below. Mineral concentrations in the plants are also highly variable in different parts but depend on how minerals are uptaken by them (Maestri *et al.,* 2009). Tolerance derives either from mechanisms leading to exclusion of excess metal (avoidance), or is linked with the plant structures which can detoxify and/or sequester the excess of toxic ions inside the cells true tolerance (Baker, 1981).

Table 2. 4: Occurrence of metals as environmental contaminants in uncontaminated soils and plant tissues, compared with threshold values for hyperaccumulator plant species (Maestri *et al*. 2010).

Elements	Average range in soil (mg/kg dry weight)	Average range in plant tissue (mg/kg dry weight)	Threshold for hyperaccumulators (mg/kg dry weight)
Mercury	<0.1	0.005-0.2	1000=0.1%
Selenium	1-2	0.01-0.2	1000=0.%
Cadmium	1-2	0.03-0.5	100=0.01%
Copper	2-60	2-20	1000=0.1%
Nickel	2-200	0.4-4	1000=0.1%
Chromium	5-1000	0.2-1	1000=0.1%
Lead	10-150	0.1-5	1000=0.1%
Zinc	25-200	15-150	1000=0.1%
Manganese	100-4000	1-700	1000=0.1%

2.7 Phytoremediation

Phytoremediation is the use of plants and trees to clean up soils and water contaminated by metals and/or organic contaminants such as solvents, crude oil, and polyaromatic hydrocarbons (PAHs) (Prasad *et al.,* 2009). Grasses are thought to be excellent phytoremediators since their rooting system can stabilize the soil and provide a large surface area for root-soil contact (Kulakow *et al.,* 2000). According to Sarma (2011), the application of indigenous plant species for phytoremediation is often favoured as it requires less management and acclimatizes successfully in native climate conditions and seasonal cycle. Important criteria of selecting plant species for phytoremediation are the following: levels of plant tolerance with respect to metals that exist at the site; level of adequate accumulation; translocation and uptake potential of metals; high growth rate and biomass yield; tolerance to water logging and extreme drought conditions; tolerance to high pH and salinity; as well as root characteristic and depth of the root zone (Maestri *et al.,* 2010). Hyperaccumulator plants uptake metal from soils, translocate and accumulate them in shoot organs, stem and leaves, whereas other plants accumulate much of the metals in their roots (Maestri *et al.,* 2010). Many plant species have been found capable of accumulating metals in tissues at concentrations which are significantly higher than those present

in the soil. Consequently, hyperaccumulator plants represent a resource for remediation of metal polluted sites, as they are able to extract a wide range of metals and to concentrate them in their upper parts tissues. In some plant species, the concentrations of metals or metalloids are accumulated in the above ground biomass and are more than one of magnitude higher than in other underground plant parts (Baker and Walker, 1989; Reeves and Baker, 2000).

2.8 Conclusion

The literature review has given an overview of relevant publications related to mineral nutrition and heavy metals uptake by plants and the potential impact of mining activities. It has been compared with the findings from the study and it has guided the discussion and recommendations.

CHAPTER 3: METHODOLOGY

3.1 Study area

3.1.1 Location of the study

The study was conducted in Rwanda, specifically in Gatumba mining area. Rwanda is geographically located in Central East Africa, between latitude 1° 04' and 2° 51' South; longitude 28° 53' and 30° 53' East and covers an area of 26,336 km^2. It is bordering in the east with Tanzania, Uganda in the north, Democratic Republic of Congo (former Zaïre) in the west, and Burundi in the south as indicated on the map below (Figure 3.1).

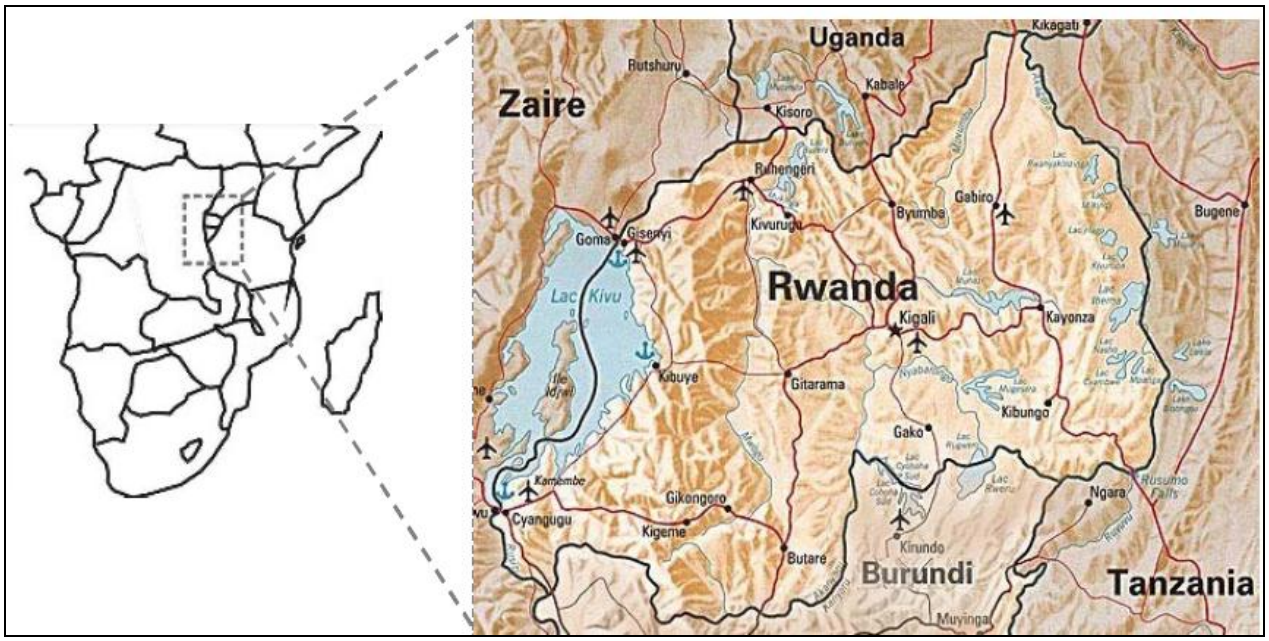

Figure 3. 1: Political map of Rwanda (ISS, 2008)

Rwanda is a member of East African Community which includes five countries, namely Burundi, Kenya, Tanzania, Rwanda and Uganda. The country is situated at ~3650 km from the Mediterranean Sea and ~3750 km from the Cape de Bonne- Esperance; at ~2200 km from the Atlantic Ocean and ~1200 km from Indian Ocean (Habiyaremye, 1995). Rwanda is a hilly and mountainous country, with an average altitude of 1700 m above the sea level (asl). The highest

point is Mountain Karisimbi which is 4507 m asl. Rwanda has volcanic mountains in the Northern part and undulating hills in most of the central plateau; but the Eastern part of the country is relatively flat and does not exceed 1500 m asl (Habiyaremye, 1995). Below is the political map of Rwanda.

Due to its high altitude, Rwanda enjoys a tropical temperate climate and the winds are generally around 1-3 ms^{-1} in the region (REMA, 2009). Generally, Rwanda's average temperature varies according to its topography. Low temperatures are observed in the regions of high altitude and range between 15 and 17°C, while temperatures can go below 0°C in some places of the volcanic region located in the North of the country. Moderate temperatures are found in areas with intermediate altitude and vary between 19 and 21°C. In the lowlands (East and South-West), temperatures are higher and the extreme can go beyond 30°C in February and July-August. The spatial distribution of annual mean of temperatures in Rwanda is shown in figure 3.2 below, including Ngororero District highlithed in the yellow-orange colour, with an average tamperature varying between 18 and 20^0C .

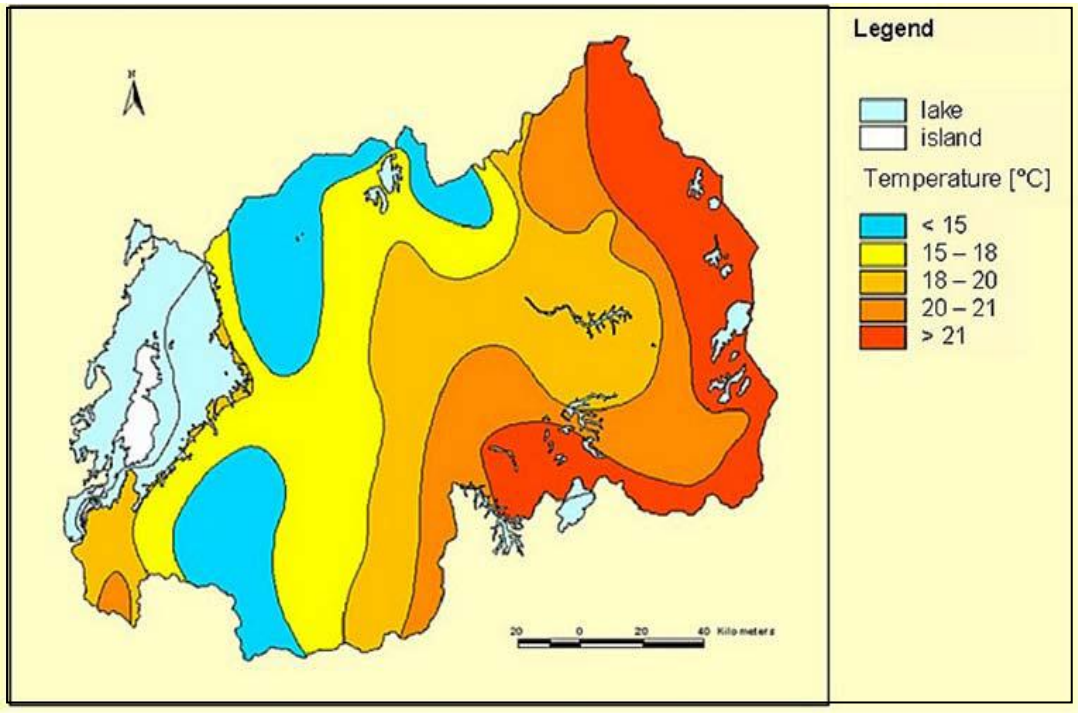

Figure 3. 2: Annual mean temperatures in Rwanda (Verdoot and van Ranst, 2003).

Rwanda has a much diversified flora due to a considerable geo-diversity and a climatic gradient from East to West. The number of vascular plants is estimated at ~3000 species which originate from different bio-geographical regions (Fischer and Killmann, 2008). Rwanda constitutes the Eastern limit for plants from the Guineo-Congolian region. An example is the *Thonningia sanguinea* VAHL. (Balanophoraceae), which is widespread in Western and central Africa, and is found in Cyamudongo forest, in the Western part of Rwanda (REMA, 2009). Plants from the Afromontane region are confined to higher altitudes, such as the orchid *Disa robusta* found in Nyungwe forest (REMA, 2009). The East African Savannah elements comprise the Zambezian floral region, and most of these plants are found in Akagera National Park and its surroundings (Fischer and Killmann, 2008). Some species found all over the country in Rwanda include *Ficus thonningii BLUME, Euphorbia tirucalli L., Erythrina abyssinica* LAM. ex A. RICH., *Vernonia amygdalina* DELILE, *Dracaena afromontana* MILDBR.. These plant species have been traditionally planted around the households since long time ago in Rwanda.

As fauna, Rwanda has 151 different types of mammal species, 11 of which are currently threatened but no endemic species (REMA, 2009). They include primates (14 to 16), with half of the remaining world population of mountain gorillas (*Gorilla gorilla berengei*) found in the Volcano National Park. Other species include the owl-faced monkey (*Cercopithecus hamlyni*) and the mountain monkey (*Cercopithecus hoesti*) in Nyungwe National Park; the Chimpanzee (*Pan troglodytes*) in Nyungwe National Park and Gishwati forest; and the Golden monkey (*Cercopithecus mitis kandti*) in Volcano National Park. Rwanda also has 15 species of antelopes, as well as a wide diversity of wild species such as buffaloes, zebras, warthogs, baboons, elephants, hippopotamuses, crocodiles, tortoises and rare species such as the giant pangolin and 670 different birds (Chemonics International Inc., 2003 and REMA, 2009).

With a population growth rate of 2.9 % per annum, the population of Rwanda is currently estimated at 10.5 million with an urban population of up to 17% from the National Census (NSI, 2012). The population is expected to be around 16 million by 2020 unless family planning, education and outreach strategies are enforced. It is one of the most densely populated countries in Africa, with about 397 inhabitants per km² (REMA, 2009). Since about 90 % of the population are inextricably linked to land, it is logical and evident that the population growth is the

underlying driver of increased demand for natural resources. Growth rates are indicative of large scale immigration, in this case mainly from North and South to the North-East in search of virgin lands for cultivation. The control of population growth requires innovative measures, including the strengthening of reproductive health services and family planning and ensuring free access to information, education and contraceptive services.

3.1.2 Sample sites

The study area is located in Gatumba mining area, found in Ngororero District, in the Western Province of Rwanda. The figure 3.3 represents the map of Ngororero district, showing sectors including Gatumba sector, which hosts Gatumba mining site.

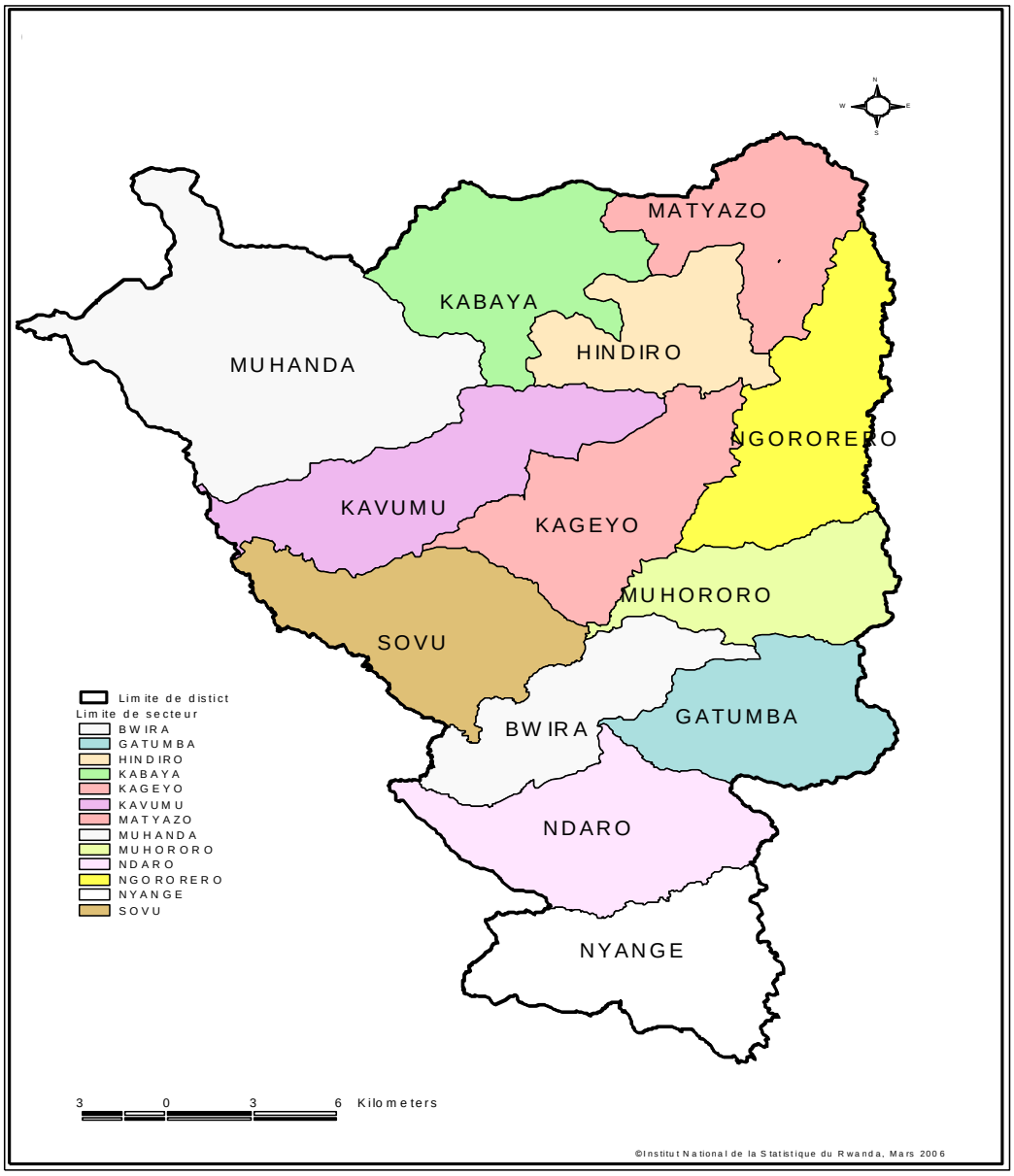

Figure 3. 3: Ngororero district showing Gatumba study site (ISS,2008).

With regard to the coordinates of Gatumba mining area, it is bounded by the following coordinates: latitude 1º53'' and 1º56' South and 9º37' and longitude 29º41' East. The study area is located in the West of the Nyabarongo River and it covers an area of about 12 km^2. It is located in two cells of Gatumba sector, namely Cyome and Ruhanga cells, which are administrative subunits of sectors and subunits of a district. It is to be explained that a cell in the Rwandan administration is an administrative subdivision of a sector. Among the two selected cells, Cyome cell comprises Birambo, Mpare and Rwasare sites, while Ruhanga cell comprises Ruhanga site. The two cells of Gatumba mining area were selected according to historical and present mining activities, plant communities, and archived photographs of mining. The choice of the study sites in Gatumba mining area was guided by the floristic heterogeneity and the plant physiognomy encountered on the ground. Below are table and figure showing the coordinates of the sampled sites (Table 3.1).

Table 3. 1: The coordinates of the soil profiles investigated in Gatumba area

Study area	Location	Sites	Soil Profile	X-cordinate	Y-Cordinate	Elevation (m asl)
Gatumba area	Cyome cell	Birambo	P10	796053	9785657	1422
			P11	796048	9785701	1426
		Mpare	P12	794654	9786498	1503
		Rwasare	P13	793443	9786153	1544
	Ruhanga cell	Ruhanga	P1	792599	9784596	1665
			P2	792633	9784538	1671
			P3	792578	9784613	1659
			P4	792507	9784736	1647
			P5	792765	9785358	1585
			P14	792378	9785049	1631

The soil and plant sampling were carried out in the sites indicated below (Figure 3.4).

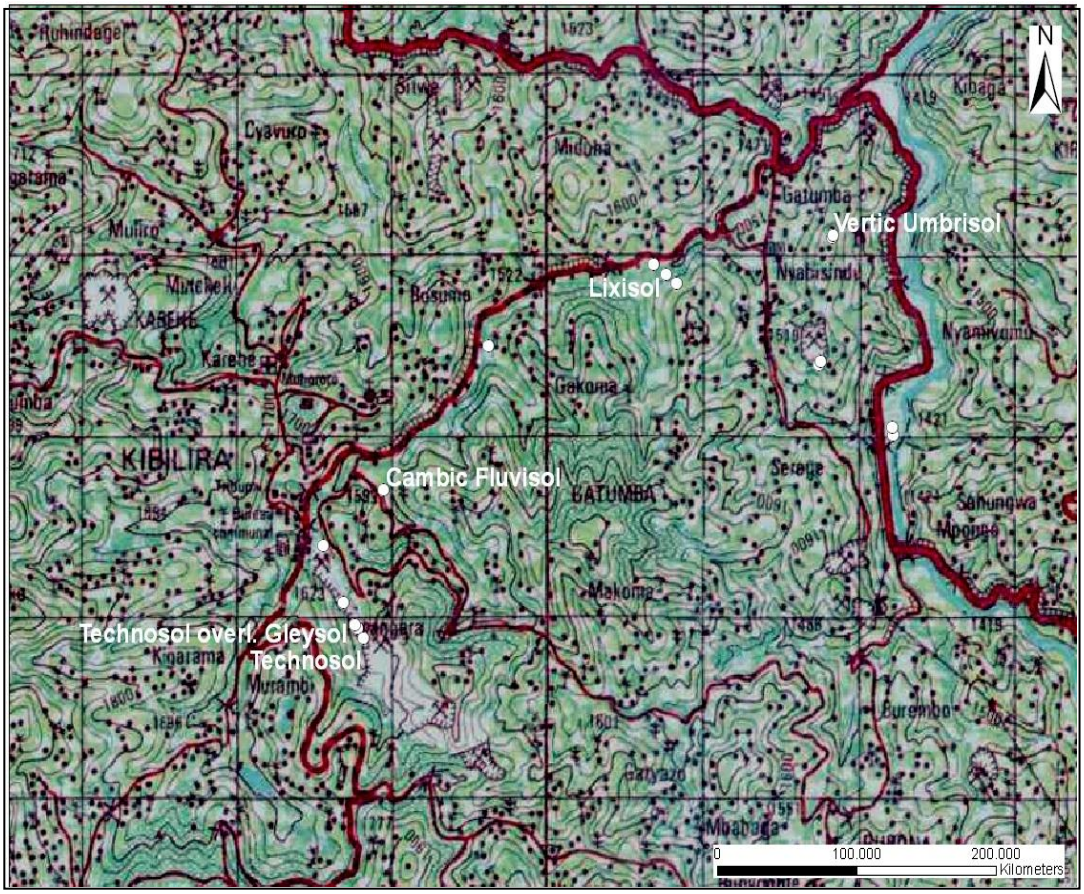

Figure 3. 4: Location (white dots) of study sites for soil profiles and plant sampling in Gatumba mining area.

3.1.2.1 Climate on the study site

Ngororero District is characterized by a tropical climate with an average annual temperature of 18ºC but this varies with altitude. The hottest months in Gatumba mining area are February and August when the maximum temperatures reach 21.1 and 21.3 ºC respectively. The average annual temperature for the period between 2009 and 2010 varied from 20.16 to 20.43 ºC, as indicated in Table 3.2 below. Ngororero district has a bimodal rainfall pattern with short rains from October to December and long rains from March to June. At an average altitude of 1700 m asl, the annual mean precipitation in the Gatumba mining area amounts to 1200 mm. The Gatumba area receives rain throughout the year, with the maximum precipitation in March and minimum in July. The year 2010 had slightly more rain than 2009 as illustrated in Figure 3.5.

According to Verdoot and van Ranst (2003), the rain seasons extended from February to June and from September to December. From September to December, about 27 % of the total annual precipitation was recorded followed by a short dry period during which rain did not completely stop in the West.

Table 3. 2: Monthly temperatures (in ^{0}C) of Ngororero District, adapted from data of Gisenyi meteorological center (2010)

Years// Months	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avar. t^{0C}
2009	19.8	19.5	20.2	19.9	20.1	20.2	19.9	21.1	20.9	20.4	19.9	20	20.16
2010	20.6	21.1	20.6	20.3	20.8	20.1	20	21.3	20.2	20.1	20	20.1	20.43

In the year 2010, there was more rain than in 2009 as it can be seen in Figure 3.5 below. The Gatumba area received rain throughout the year, with the maximum precipitation in March (237.1 mm) and minimum in July (3.8 mm) for the year 2010. As for the year 2009, the maximum was 229.8 mm in November while the minimum was 1.5 mm in July. For the year 1996, 40% of the annual precipitation fell during the long rainy season from February to June which was followed by a long dry season that lasted from two months to three in the highlands of Rwanda, in the eastern savannah of Ngororero District (Briggelaar, 1996). In general, March-April and October-November are the months that record the highest annual rainfall intensity in Rwanda (Fischer, 1997). Below is a histogram showing rainfall in Ngororero District, in Rwanda.

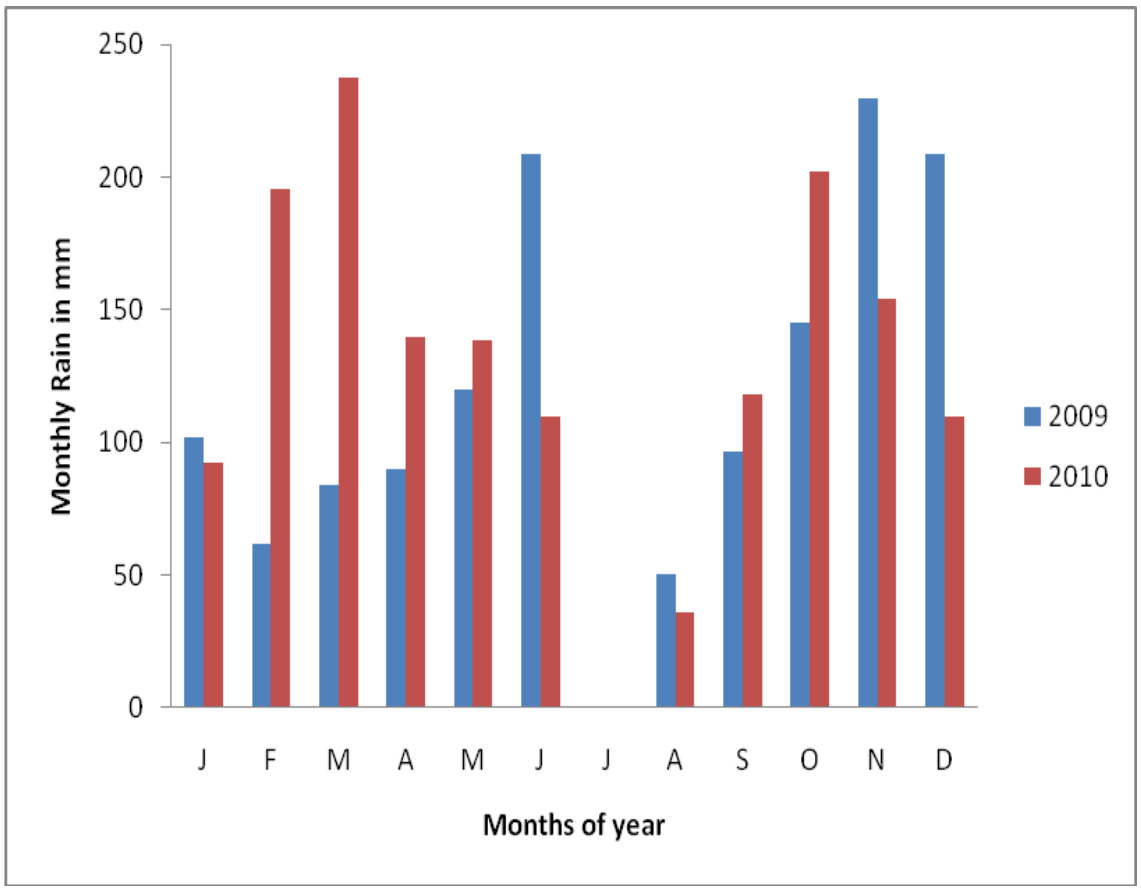

Figure 3. 5: Monthly rainfall of Ngororero District (adapted from data of Gisenyi meteorological center (2010)

3.1.2.2 Soils at Gatumba mining area

According to Reetsch (2008), the soils of the Gatumba mining area are typical soils of the tropical highlands of Rwanda. The soils of the tropical highlands of Rwanda are relatively young, flat grounded, influenced by landslides and soil flushing, containing non-weathered material and often characterised by higher soil fertility than lowland soils (FAOSTAT, 2007). The typical Soil Reference Groups (WRB, 2006) identified the types of soils found in the investigated area of Gatumba mining as technosol, greysol, combic-fluvisol, fluvisol, luxisol, umbrisol, lixisol and leptosol. In Gatumba, the mine spoils are commonly used for cultivation of annual crops such as *Manihot esculenta* CRANTZ (cassava), *Colocasia esculenta* L. SCHOTT (colocase), *Musa sapientum* L. (bananas), *Ipomoea batatas* (L.)LAM**.** (sweet potatoes), *Phaseolus vulgaris* (beans), *Zea mays* L. (maize), *Sorghum sp*., *Pisum sativa L.* (peas), *Glycine*

max (L.) MERR. (soya beans), and small-scaled farming systems have been developed. The relationship between plants and soil is interdependent because vegetation uptake their nutrients directly from the soil using roots or from the atmosphere by absorbing aerosol containing minerals through stomata located on plant leaves.

3.1.2.3 Hydrology in the investigated area

Kibilira and Gisuma streams which are tributaries of Nyabarongo River deeply dissect the topography of Gatumba. This dissection resulted in a landform characterized by steep hills of various forms, separated by groove-shaped valleys. These areas are drained by other numerous small streams that can be important during rainy seasons (Byizigiro and Biryabarema, 2007). In Rwanda, from an average annual precipitation of 1,200 mm, 360 mm are stored as surface water in the internal water cycle; 265 mm are stored as groundwater, while 575 mm drains the surface as runoff. About 200 mm that originate from ground and surface water renew the national fresh water reserves (Reetsch, 2008).

3.1.2.4 Flora in the investigated area

The Gatumba mining area is located in an agricultural zone called the "central plateau". This central plateau is an association of hills and valleys ranging between the Congo-Nile-Watershed divide and the Granitic Ridge. The vegetation of the study area is mainly savannah with some reforested patches on the top of the hills (Ndabaneze *et al*., 2008).

3.1.2.5 Social economic development of Ngororero District

Gatumba area is predominantly agricultural with inadequate options that would reduce the pressure on land resources. High population density in a fragile ecology and especially in the mining area has predisposed the Ngororero district's natural resources to degradation. Moreover, the degradation of soil in that region has worsened over the years, since the starting of mining exploitation.

In this region, the major problem facing the environment lies in the imbalance between the population size and the natural resources (land, water, flora and fauna and non renewable

resources) which have been deteriorating since decades (REMA, 2009). The critical environmental problem observed in Gatumba region is land degradation as a result of population pressure, serious soil erosion, loss of soil fertility, massive deforestation, degradation of wetland, loss of biodiversity, various forms of pollution, lack of a coherent political, institutional and legal framework as well as unregulated mining exploitation (REMA, 2003).

3.1.2.6 Socio-economic impacts of mining activities in Gatumba area

Since 1990, the export of crops has decreased whereas the export of minerals has increased exponentially up to ten times due to increasing prices of minerals worldwide. This has attracted a great number of different categories of the population to artisanal mining as it requires lower operational capital. However, this is likely to have a significant and often irreversible environmental impact if the mining activities are not well regulated and managed (REMA, 2009). In the Gatumba mining area, pegmatites are mined for columbite and tantalite (coltan). Small and unregulated artisanal mining operations leave open pits that enhance erosion and affect both environment and biodiversity, as illustrated in Plate 3.1 below.

Plate 3. 1: The effect (signs of soil erosion/land degradation) of mining activity in Ruhanga site (a picture taken on the site).

As effect of mining activities in Gatumba area, Ndagijimana (2006) observed that they have led to a multitude of problems for local people including social group dysfunction and mining-related illnesses. As more women are turning to mining for economic survival, they are faced with dangerous tasks such as pounding rocks which contain Nb, Ta and U. The release and inhalation of toxic dust from these elements affect lungs of women and their babies (IRIN, 2002). More worryingly, the majority of babies, who are often clinging on the backs of their mothers during the horrendous task of pounding rocks, have started showing similar signs of disease and pain as those of their mothers. Skin irritation, respiratory diseases and stomach ache are also among the illnesses that afflict the people working in the mining in Gatumba area (Ndagijimana, 2006). Injuries and death risks are widespread in mined zones due to subsidence of pits and unknown diseases.

Additionally, coltan mining has contributed to soil and vegetation loss and degradation. The extraction of coltan has led to a societal problem of human rights violations, the forced labour of children and women in the mining activities with insufficient wages to sustain their families.

These mining activities facilitate the accumulation of trace elements in top soils, especially in plant roots which become available for plants uptake and finally end up in the food chain.

In general, artisanal and small-scale mining (ASM) is globally growing due to the sharp price increase in mineral commodities over the last years, and due to scarce employment alternatives in many developing countries. It is estimated that up to 20 million men, women, and children from over 50 developing countries are engaged in the ASM sector, where extreme poverty is a common condition and where ASM often represents an important source of income. In Africa, over five million people are directly engaged in ASM, and that figure is expected to triple in the next decade, as low economic growth persists in many african countries (CASM, 2008). Health and safety measures are regularly absent in ASM activities, aggravated by crime and sexual abuse in politically destabilized regions. Environmental sustainability is commonly absent, and siltation of rivers, deforestation, and loss of habitat are common/dominant features (Byizigiro and Biryabarema, 2007).

3.1.2.7 Comparative contribution of crops and mining in the socio-economic development

As indicated in Table 3.3 below, the export of crops in Rwanda has decreased since 1990, while minerals prices have increased exponentially up to ten times on foreign markets. This trend can be an evidence showing that mineral extraction in the mined area attracted many different workers (men, women, children, and youth) from many categories among the local population. This can be seen when analyzing the increased ratio between mining Growth Domestic Product (GDP) and export crops GDP.

Table 3. 3: Development of the mining sector in GDP and the one of major export crops. Mining and Geology Department/Rwanda (2006).

Year	Export crops in Rwanda Franc (FRW)	Mining products (FRW)	Ratio mining GDP/export crops GDP
1990	8 778 000 000	497 000 000	6%
1995	8 621 000 000	326 000 000	4%
1999	7 667 000 000	1 355 000 000	18%
2000	7 143 000 000	1 965 000 000	27%
2001	8 236 000 000	3 628 000 000	44%
2002	5 872 000 000	3 918 000 000	67%

3.2 Materials used in the study

This section describes the materials used on the field as well as the laboratory materials used.

3.2.1 Field instruments

The materials used on the field included a decameter to measure the length of transects, a handheld GPS **(**Garmin Map60csx) to provide geographical coordinates, a digital camera, cardboard paper and newspapers for conservation of collected plant specimens, clippers to cut plant samples, a large knife to clear passage in the vegetation when needed, a pickaxe to dig up soils and plastic bags for the collection and conservation of the soil samples, carton sheets to conserve and dry plant samples, a notebook, a pen and a pencil.

3.2.2 Plant materials

Plant materials used during this survey were made of specimens of plants sampled in Gatumba mining area. Among these plant samples, the flowering plants included crops and weeds growing in cultivated zones as well as some non-flowering plants such as gymnosperms and pteridophytes. The dried plant specimens were kept in the herbarium of Kigali Institute of Education (KIE).

3.3 Field methodology

Methodology is defined as a set of methods, techniques used in order to collect data and to verify their veracity for future researchers (Mouton, 2001). These methods and techniques are tools to conduct a systematic analysis of all collected data and all received information. Field, laboratory and statistical methods that were used to collect, analyse and facilitate the interpretation and display the data are summarised. The field methods used are described hereafter.

3.3.1 Transect methods

The transect method refers to the establishment of a line along which the sampling of plant species is conducted (Troupin, 1966). This method is typically used when there is apparent vegetation heterogeneity on a site. For example, when sampling an area containing a river, wetland and upland, establishing a transect line that crosses these distinct habitats is a reliable method of collecting representative data. During the field work, each transect was limited by two wooden pickets separated by 50 m measured by using a rope. In total, 20 transects were investigated and plants were sampled in each 5 m along transects, on a 4 m^2 surface plot. From the sampled plants in each plot, dominant plant species were selected for analysis of trace elements and this is due to the fact that those plants are supposed to be well adapted on such a type of soil. In August 2010 and in March 2011, a total of 102 plant species were sampled and scientific names were assigned. As a total of sampled plants, seventeen dominant plant species were selected for identification of trace elements (heavy metals) concentration. In addition, shoots, roots, stems and leaves of all the selected plant species were carefully washed in distilled water, dried first on sun light and weighed (dry weight=DW).

3.3.2 Abundance-dominance of the investigated plants

From the transect method used for plant sampling, each plant species was given a coefficient of abundance-dominance according to Troupin (1966). r, +, 1, 2, 3, 4, 5 were used as coefficient in this study, and each coefficient corresponds with a certain percentage of surface covered by vegetation.

5: plant species covering more than 75% of the sampled area,

4: plant species covering 50-75% of sampled area,

3: plant species covering 25-50 % of sampled area,

2: plant species covering 5-25 % of sampled area,

1: few individual species covering less than 5 % of the sampled area,

+: individuals with no signicant coverage,

r: individuals with very insignificant coverage.

The above-mentioned scale indicates that abundance coefficient of collected plant species is expressed by index which indicates the relative density of each plant species.

3.3.3 Conservation of plant samples

The collected plants were put into newspaper sheets and dried. Newspaper sheets containing plant materials were changed each day until the plants were well dried. Thereafter, the dried plant materials were mounted on Bristol paper, labelled and conserved in the herbarium of Kigali Institute of Education.

3.3.4 Soil sampling in Gatumba mining area

In August 2010, ten soil profiles were investigated and eleven transects covering those soil profiles were analysed. These profiles (P) were P1, P2, P3, P4, P5 and P14 in Ruhanga, P12 in Mpare, P13 in Rwasare, P10 and P11 in Birambo. Details on their illustration are found in Table 3.1 and Figure 3.4 presented above. Soil samples were collected from mining sites in different identified soil profiles. Ten pedological profiles were dug during the dry season while nine were dug in the rainy season. Topsoil (0-35 cm) for each profile was sampled using a pickaxe to collect soil sample. The soil samples were collected in clean polyethylene bags for transportation to the laboratory of Technical University (TU) of Braunschweig, in Germany. Plate 3.2 and 3.3 a, b are pictures that show the samples of technosol and fluvisol soils profiles sampled respectively at Ruhanga and Birambo sites. The soils investigated were mostly under cultivation. In some areas, terracing and hedges were being applied to minimize erosion due to human

activities, especially during the rainy season (March - April). Plate 3.4 below shows a terrace model practised in Gatumba mining area to minimize mass wasting and soil erosion.

Plate 3. 2: A profile of a technosol soil horizon (picture taken at Ruhanga site).

Plate 3. 3: a wetland; b: a profile of a fluvisol soil horizon located in a wetland shown in a (pictures taken in wasteland at Birambo site)

Plate 3. 4: Terracing to stabilize steep slopes at Gatumba (picture taken at Gatumba site)

3.3.4 Laboratory methods

3.3.4.1 Plant identification

Plant species were identified according to Troupin (1978, 1982, 1985 and 1988) and Troupin and Nicole (1975). Local names were provided by local population in the field and were also helpful for plant identification. Known plant specimens already identified by previous researchers in the region served as reference material to assign the names to the collected plant specimens. Binocular and microscope were used during the plants' identification process. Plants kept in KIE herbarium were used as a reference to confirm collected plant specimens.

3.3.4.2 Analysis of trace element concentration in plants and soils

Within the framework of the Coltan project funded by Volkswagen Foundation, all soil and plant samples were analysed for trace elements concentration in the Laboratory of Technical University of Braunschweig, in Germany. Seventeen plant species were selected for trace element analysis in order to assess their levels of metal accumulation and their ability to translocate the metal to the aerial plant parts. They were separated first into shoots, stem, leaves and sometimes flowers or fruits. Those plant species investigated are already known as accumulators and include *Ageratum conyzoides* L. and *Tithonia diversifolia (HEMSLEY)A. GRAY*. (Asteraceae), *Crotalaria arrecta A. RICH* and *Crotalaria dewildemaniana* WILCZEK (Fabaceae), *Cyperus papyrus* L. (Cyperaceae), *Digitaria abyssinica (HOCHST. ex A. RCH.) STAPF* and *Pennisetum purpureum SCHUM.(*Poaceae), *Manihot esculenta CRANTZ* (Euphorbiaceae), *Centella asiatica (L.) URBAN)(*Apiaceae), *Colocasia esculenta (L.) SCHOTT* (Araceae), *Ipomoea batatas (L.) LAM. (*Convolvulaceae) and *Ludwigia abyssinica A. RICH. (*Onagraceae) (Sarma *et al.,* 2011). Prior to analysis, the soil and plant samples were respectively air-dried naturally under sun light in Ngororero, where then temperature was low (average 21^{o}C) and in Kigali where the temperature was high (up to 30°C). For thorough drying, they were put in an oven at 40°C for about 48 to 72 hours. Afterwards, the dried parts of the plants were homogenized by grinding them mechanically into a mortar to produce fine powder. High nitric acid concentration was used for digesting 0.2 g of fine powder of soil and plant samples whereas

a mixture of three parts of HNO_3 and one part of HCl was used to reduce contamination in 0.2 g of soils. Then, all those samples were digested in a microwave. The total concentration of trace elements in the sampled soils and plants were determined using Inductively Coupled Plasma–Mass Spectrometry (ICP-MS).

As for the analysis of physical characteristics of soil, it was done at the National University of Rwanda. The soil samples were dried, mixed and sieved prior to determination of physical characteristics. Soil water content was determined by using gravimetric method. The percentage of soil water content was calculated by using Davis *et al.'s* (1973) formula. Such a percentage was derived from [(Fresh weight soil-dry weight)/dry weight]*.100. The pH of saturated soil was measured with the help of a glass electrode by using a pH probe, model Oyster-10 (Jackson, 1962 and Hussain, 1989).

3.3.5 Statistical methods

3.3.5.1 Abundance-Dominance coefficient

The Abundance-Dominance (AD) coefficient is the average percentage of the surface covered by the individual plant species present in a sampled site. Braun-Blanquet (1934) cited in Troupin (1966) estimated the values of the average surface covered by plant species and categorised those values as shown in Table 3.4.

Table 3. 4: The values of the Abundance-Dominance coefficient.

Abundance-Dominance (AD) coefficient Braun-Blanquet (1934)	Range in coverage (%)	Medium coverage (%)
5	100-75	87.5
4	75-50	62.5
3	50-25	37.5
2	25-5	15
1	<5	2.5
+	Low coverage	0.2
R	one individual	0.1

As illustrated in the table above, the medium of coverage classes is considered to be the most significant but it gives a very big importance to the elevated surface coverage. This method proposed by Braun-Blanquet and developed in Troupin (1966) has the merit of being operational on the data obtained on the ground over the other methods developed by van der Maarel (1975) which has the higher scale value.

3.3.5.2 Comparison of vegetation similarity and dissimilarity index

Based on Jaccard similarity index (J) (1908), different transects were compared to assess the similarity and dissimilarity of plant sample sets. The Jaccard similarity index can be calculated according to equation 3.1:

$$J_{i,j} = \frac{a}{a+b+c} \qquad (3.1)$$

where *i* and *j* are a set of two transects, *a* is the number of plant species present in the two transects, *b* is the number of plant species present only in the first transect, and *c* is the number of plant species present only in the second transect. The Jaccard indices were calculated using Multivariate Statistical Package (MVSP) and displayed on horizontal axis of different dedrograms. According to Gillet (2000), the value of Jaccard similarity index varies from 0 (very dissimilar) to 1 (very similar vegetation investigated). If J is <0.5, the vegetation investigated is heterogeneous, but if *J* is >0.5, the vegetation is homogeneous. This similarity index was used to represent and determine the relationships between transects realized in the Gatumba vegetation.

3.3.5.3 Vegetation diversity index mesurements

Shannon diversity index (*H*) (1948) was used to measure the diversity in categorical order. It can be calculated using equation 3.2:

$$H = -\sum_{i=1}^{s} (P_i * \log 10 * P_i) \qquad (3.2)$$

where P_i is the fraction of the entire population made up of species *i*, and *L* is the number of species encountered on site. *H* value indicates not only the number of species but also how the abundance of the species is distributed among all the plant species in the community. After using MVSP for Shannon diversity index calculation, the H values of the indices were typically compared to ½*$\log_{10}$ *N, where N represents the total number of plant species found in a given site. When the H value is higher than the ½ $\log_{10}$ N, the studied vegetates is diversified.

3.3.5.4 Bioaccumulation and Translocation Factors

The metal accumulation in each plant part was determined by the Bioaccumulation factor (*BCF*) (Baker *et al*., 1994; Raskin *et al*., 1994; Mattina *et al.*, 2003). Bioaccumulation portrays the tolerance of trace elements by each plant species. The BCF and BCF' are calculated using equations 3.3 and Translocation Factor (TF) is calculated using equation 3.4:

$$BCF = \frac{C.roots}{C.soil} \quad \text{and} \quad BCF' = \frac{C.aerial}{C.soil} \tag{3.3}$$

$$TF = \frac{BCF'}{BCF} \tag{3.4}$$

where *C* is the concentration of trace elements in soil or in plants. The BCF' is for aerial parts and BCF for the plant roots relationship.

3.3.5.5 Additional phyto-sociological parameters

In order to analyze plant communities, the following phyto-sociological parameters were calculated (Troupin, 1966):

i) **Presence** (*P*) represents the presence or absence of a plant species along a transect;

ii) **Frequency** (*F*) is the presence rate of plant species along a transect and is given by equation 3.5.

$$F = \frac{P}{N} * 100 \tag{3.5}$$

where *N* is the number of sampling points (relevées).

iii) **Relative frequency** (*RF*) is the percentage rate of the frequency of one plant species compared to the total frequencies of plant species of a transect, and it is calculated using the formula in equation 3.6:

$$RF = \frac{F}{\sum F} * 100 \qquad (3.6)$$

iv) **Dominance** (*D*) is the sum of all medium coverage for each plant species within the transect. The **relative dominance** (RD) is the percentage rate of the dominance of one plant species compared to the total dominance of all species within a transect. It can be given by equation 3.7:

$$RD = \frac{D}{\sum D} * 100 \qquad (3.7)$$

v) **Frequency- dominance** (*FD*) is the sum of relative dominance and relative frequency.

vi) **Performance index** (φ) is the dominance of a species along a transect which is calculated according to equation 3.8:

$$\varphi = \frac{FD}{\sum FD} * 100 \qquad (3.8)$$

3.4 Conclusion

This chapter describes the study area, the materials and methodology used for data collection and analysis. Field methods included transects, plant sampling techniques, conservation of plant samples, and collection of soil samples. In the laboratory, plants were identified and the chemical concentration of trace element in soils and plants were analysed. Statistical methods that were used to collect, analyse, interpret and display data were Abundance-Dominance coefficient, Presence, Frequency, Relative frequency, Relative dominance, Frequency- dominance, Performance index, Jaccard Similarity index, Shannon diversity index, as well as Bioaccumulation and Translocation Factors. According to Mouton (2001), a good methodology ensures the quality of the results and good strategies for further findings.

CHAPTER 4: PRESENTATION OF RESULTS

4.1 Introduction

This chapter presents the results of all field data (types of plants, trace element concentration in plants, types of soil, physical characteristics and mineral concentration of soil) that were collected and analyzed statistically. These data were collected during the dry season of August 2010 and the wet season of March 2011 on sites illustrated in Figure 3.4 in chapter 3. The presentation includes graphics indicating the possible relationship between the dominant plant species and the type of soil.

4.2 Presentation of plant diversity in Gatumba area

From a total of 20 transects done on the study site, 102 plant species were collected and grouped into 83 genera and 35 families, dominantly presenting flowering plants, as illustrated in Table 4.1 below. Among the flowering plants, monocotyledons and dicotyledons were identified. For monocotyledons, 31 species, 23 genera and 6 families were found, representing 30,4% of the total species collected as shown in figure 4.1. As for dicotyledons, 68 plant species, 56 genera and 26 families were found, representing 65,69% of the entire population. Among the monocotyledons the dominant family is Poaceae, with 19.6% of total species collected. As for the dicotyledons, the dominant family is Asteraceae, with 15%.

Rare non-flowering plants were also found, and they include gymnosperms and pteridophytes representing 0.98% and 2.94%, respectively. In this regard, a small number of non-flowering plants such as *Pteridium aquilinum*, *Cupressus* sp. and *Selaginella* sp. were found. From the overall number of plant species found on the study site, Ruhanga site has the largest number of species (77), followed by Mpare site (44) and Birambo site (40), while the lowest numbers of plant species was found at Rwasare site (36). Figure 4.1 and Table 4.1 below present the diversity of plant categories found in Gatumba mining area.

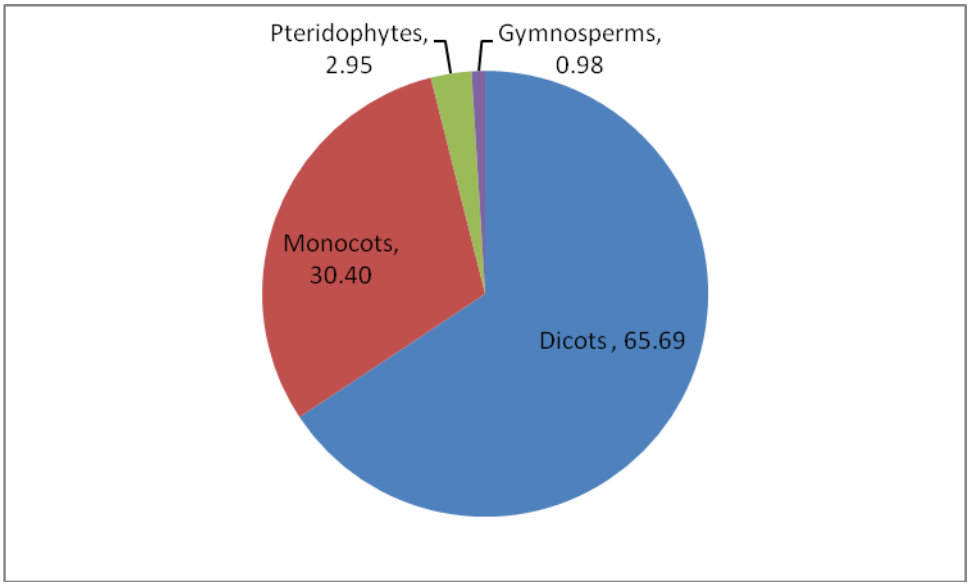

Figure 4. 1: Distribution of plant categories found in Gatumba mining area

Table 4. 1: Families, genera and species of plants collected in Gatumba mining area.

Families	Species	Genera number	Species Number
Dicotyledons			
Acanthaceae	*Acanthus pubescens (OLIVER) ENGL.*	2	3
	Acanthus repens OLIVER		
	Dyschoriste trichocalyx (OLIVER) LINDAU		
Amaranthaceae	*Achyranthes aspera L.*	1	1
Anacardiaceae	*Mangifera indica L.*	1	1
Apiaceae	*Centella asiatica (L.)URBAN)*	1	1
Araliaceae	*Polyscias fulva (HIERN) HARMS*	1	1
Asteraceae	*Ageratum conyzoides L.*	12	15
	Aspilia kotschyi (SCHULTZ-BIP. ex. HOCHST.) OLIVER		
	Bidens grantii (OLIVER) SHERFF		
	Bidens pilosa L.		
	Bothriocline longipes OLIVER et HIERN.		
	Conyza welwitschii (S. MOORE) WILD.		
	Crassocephalum vitellinum (BENTH.) S.MOORE.		
	Gynura scandens O. HOFFM.		

	Helichrysum globosum SCHULTZ-BIP. ex A. RICH.		
	Helichrysum mechoianum P. BEAUV		
	Helichrysum newll OLIVER et HIERN.		
	Microglossa pyrifolia (LAM.) KUNTZE		
	Tithonia diversifolia (HEMSLEY) A.GRAY.		
	Galisonga parviflora CAV.		
	Vernonia amygdalina DELILE		
Balsaminaceae	*Impatiens burtonii HOCHST.f.*	1	2
	Impatiens bequaertii DE WILD.		
Convolvuulaceae	*Ipomoea batatas (L.) LAM.*	2	2
	Ipomoea cairica (L.) SWEET		
Euphorbiaceae	*Acalypha racemosa WALLICH. et BAILLON*	4	5
	Bridelia brideliifolia (PAX.) FEDDE		
	Bridelia micrantha (HOCHST.) BAILLON		
	Euphorbia tirucalli L.		
	Manihot esculenta CRANTZ		
Fabaceae	*Cassia singueanna DELILE*	10	12
	Rhynchosia minima (L.) DC.		
	Caesalpinia decapetala (ROTH) ALSTON		
	Crotalaria dewildemaniana WILCZEK		
	Crotalaria recta A. RICH.		
	Desmodium intortum (MILL.) URB.		
	Eriosema montanum BAKER f.		
	Erythrina abyssinica LAM. Ex A. RICH.		
	Indigofera arrecta HOCHST. ex A. RICH.		
	Rhynchosia luteola (HIERN.) SCHUMANN		
	Sesbania sesban (L.) MERRILL var nubica CHIOV.		
	Tephrosia pumila (LAM.) PERSON		
Flacourtiaceae	*Dasylepsis racemosa OLIVER*	1	1
	Hoslundia opposita VAHL.		
Lamiaceae	*Leonotis nepetaefolia (R.BR.) ALTON f.*	2	2
Malvaceae	*Triumfetta cordifolia A. RICH.*		
	Hibiscus ludwigii ECKLON et ZEYHER.	2	3
	Hibiscus noldeae BAK. f.		
Melastomataceae	*Dissotis ruandensis ENGL.*	1	1
Myrtaceae	*Psidium guajava L.*	2	2
	Eucalyptus ficifolia F.J.MUELL		

Myricaceae	*Myrica silicifolia HOCHST. ex A. RICH.*	2	2
Myrsinaceae	*Measa lanceolata FORSSKAL.*	1	1
Onagraceae	*Ludwigia abyssinica A. RICH.*	1	1
Oxalidaceae	*Biophytum petersianum KLOTZSCH*	2	2
	Oxalis latifolia KUNTH		
Passifloraceae	*Passiflora edulis SIMS.*	1	2
	Passiflora ligularis JUSS.		
Phytolaccaceae	*Phytolacca dodecandra L'HERIT.*	1	1
Polygonaceae	*Polygonum pulchrum BLUME*	1	1
Rosaceae	*Rubus rigidus SMITH.*	1	1
Rubiaceae	*Spermacoce princae (SCHUMANN) VERDC.*	1	1
Verbanaceae	*Clerodendrum myricoides (HOCHST.) R.BR. ex VATKE*	2	3
	Clerodendrum rotundifolium OLIVER		
	Lantana camara L.		
Monocotyledons			
Agavaceae	*Dracoena afromontana MILDBR.*	2	
	Senseviera dawei STAPF.		2
Araceae	*Colocasia esculenta (L.) SCHOTT*	1	1
Cyperaceae	*Cyperus distans L.f.*	2	6
	Cyperus latifolius POIRET		
	Cyperus papyrus L.		
	Cyperus pseudoleptocladus KUEK.		
	Cyperus rigidifolius STEUDEL		
	Lipocarpha chinensis (OSBECK)J. KERN		
Commelinaceae	*Commelina benghalensis L.*	1	1
Musaceae	*Musa sapientum L.*	1	1
Poaceae	*Bambusa vulgaris SCHREDER*	16	20
	Brachiaria semiundulata (HOCHST. ex A. RICH) STAPF		
	Cynodon nlemfuensis VANDERYST		
	Digitaria abyssinica (HOCHST. ex A. RCH.) STAPF		
	Digitaria velutina (FORSSAKAL) P. BEAUV.		
	Eragrostis exasperata PETER.		
	Euleusine indica (L.) GAERTN.		
	Hyparrhenia collina (PILG) STAPF		
	Hyparrhenia filipendula (HOCHST. ex STEUDEL) STAPF		
	Hyparrhenia rufa (NEES)STAFF		

	Imperata cylindrica (L.)BEAUV.		
	Leersia hexandra SWARTZ		
	Melinis minutiflora P.BEAUV.		
	Panicum chionachne MEZ		
	Paspalum conjugatum FLUEGGE		
	Paspalum scrobiculatum L.		
	Pennisetum purpureum SCHUM.		
	Rhynchelytum repens (WILLD.) C.E. HUBB.		
	Sporobolus pyramidalis P. BEAUV.		
	Zea mays L.		
Non-flowering plants			
Pteridaceae	*Nephrolepis cordiofolia L.*	2	2
	Pteridium aquilinum (L.)KUHN		
Selaginellaceae	*Selaginella* sp.	1	1
Cupressacae	*Cupressus* sp.	1	1

4.3 Dominant plant communities per site

For each site investigated in Gatumba mining area, a number of dominant plant species were found, based on the above-mentioned list and using the performance index as a criterium. Performance indices were calculated for each plant in each transet at every site, as illustrated in Appendix 3. Various tables and histogrammes presented below indicate plant species with higher performance indices, which have been selected to characterize dominant plant species by site. The performance index value plotted on histogramme represents dominant plant species per site. Those tables serve as basic value indices of different spectra which characterize dominant plant species per site.

Multivariate statistical package (MVSP) was used to group the transects into clusters, ranged into dendrograms. Three dendrograms were developed using transects from Ruhanga, Mpare, Birambo sites respectively, while one dendrogram grouped all transect from Gatumba mining vegetation as a whole.

4.3.1 Dominant plants in Ruhanga site

Table 4.2 below presents dominant plant species and their respective performance indices for Ruhanga site. It was found that Ruhanga site is characterized by Technosol type, which is a type of soil found in areas disturbed by mining activities.

Table 4. 2: Performance indices of dominant plant species in Ruhanga site

Sol types	Dominant plant species	Performance indices (Φ%)
Technosol	*Digitaria abyssinica*	45.55
Technosol	*Crotalaria dewildemaniana*	26.69
Cambic Fluvisol	*Ageratum conyzoides*	23.59
Lixisol	*Lantana camara*	22.24
Technosol	*Sesbania sesban*	15.32
Technosol	*Centella asiatica*	10.89
Technosol	*Acanthus pubescens*	9.97
Technosol	*Rubus rigidus*	8.96

A histogramme representing the performance indices for dominant plant species is in the Figure 4.2 below presented.

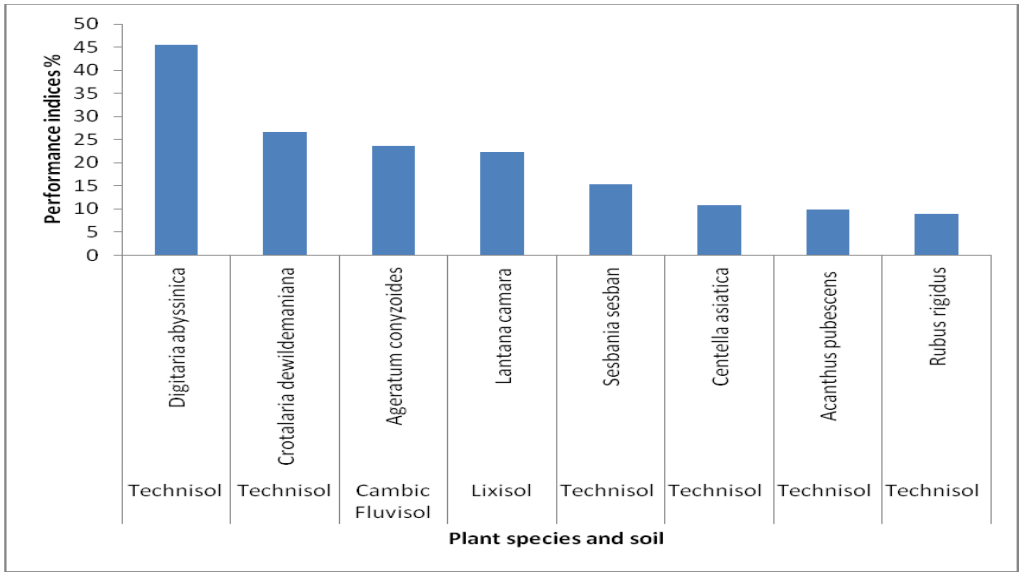

Figure 4. 2: Histogramme showing performance indices of dominant plant species in Ruhanga site according to their respective soil types

From the table and histogramme for Ruhanga site presented above, it was found that *Digitaria abyssinica* (HOCHST. ex A. RCH.) STAPF dominates herbaceous stratum with performance index of 45.55% values. It is followed by *Crotalaria dewildemaniana* with 26.69%., *Ageratum conyzoides* L. with 23.59%, *Lantana camera* .L. with 22.24% and *Sesbania sesban* with *15.32%* that dominate shrubby stratum of Ruhanga vegetation. Other plant species have lower performance index values, which are less than 15%. This is the case for *Acanthus pubescens* (OLIVER) ENGL. with 9.97%, *Centella asiatica (L*.) URBAN) with 10.89%, and *Rubus rigidus* with 8.96%. The performance indices represent the percentage of the coverage and the frequencies of plant species in certain sites. The vegetation of Ruhanga site can be defined as a shrubby-grassland dominated by *Digitaria abyssinica, Crotalaria dewildemaniana, Sesbania sesban* and *Acanthus pubescens.*

It was observed that the Ruhanga soil is very disturbed by mining and other human activities and this Technosol type is covered by poor vegetation. At this site, the mining activities were still going on for extraction of coltan and other metals. The extraction of mineral was done on steep slope which facilitated the movement of soil as land slide.

The 10 transects done on Ruhanga site were recorded in binary format (presence or absence of plant species). For each transect, plant species present received value 1 whereas an absent plant species received value 0, as illustrated in Appendix 4. Multivaiate Statistical Package Programme (Kovack, 1993) was used to determine the similarity between transects, based on dendrograms, as presented in Figure 4.3 below.

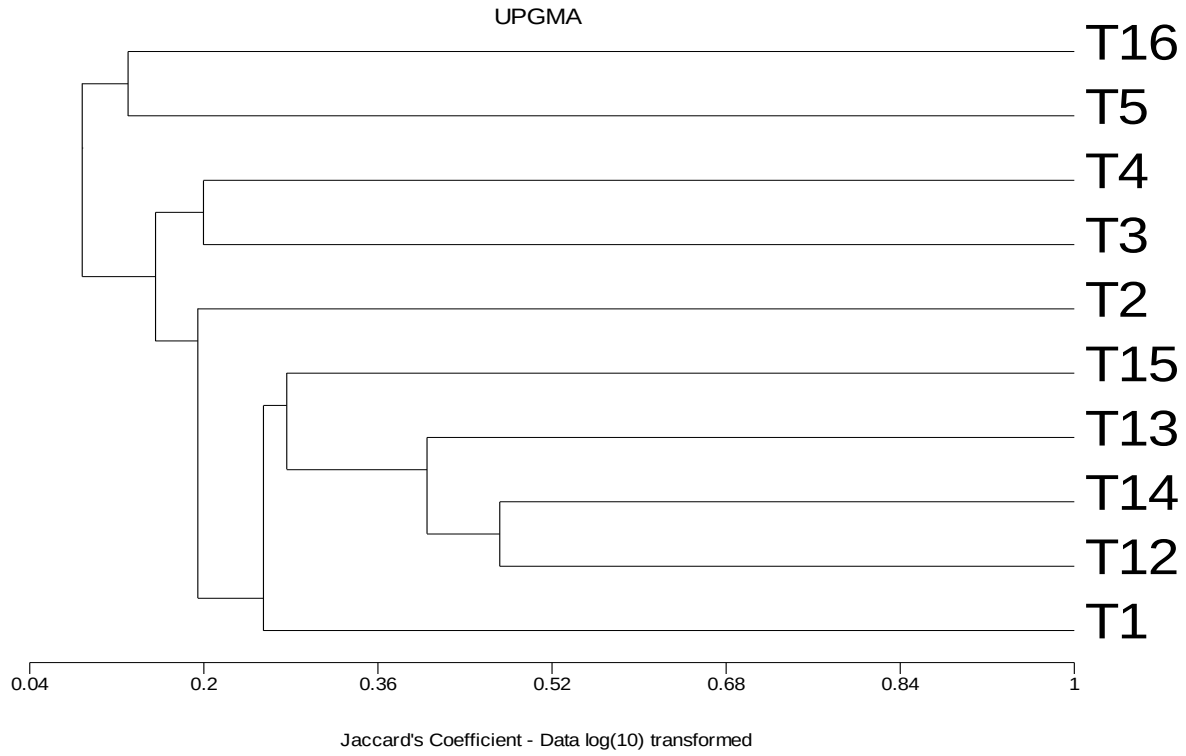

Figure 4. 3: Dendrogram showing similarity between transects of Ruhanga site. (T: represents transects).

4.3.2 Dominant plants in Mpare site

Table 4.3 below presents dominant plant species with their performance indices for Mpare site. The Mpare soil is a fluvisol type.

Table 4. 3: Performance indices of dominant plant species in Mpare site

Sol types	Dominant plant species	Performance indices (Φ%)
Fluvisol	*Digitaria abyssinica*	35.84
Fluvisol	*Ageratum conyzoides*	12.02
Fluvisol	*Hoslundia opposite*	7.53
Fluvisol	*Triumfetta cordifolia*	6.09
Fluvisol	*Eragrostis exasperata.*	6.07
Fluvisol	*Vernonia amygdalina*	5.59

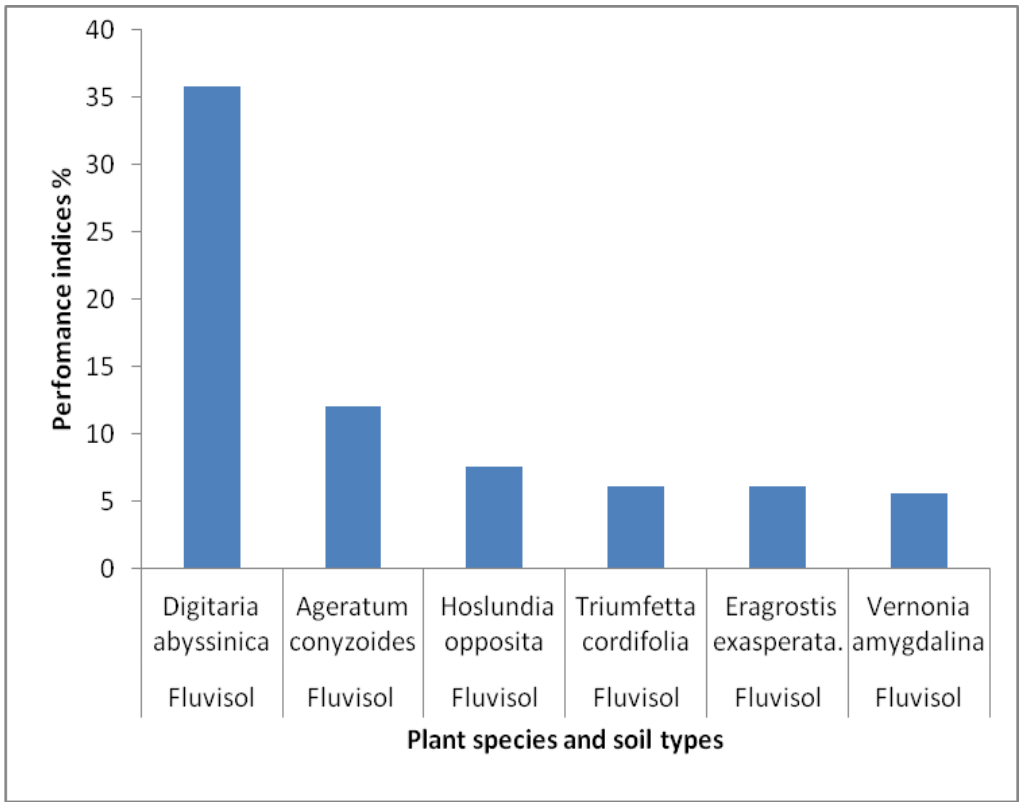

Figure 4. 4: Histogramme showing performance indices of dominant plant species in Mpare site according to their soil type

From Table 4.3 and Figure 4.4 mentioned above for Mpare site, it was observed that this site is located downstream of Ruhanga site and is colonized by agricultural activities. Natural vegetation was strongly disturbed by human activities such as mining excavations. The vegetation was dominated by *Digitaria abyssinica* (HOCHST. ex A. RCH.) STAPF with the performance index equivalent to 35.84%, followed by *Ageratum conyzoides* L with 12.02%. The shrubby stratum is dominated by *Hoslundia opposita VAHL.*with 7.53%, *Triumfetta cordifolia A. RICH.* with 6.09% and *Vernonia amygdalina* DELILE with 5.59% of performance index. The shrubby grassland characterizes the heterogeneous vegetation of Mpare site. Thus, the vegetation of Mpare site can be defined as a shrubby-grassland made by an association dominated by *Digitaria abyssinica, Hoslundia opposita VAHL.*with *7.53%, Triumfetta cordifolia A. RICH.* with 6.09% and *Vernonia amygdalina* DELILE. The soil was fluvisol with influence of water flow from Ruhanga mining site and contained heavy metals escaped from mining excavation or other activities such as washing minerals.

Figure 4.5 below is a dendrogram showing the transect grouping and the Jaccard similarities indices on horizontal axis between transects T6, and T7 - T17 indicating that their relationship was probably dissimilar. Detailed phytosociological data recorded for the sites are shown in Appendix 4.

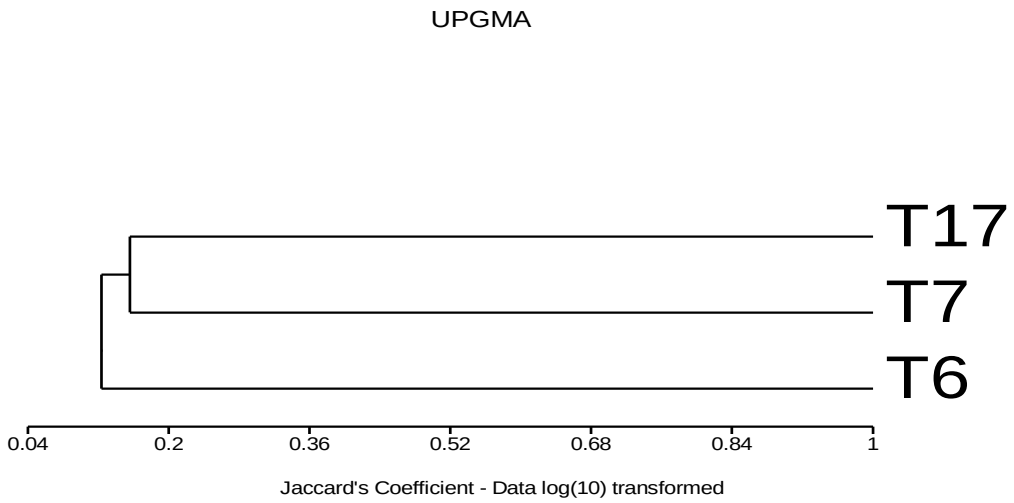

Figure 4. 5: Dendrogram showing similarity between transects of Mpare site. (T: represents transects)

4.3.3 Dominant plants in Rwasare site

Table 4.4 below presents dominant plant species with their performance indices for Rwasare site. The type of soil found in Rwasare is fluvisol.

Table 4. 4: Performance indices of dominant plant species in Rwasare site

Soil types	Dominant plant species	Performance indices Φ%
Fluvisol	*Ageratum conyzoides*	15.61
Fluvisol	*Erythrina abyssinica*	14.81
Fluvisol	*Pennesetum purpureum*	10.41
Fluvisol	*Digitaria abyssinica*	8.87
Fluvisol	*Bambusa vulgaris*	7.54
Fluvisol	*Triumfetta cordifolia*	3.10

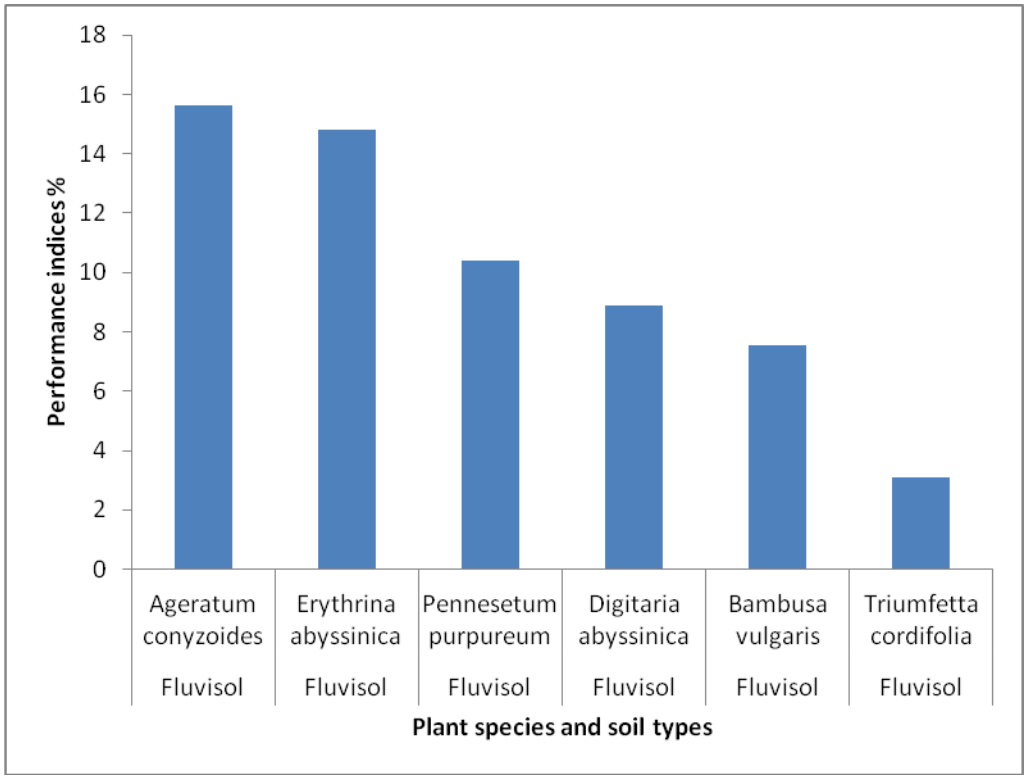

Figure 4. 6: Histogramme showing the performance indices of dominant plant species in Rwasare site according to their respective soil types

From Table 4.4 and Figure 4.6 mentioned above for Rwasare site, it was observed that Rwasare site is also located down stream of Ruhanga site. The vegetation was dominated by *Ageratum conyzoides L.* with performance index of 15.61%. It was followed by *Erythrina abyssinica LAM. Ex A. RICH.*with 14.81%. It is observed that this *Erythrina abyssinica* tree grows in areas that used to be inhabited by people and abondoned afterwards. Other plant species mentioned in the table are less frequent and do not cover a great surface of soil. Thus, the vegetation of Rwasare site can be defined as a shrubby-grassland made of the association of *Ageratum conyzoides L, Erythrina abyssinica LAM. Ex A. RICH.,Triumfetta cordifolia A. RICH* and *Digitaria abyssinica (HOCSHT. ex A. RICH.) STAPF.* The soil was found to be fluvisol due to its richness in limon and other sediments characterizing this type of soil.

4.3.4 Dominant plants in Birambo site

Table 4.5 below presents dominant plant species with their performance indices for Birambo site. The type of soil found in Birambo is fluvisol.

Table 4. 5: Performance indices of dominant plant species in Birambo site

Soil types	*Plant species,*	Performance indices Φ%
Fluvisol	*Cyperus papyrus*	42.79
Fluvisol	*Leersia hexandra*	35.54
Fluvisol	*Polygonum pulchrum*	28.34
Fluvisol	*Pennisetum purpureum*	13.88
Fluvisol	*Ludwigia abyssinica*	7.75
Fluvisol	*Cyperus latifolia*	5.05

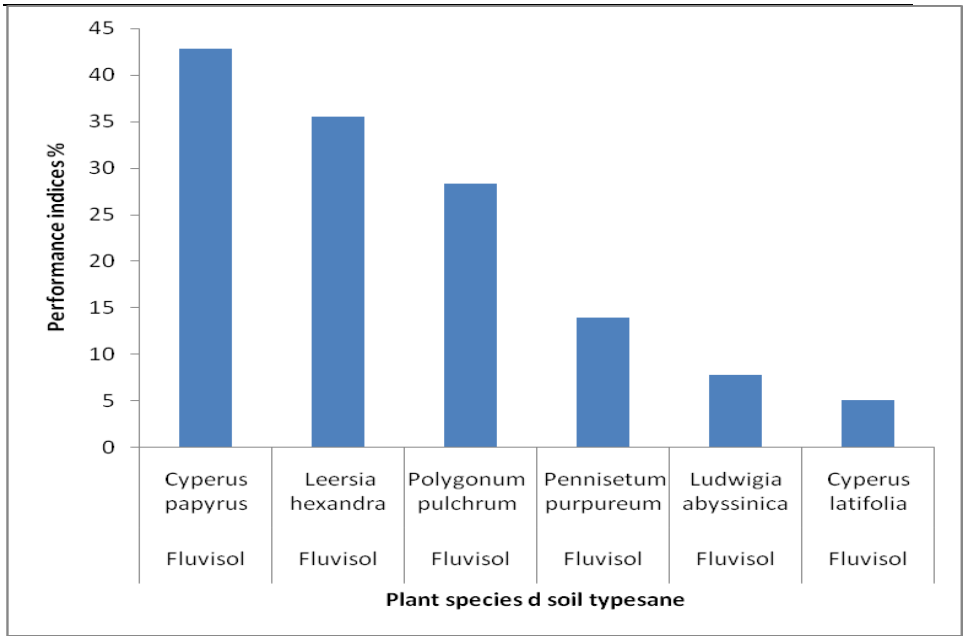

Figure 4. 7: Histogramme showing performance indices of dominant plant species in Birambo site according to their respective soil types

From Table 4.5 and Figure 4.7 mentioned above for Birambo site, it can be observed that Cyperaceae family dominates the Birambo site, especially the *Cyperus papyrus* L. with a performance index of 42.79%. This site is located in the valley of Nyabarongo River and received a great amount of sediments rich in limon and silt from many of their affluent streams.

It is well known that *Cyperus papyrus* L. grows in aquatic area, with soil rich in humus. The next dominant plant species were *Leersia hexandra SWARTZ, Polygonum pulchrum* BLUME and *Pennisetum purpureum* SCHUM. with performance indices of 35.54%, 28.34% and 13.88% respectively. The other plant species that were less represented in that site were *Ludwigia abyssinica A.RICH.* with performance index of *7.75%* and *Cyperus latifolia POIRET* with 5.05%. The vegetation of Birambo site can be defined as a shrubby-grassland made *of Cyperus papyrus, Leersia hexandra, Ludwigia abyssinica* and *Polygonum pulchrum* association. The soil was a fluvisol, which was very rich in humus brought by affluent streams of Nyabarongo River. The data recorded for this site are shown in Appendix 4 and Figure 4.8 represents transects relationship in the form of dendrogram as well as the Jaccard similarity indices.

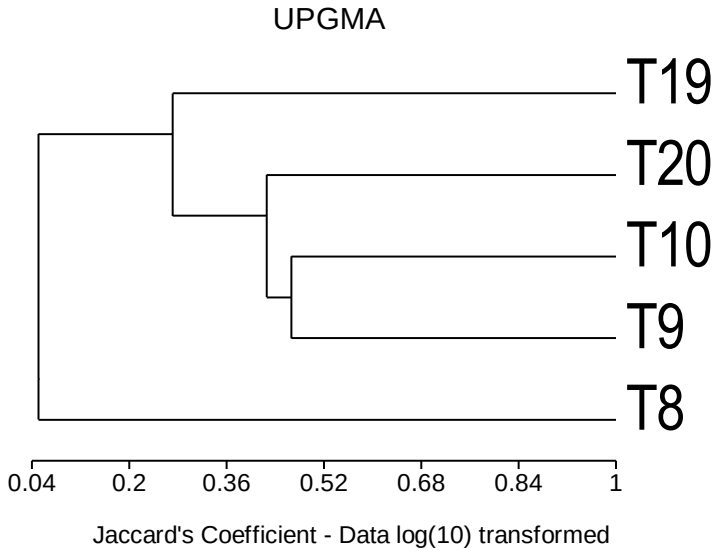

Figure 4. 8: Dendrogram indicating the similarity between the transects of Birambo site. (T: represents transects)

4.4 Overall dendrogram of similarity between transects in vegetation of Gatumba mining area

The index threshold of 0.5 calculated by Jaccard, cited in Gillet (2000) categorizes vegetations. The vegetation with lower value of Jaccard index of 0.5 was classified as heterogeneous, while the one which had a value equal or higher than 0.5 was classified as homogeneous. Couple of transects have been correlated in order to analyse their similarities or dissimilarities using MVSP program which clusters closer transects together. At the same time, MVSP displays both

dendrograms and Jaccard similarity indices among couples of transect to highlight their similarity relationship. In twenty transects combined from all four sites, the dendrogram (illustrated in Figure 4.9 below) shows that some couples of transects (T5-T9, T4-T8 and T12-T14) with Jaccard similarities indices on horizontal axis, are higher than 0.5 values. The remaining couples of transects present Jaccard Coefficients which are less than 0.5, demonstrating dissimilarity according to the definition of Gillet (2000). However, as this dendrogram shows many small groups, this indicates similarity within the groups. The results show that there is no similarity between more than three couples of transects in the region, meaning that the flora of Gatumba is heterogeneous. Detailed data of transects from Gatumba mining area are shown in Figure 4.9 below and in Appendix 5.

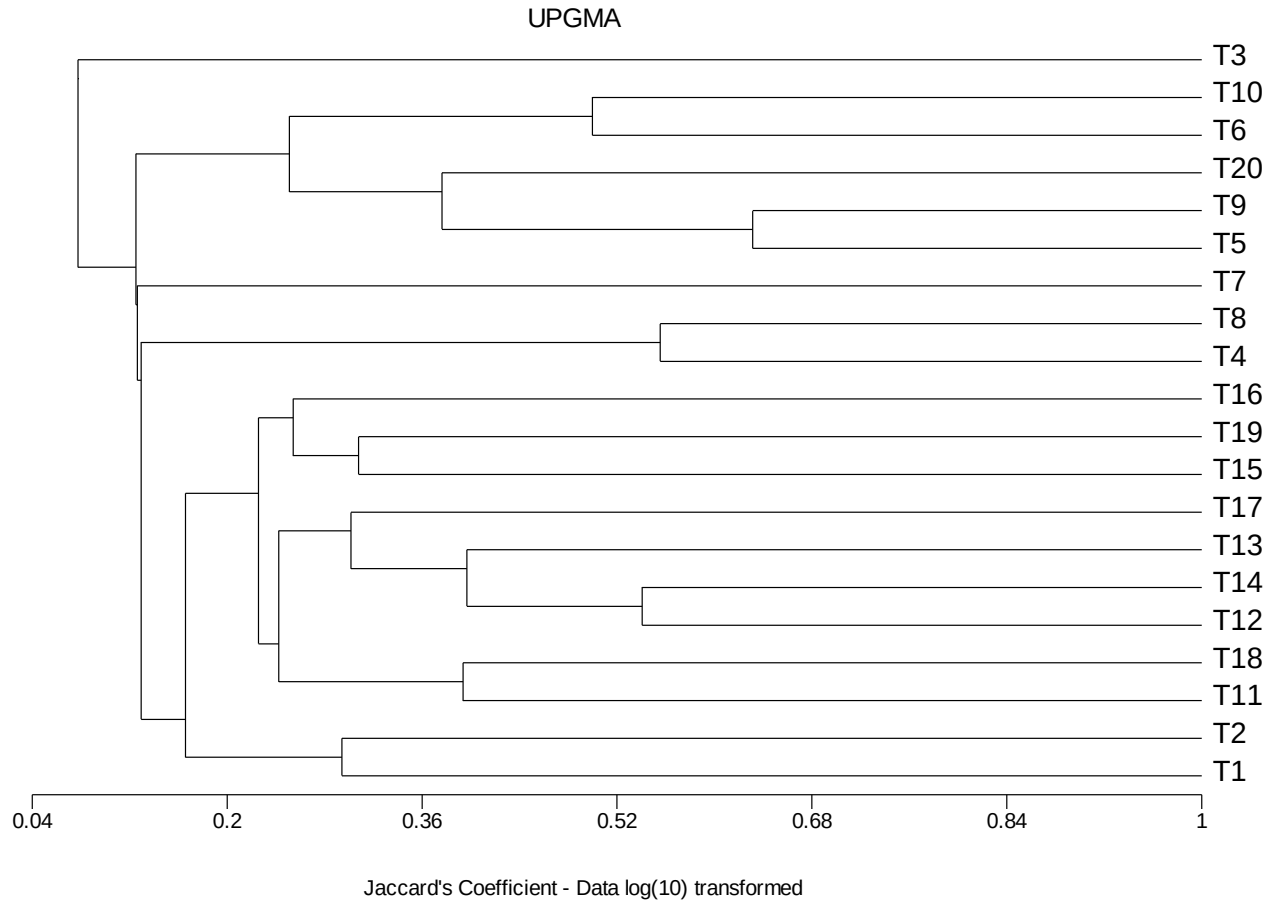

Figure 4. 9: Dendrogram indicating the transects similarity between 20 transects of Gatumba mining area. (T: represents transects).

4.5 Plant communities species diversity index for Gatumba vegetation

The Shannon indices were calculated by using MVSP programme and are presented in figure 4.10 below.

Ruhanga site has 77 plant species. To show the flora diversity in Ruhanga site, the $\log_{10*}77$ was calculated and the threshold value of diversity index gives $½*\log_{10*}77$= 0.99 which can be compared to 10 Shannon indices for 10 transects representing Ruhanga vegetation. According to this Shannon value, the vegetation of Ruhanga site was diversified as illustrated in Figure 4.10 below and in Appendix 6.

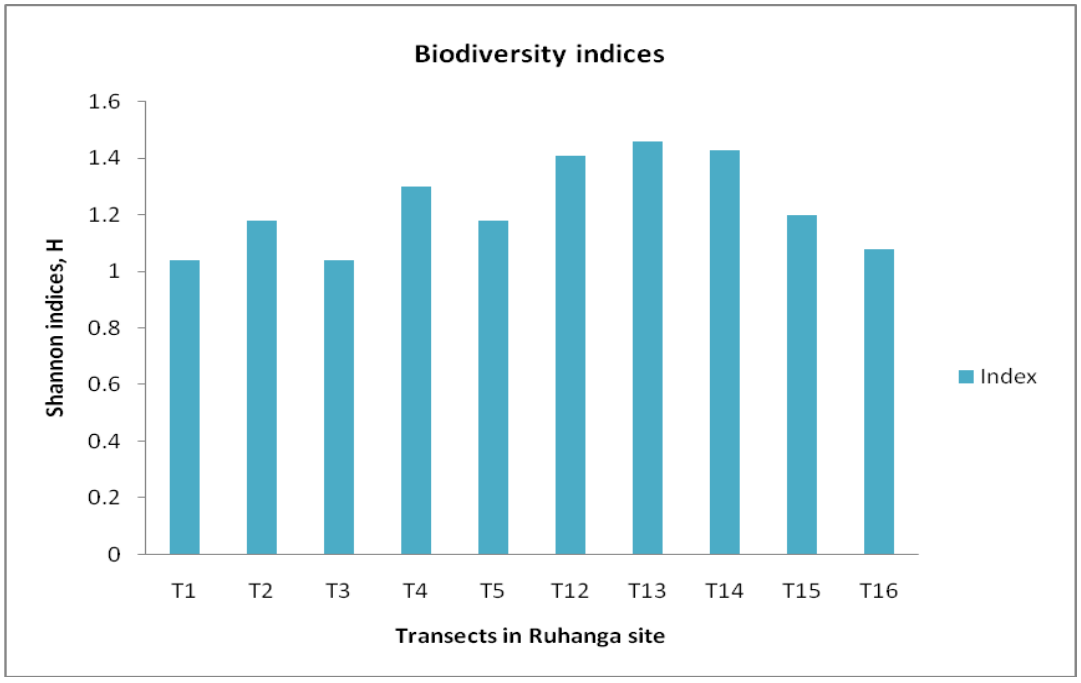

Figure 4. 10: Histogramme showing Shannon indices for Ruhanga flora

For Birambo site, 40 plant species were identified. Log $_{10*}$ 40 is 1.60, which represents diversity index for Birambo vegetation. All the diversity indices for Birambo vegetation were found to be superior to ½ the log $_{10}$ 40 which is 0.8, as illustrated in Figure. 4.11 below. Therefore, Birambo site has a diversified flora.

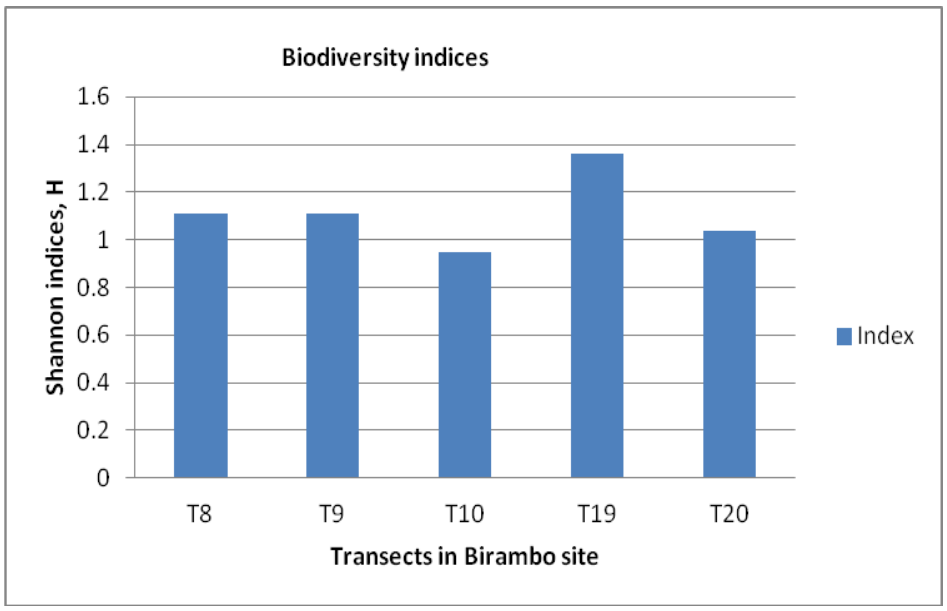

Figure 4. 11: Histogramme showing Shannon indices for Birambo flora

As for Rwasare and Mpare sites, the flora diversity indices were calculated but not represented. This was due to the fact that very few couples of transects were done as the sites were poor in vegetation.

An overall calculation of the Shannon diversity indices for all sites (Ruhanga, Rwasare, Mpare and Birambo) are presented in Appendix 6. However, the values obtained from Shannon diversity indices calculations are represented in Figure 4.12 to summarize the diversity indices of Gatumba flora as a whole. Those values indicate that the flora of Gatumba is diversified in general. Only T2 and T20 have 1 and 0.95 values of diversity index respectively, which are lower than 1.002, representing the threshold for Gatumba vegetation. All the remaining transects possess the indices values that are higher than 1,002, representing the threshold value for the 102 plant species identified in the whole Gatumba area.

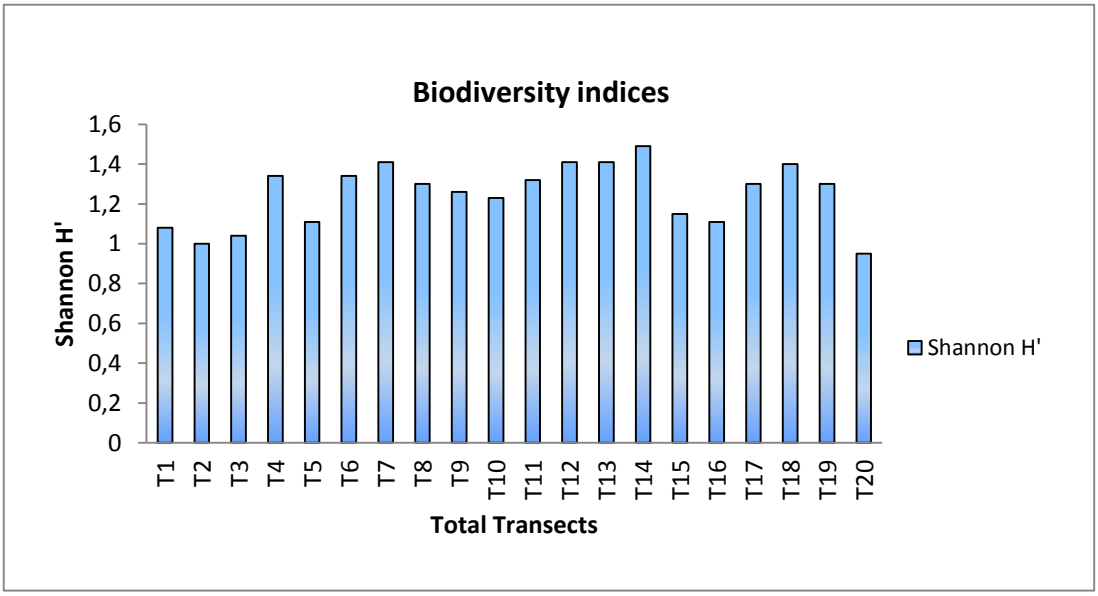

Figure 4. 12: Histogramme of overall Shannon diversity indices for all Gatumba mining flora

4.6 Findings on trace element concentration in Gatumba vegetation

Table 4.6 below illustrates the trace elements that were found in a mixed powder of ground plant stems (S) and leaves (L). Such a mixture is collectively known as shoots (Sh) and it was produced during the dry season, in August 2010. However, the identification of trace elements from individual parts of the plants such as stems (S), fruits/flowers (F), roots (R) and leaves (L) was done during the wet season, in March 2011.

The general findings show that trace elements present lower concentration in all parts of the plant. However, higher concentration of Li, Cu, Zn, and Rb was found in different parts of the plant, while lower concentration of As, Cd, Cs, Pb and U was found in those parts. In general, the occurrence of trace element concentration in different parts of the investigated plants is generallyis slight but discernable. If we compare the level trace element concentration in plant parts during the wet season and the dry season, we observe that it slightly increases during the dry season, while it relatively decreases during wet season, as illustrated in table 4.6.

It was also observed that there was a very low level of concentration for some trace elements like Cd and U, whose level of concentration did not reach the instrument detection limits.

Table 4. 6: Trace metals concentration in different plant species collected from Gatumba mining area, during both dry and wet seasons.

Plant species	Plant part	Li(µg/g)	Cu(µg/g)	Zn(µg/g)	As(µg/g)	Rb(µg/g)	Cd(µg/g)	Cs(µg/g)	Pb(µg/g)	U(µg/g)
Dry season										
Centella asiatica	P1, 1 Sh	2.65	9.88	80.29	0.23	142.92	0.29	4.24	0.96	0.08
Digitaria abyssinica	P1, 3 Sh	2.32	8.25	20.76	0.12	38.92	0.05	1.17	1.23	0.07
Melinis minutiflora	P1, 4 Sh	10.43	3.53	32.09	0.14	42.1	0.1	1.91	1.5	0.12
Ipomoea batatas	P2, 10 Sh	3.9	10.41	23.74	0.03	174.8	b.d.l.	11.35	0.35	0.02
Crotalaria dewildemaniana	P3, 14 Sh	21.2	10.21	36.29	b.d.l.	265.76	0.23	5.22	0.27	0.03
Sesbania sesban	P3, 15 Sh	78.28	5.05	49.5	0.08	383.33	0.02	9.16	0.47	0.05
Manihot esculenta	P5, 16 Sh	0.77	6.85	114.47	0.05	38.75	0	0.37	0.47	0.02
Ageratum conyzoides	P5, 17 Sh	8.08	14.61	62.97	0.12	168.14	1.25	1.3	0.38	0.04
Pennisetum purpureum	P10, 23 Sh	0.05	5.51	22.37	0.02	118.36	0.07	0.32	0.87	b.d.l.
Polygonum pulchrum	P11, 24 Sh	0.6	8.55	42.27	0.17	106.3	0.17	0.4	1.91	0.01
Cyperus papyrus	P11, 25 Sh	0.3	2.5	10.16	0.03	34.52	0.04	0.35	0.72	b.d.l.
Ludwigia abyssinica	P11, 45 Sh	0.78	17.11	64.5	0.06	70.34	0.05	0.28	0.95	0.01
Ipomoea cairica	P12, 38 Sh	1.64	12.42	24.53	0.06	73.82	0.05	0.45	0.95	0.02
Colocasia esculenta	P13, 26 Sh	0.8	6.82	24.27	0.03	54.1	0.23	0.2	0.98	0.02
Erythrina abyssinica	P13, 29 Sh	2.89	43.92	121.6	0.08	31.36	b.d.l.	0.93	0.76	0.03
Phytolacca dodecandra	P14, 47 Sh	1.96	12.28	73.74	0.03	195.39	0.25	2.85	0.21	0.02

Wet season										
	P1, 1 S	1.76	8.48	54.34	0.21	133.04	0.21	2.98	1.56	0.06
Centella asiatica	P1, 1 L	2.96	9.4	57.76	0.25	167.31	0.13	4.07	1.99	0.08
	P1, 3 R	2.47	17.19	17.9	0.3	33.2	0.05	0.89	0.99	0.13
	P1, 3 S	0.68	18.06	55.95	0.08	50.65	0.02	0.77	0.93	0.04
Digitaria abyssinica	P1, 3 L	3.6	6.05	25.53	0.45	46.55	0.08	1.59	3.34	0.21
	P1, 4 R	2.74	7.73	9.49	0.31	26.42	0.15	0.95	2.08	0.22
	P1, 4 S	1.85	3.61	61.54	0.06	33.12	b.d.l.	0.79	b.d.l.	0.03
Melinis minutiflora	P1, 4 L	14.88	6.32	47.28	0.47	53.8	b.d.l.	3.33	1.33	0.28
	P2, 10 S	2.83	12.59	20.05	0.07	189.04	b.d.l.	7.96	b.d.l.	0.05
	P2, 10 L	3.27	10.52	14.38	0.35	199.49	0.29	8.1	1.95	0.1
Ipomoea batatas	P2, 10 F	3.02	7.77	14.38	0.02	153.81	b.d.l.	4.32	b.d.l.	0.01
	P3, 14 S	5.14	6.71	18.42	0.07	278.68	b.d.l.	5.86	b.d.l.	0.02
	P3, 14 L	8.33	15.04	31.58	0.14	241.1	b.d.l.	10.23	0.36	0.04
Crotalaria dewildemaniana	P3, 14 F	2.16	7.08	17.93	b.d.l.	270.17	b.d.l.	4.4	b.d.l.	b.d.l.
	P4, 15 S	8.65	6.18	37.88	0.03	379.41	b.d.l.	5.84	0.47	b.d.l.
	P4, 15 L	80.91	9.43	51.76	0.1	222.96	b.d.l.	8.08	b.d.l.	0.01
Sesbania sesban	P4, 15 F	3.87	5.53	24.12	0.02	191.99	b.d.l.	2.64	b.d.l.	b.d.l.
	P5, 16 S	0.05	19.5	106.77	0.02	76.05	0.06	0.76	0.17	b.d.l.
Manihot esculenta	P5, 16 L	0.2	7.91	76.25	0.06	69.13	b.d.l.	0.59	b.d.l.	0.01
	P5, 17 R	3.93	52.91	34.95	0.75	60.12	0.4	1.1	3.91	0.2
	P5, 17 S	0.56	6.23	25.62	0.09	56.76	0.5	0.44	0.81	0.02
Ageratum conyzoides	P5, 17 L	3.43	10.72	72.8	0.53	57.85	1.1	1.06	3.05	0.09
Pennisetum purpureum	P10, 23 S	0.16	14.48	215.31	0.03	269.99	b.d.l.	0.26	1.75	b.d.l.
	P10, 23 L	0.32	6.79	22.92	0.07	87.44	b.d.l.	0.42	b.d.l.	b.d.l.
	P11, 24 S	0.15	7.8	31.84	0.08	120.43	b.d.l.	0.31	b.d.l.	b.d.l.
Polygonum pulchrum	P11, 24 L	0.72	5.2	28.59	0.26	63.87	b.d.l.	0.36	0.09	0.02
Cyperus papyrus	P11, 25 S	0.11	1.95	12.45	0.1	55.44	0.25	0.62	b.d.l.	b.d.l.

	P11, 25 P	0.11	2.13	13.73	0.06	20.91	0.36	0.21	b.d.l.	0
	P11, 25 F	0.51	2.75	15.34	0.16	13.18	1.24	0.2	30.16	0.01
	P11, 45 S	0.21	16.59	68.41	0.03	106.33	0.67	0.56	12.41	b.d.l.
Ludwigia abyssinica	P11, 45 L	0.9	18.25	79.27	0.08	51.09	0.03	0.51	b.d.l.	0.01
	P12, 20 S	0.37	14.44	141.85	0.02	26.12	0.77	0.04	5.31	b.d.l.
	P12, 20 L	1.77	8.35	84.03	0.12	46.7	0.59	0.15	1.37	0.03
Tithonia diversifolia	P12, 20 F	0.16	9.24	236.41	0.01	46.62	0.28	0.04	b.d.l.	b.d.l.
	P12, 38 S	0.65	13.76	55.87	0.08	29.69	0.32	0.17	b.d.l.	0.04
Ipomoea cairica	P12, 38 L	0.78	11.84	35.53	0.07	44.97	0.34	0.25	b.d.l.	0.03
	P13, 26 L	0.98	8.75	30.79	0.04	17.5	0.47	0.1	1.01	0.02
	P13, 26 P	0.62	14.01	69.63	0.01	50.9	0.44	0.06	1.52	0.01
Colocasia esculenta	P13, 26 R	2.12	7.92	49.23	0.09	48.58	0.08	0.2	b.d.l.	0.04
	P13, 29 S	0.19	15.79	45.5	0.02	96.49	b.d.l.	0.4	b.d.l.	b.d.l.
Erythrina abyssinica	P13, 29 L	0.29	27.06	29.23	0.06	42.24	b.d.l.	0.44	b.d.l.	0.01
Phytolacca dodecandra	P14, 47 S	0.31	10.27	55.95	0.02	86.98	0.15	1.26	b.d.l.	0.01
	P14, 47 L	0.62	13.91	62.26	0.08	132.46	0.12	2.82	b.d.l.	0.01

Label:

b.d.l.: below instrument detection limits

S: stem

L: leaves

R: roots

F: fruits/flowers

Sh: shoots

P: stalk

4.7 Physical and chemical characteristics of soils sampled in Gatumba mining area

Table 4.7 summarizes the characteristics and nutrients concentration of the sampled soils. Gatumba soils were classified based on WRB (2006) denominations of soils worldwide. In this regard, the study found that Gatumba mining area has technosol on minespoil (P1 and P2), technosol overlaying gleysol in pegmatite material (P3), technosol without soil development (P4 and P5), cambic fluvisol (P10), fluvisol (P11), fluvisol covered by colluvium (P12), strongly disturbed fluvisol (P13) and lixisol (P14). The soils were found to be generally acidic (pH of 4.4-6.4) with minimal seasonal changes. The study also observes lower levels of nutrients (like P, K and B), which slightly decreased in concentration from dry to wet seasons; but K stays higher than other minerals present in soil during the study period. All these levels of nutrients were variable within the different types and horizons of soil, as well as within the pH soil characteristics.

The low ratio of C/N was observed in all profiles with the maximum in Cambic fluvisol (C/N=14.5 values) and the minimum in Technosol with 9.6 values, during the dry season. This result shows the absence of organic matter in decomposition in technosol found at Ruhanga site, during the dry season. The C and N soil content were very low with maximum soil-Carbone of 1.28% in lixisol and fluvisol.

However, it is to be mentioned that the level of concentration for N, C and C/N ratio are only analysed in dry season in Table 4.7, but not in wet season. This was due to the fact that the material preparation for the wet season got contaminated for these three nutrients elements. They could therefore not be analysed to avoid unreliable results.

Table 4. 7: Physical characteristics and nutrient concentration of soil profiles sampled at Gatumba mining area

Soil Types	Soil profile	pH	K (mg/kg)	P (mg/kg)	B (µg/g)	N %	C %	C/N
Dry season								
Technosol	P1AhC	4.4	1571.2	227.1	11.6	0.01	0.11	9.6
	P2Ah+C	4.9	2523.9	297.5	12.3	0.01	0.18	13.9
	P3C	4.9	3521.0	375.8	16.1	0.02	0.16	10.8
	P4C	5.2	6058.4	278.2	5.7	0.01	0.07	9.9
Cambic Fluvisol	P5Ah+Bw	5.0	2788.9	262.3	10.0	0.07	0.67	10.4
Lixisol	P14E	4.6	2541.4	453.4	20.9	0.10	1.28	12.6
Fluvisol	P12 M	5.1	1968.0	300.0	8.9	0.03	0.35	11.3
Fluvisol	P13 M	5.3	2637.5	223.9	8.2	0.03	0.32	9.3
Cambic Fluvisol P10	P10MBw	5.2	4678.9	411.7	12.2	0.08	1.18	14.5
Fluvisol	P11 AhBwBg	5.3	5301.8	457.9	13.6	0.11	1.28	12.0
Wet season								
Technosol	P1AhC	4.4	1107.3	224.1	9.7	-	-	-
	P2AhC	4.8	1272.5	305.3	11.6	-	-	-
	P3C	5.0	3245.3	402.7	17.6	-	-	-
	P4C	6.4	5175.4	147.5	2.7	-	-	-
Cambic Fluvisol	P5AhBw	5.2	1218.6	220.0	8.1	-	-	-
Fluvisol	P12 M	5.0	2583.3	315.2	9.6	-	-	-
Fluvisol	P13 M	5.5	2376.5	209.6	7.4	-	-	-
Cambic Fluvisol P	P10MBw	5.2	3096.6	304.8	9.1	-	-	-
Fluvisol	P11 AhBwBg	5.1	4458.1	509.2	15.6	-	-	-

-: data not available because the soil samples could not be analysed as they got contaminated

Table 4.8 below shows the level of 13 trace elements identified in the soil sampled in the four sites selected in Gatumba mining area.

Table 4. 8: Level of trace metals concentration in soils sampled from Gatumba mining area.

Dry Season August 2010														
Soil type	Soil profile	Li(µg/g)	Cr(µg/g)	Ni(µg/g)	Cu(µg/g)	Zn(µg/g)	As(µg/g)	Rb(µg/g)	Cd(µg/g)	Sb(µg/g)	Cs(µg/g)	Pb(µg/g)	Bi(µg/g)	U(µg/g)
Technosol	P1, AhiC	20.29	40.14	9.46	3.03	16.50	2.77	49.01	0.36	0.05	12.60	12.54	0.21	2.32
Technosol	P2(Ah +C)	18.26	54.04	16.75	6.59	0.79	2.56	70.50	0.09	0.03	23.16	4.87	0.06	2.68
Technosol	P3, C	45.22	47.22	14.93	2.41	8.03	3.46	149.94	0.15	b.d.l.	45.94	10.06	0.12	3.02
Technosol	P4, C	336.79	66.87	18.78	3.47	15.64	1.76	419.56	0.56	0.02	41.08	7.08	0.12	5.46
Cambic Fuvisol	P5(Ah+ Bw)	12.07	31.02	11.45	14.30	9.31	6.29	52.20	0.13	0.03	5.91	6.99	0.49	1.98
Cambic Fuvisol	P10(M+ Bw)	12.18	38.90	15.38	20.52	25.61	7.69	51.62	0.14	0.06	4.37	9.78	0.48	1.97
Fluvisol	P11(Ah +BwBg)	12.60	57.71	23.58	30.69	35.34	10.71	77.15	0.19	0.07	5.54	17.22	0.82	2.89
Fluvisol	P12, M	6.37	40.39	12.51	25.04	7.01	6.47	40.63	0.08	0.01	5.36	6.35	0.54	1.37
Fluvisol	P13, M	21.53	33.03	14.62	17.75	14.70	8.12	58.44	0.16	0.02	7.00	5.34	0.24	1.43
Lixisol	P14, E	12.67	94.20	20.91	38.12	16.26	3.67	53.04	0.33	0.07	7.48	12.96	0.29	1.89
Rain Season March 2011														
Technosol	P1, AhiC	14.53	37.21	7.73	2.50	b.d.l.	2.89	45.93	0.36	0.01	16.65	14.11	0.15	1.97
Technosol	P2(Ah+ C)	21.25	50.99	15.81	6.22	2.58	2.19	52.39	0.09	0.01	15.67	4.42	0.06	1.67
Technosol	P3, C	32.47	62.41	17.21	4.10	18.19	3.87	134.29	0.25	0.03	46.05	8.13	0.38	2.65
Technosol	P4, C	271.71	18.48	16.94	0.50	15.60	0.54	312.04	0.27	b.d.l.	35.95	3.62	0.06	1.68
Cambic Fuvisol	P5(Ah +Bw)	16.39	27.51	9.75	12.75	17.38	5.02	32.79	0.20	b.d.l.	4.56	6.48	0.11	1.38
Cambic Fuvisol	P10(M+ Bw)	10.55	39.50	16.50	20.77	31.13	7.45	54.22	0.05	0.04	4.90	9.65	0.59	2.04
Fluvisol	P11(Ah+ BwBg)	18.93	53.60	22.79	30.48	41.80	10.45	61.38	0.07	0.06	4.92	13.60	0.82	2.75
Fluvisol	P12, M	10.63	37.58	11.40	23.88	14.07	5.54	35.56	0.22	0.02	3.52	6.87	0.65	1.63
Fluvisol	P13, M	31.23	32.73	12.87	16.67	19.31	8.03	47.81	0.08	0.02	5.56	4.48	0.29	1.57

b.d.l. is below instrument detection limit

The general findings indicate that all 13 trace elements present lower concentration in all the soil samples analysed. However, higher concentration of Li, Cr, Cu, Ni, Zn, Rb and Cs was found in those soil samples, while lower concentration of As, Cd, Sb, Pb, Bi and U were found in those sampled soils. The general observation of trace element concentration occurrence during the wet and dry seasons revealed that concentration is higher during dry season, while it is lower during wet season, as illustrated in Table 4.8.

In addition, Table 4.6 shows that the trace element concentrations of plant parts follow a pattern which is similar to the one observed in the soil trace element concentration. However, some elements (like As and Pb) have a higher order of magnitude in soils, as illustrated in Table 4.8; but with lower order of magnitude in plants, as indicated in Table 4.6.

It is to be mentioned that the main compound of coltan, namely Nb, Sn and Ta were not analysed in soil samples due to lack of appropriate equipment to detect them.

4.8 Findings on relationships between plants and soils in the sampled area

4.8.1 Relationship between dominant plant species and soils types per season

Table 4.9 shows the types of soil, the corresponding dominant plant species, together with their performance indices in Gatumba mining area. It is apparent that *Digitaria abyssinica* is the most tolerant plant species in both seasons. It is also the most dominant within several soil types (like technosol and fluvisol) and profiles. It was also observed that Gatumba mining area has been influenced by agriculture of *Zea mays* and *Manihot esculenta*, which are cultivated on cambic fluvisol and fluvisol. *Crotalaria arrecta* and *Sesbania sesban* were also able to colonise the disturbed and nutrient-poor soils like technosol. The general observation from Table 4.9 indicates that, among all species the performance index for the dominant plants in the region is consistently higher for grasses (e.g. *Digitaria abyssinica).*

Table 4. 9: Correlation between the type of soil and associated dominant plant species with their performance indices in Gatumba mining area, in both dry and wet seasons.

Soil profile	Soil type	Dominant plant species	φ (%)
a) Dry season (August 2010)			
P1: AhiC	T1: Technosol	*Digitaria abyssinica* (HOCHST.ex A.RICH.) STAPF	26.65
P2: AhiC	T2: Technosol	*Digitaria abyssinica* (HOCHST.ex A.RICH.) STAPF	45.55
P3 C	T3: Technosol	*Digitaria abyssinica* (HOCHST.ex A.RICH.) STAPF	22.65
P4 C	T4: Technosol	*Lantana camara L.*	22.24
P5 (Ah Bw)	T5: Cambic Fluvisol	*Digitaria velutina* (FORSSKAL) P. BEAUV.	17.97
P10(M Bw)	T6: Fluvisol	*Ipomoea batatas (L.)LAM.*	27.98
P11 (Ah BwBg)	T7: Cambic Fluvisol	*Digitaria abyssinica* (HOCHST.ex A.RICH.) STAPF	35.84
P14E	T8: Lixisol	*Bridelia micrantha* (HOCHST.) BAILLON	15.0
P12, M	T9: Fluvisol	*Polygonum pulchrum BLUME*	17.17
P13, M	T10: Fluvisol	*Cyperus papyrus L.*	42.79
P13M	T11: Fluvisol	*Digitaria abyssinica* (HOCHST.ex A.RICH.) STAPF	8.87
b) Rainy season (March 2011)			
P1, AhiC	T12: Techonosol	*Digitaria abyssinica* (HOCHST.ex A.RICH.) STAPF	30.81
P2(Ah C)	T13: Technosol	*Digitaria abyssinica* (HOCHST.ex A.RICH.) STAPF	25.19
P3, C	T14: Technosol	*Digitaria abyssinica* (HOCHST.ex A.RICH.) STAPF	21..72
P4, C	T15: Technosol	*Digitaria abyssinica* (HOCHST.ex A.RICH.) STAPF	27.92
P5(Ah Bw)	T16 Cambic Fluvisol	*Ageratum conyzoides L.*	23.59
P10(M Bw)	T17 Cambic Fluvisol	*Manihot esculenta* CRANTZ	28.36
P11(Ah BwBg)	T18 Fluvisol	*Erytrina abyssinica. LAM. Ex.A.RICH.*	14.81
P12, M	T19 Fluvisol	*Leersia hexandra* SWARTZ	35.34
P13, M	T20 Fluvisol	*Polygonum pulchrum* BLUME	28.34

The table above indicates that the vegetation of Gatumba mining area is mainly influenced by agriculture where *Manihot esculenta* CRANTZ and *Ipomoea batatas (L.)LAM.* are found. However, the vegetation is dominated by *Digitaria abyssinica* (HOCHST.ex A. RICH) STAPF, *Lantana camara L., Ageratum conyzoides L., Leersia hexandra* SWARTZ and *Polygonum pulchrum* BLUME, which are predominantly found in hallow areas extending to a great part of Mpare, Rwasare and Birambo sites. Some bushes were found dispersed in a small part of

Ruhanga site where *Erytrina abyssinica LAM. ex A.RICH.* and *Bridelia micrantha* (HOCHST.) BAILLON are dominant shrubby. *Digitaria abyssinica, Ageratum conyzoides* and *Lantana camara* were also found in the non cultivated areas of Gatumba mining area. Therefore, it is vegetation characterized by a *Digitaria- Ageratum- Lantana* plant association.

4.8.2 Findings on Bioaccumulation Factors (BCF) values of different trace elements in plant parts

The BCF for different trace elements in plant parts was calculated using equation 4.3 and the results are shown in table 4.10 below and in Appendix 7. It was found that Bioaccumulation factors (*BCF*) of the analysed trace elements (Sb, Bi, As, U and Pb) in plant parts are generally low (BCF<1). This value is a characteristic of excluder plants, that is, the plants that do not tolerate the absoption of those trace elements. As for Cd, Cu, Zn and Rb, the calculated BCF value was generally higher (BCF >1), which indicates that plants can accumulate those trace elements.

During the dry period, BCF_{Cd} value was greater than 1 in shoots of *Crotalaria dewildemaniana* (BCF_{Cd} =1.56) and *Ageratum conyzoides* (BCF_{Cd}= 9.39), while in wet season, a similar accumulation of these trace elements is observed in leaves, as illustrated in Table 4.10 below. BCF_{Cu} value is also greater than 1 in shoots of *Centella asiatica* (BCF_{Cu}=3.26), *Digitaria abyssinica* (BCF_{Cu}=3.20), and *Ageratum conyzoides* (BCF_{Cu}= 9.39) in dry season, while a similar accumulation of these trace elements is observed in stems and leaves, in wet season. In the same context, BCF_{Zn} is >1 value in shoots of some plant such as *Centella asiatica* (BCF_{Zn}= 4.87), *Melinis minutiflora* (BCF_{Zn}=1.95), *Digitaria abyssinica* (BCF_{Zn}=1.26), *Ipomoea batatas* (BCF_{Zn}=30.21), *Manihot esculenta* (BCF_{Zn}=12.30), *Erytrina abyssinica* (BCF_{Zn}= 8.27) and *Sesbania sesban* (BCF_{Zn}=3.16) in dry season, while a similar accumulation of these trace elements is observed in stems and leaves, in wet season. Thus, the highest accumulation of trace elements is commonly observed in the leaves followed by stems and roots, as illustrated in Table 4.10.

Figure 4.13 plots the BCF values of different trace elements in plant shoot and compares them with the threshold, which is equal to 1.

Table 4. 10: Variation of Bioaccumulation factors and Translocation factors of main trace elements in plants in Gatumba mining area.

	Bioaccumulation factors				**Translocation factors**	
	Dry season	**Rainy season**				
Plant species	Shoots	Roots	Stems	Leaves	Stems	Leaves
BCF_{Cd} and TF_{Cd}						
Centella asiatica	0.80		0.57	0.37		
Digitaria abyssinica	0.14	0.15	0.06	0.22	0.39	**1.51**
Melinis minutiflora	0.28	0.42				
Ipomoea batatas				**3.26**		
Crotalaria dewildemaniana	**1.56**					
Sesbania sesban	0.03		0.00			
Manihot esculenta	0.02		0.30			
Ageratum conyzoides	**9.39**	**2.01**	**2.49**	**5.51**	**1.24**	**2.74**
Pennisetum purpureum	0.39					
Polygonum pulchrum	0.89					
Cyperus papyrus	0.21		**3.57**			
Ludwigia abyssinica	0.26		**9.51**	0.45		
Ipomoea cairica	0.67		**1.46**	**1.56**		
Tithonia diversifolia			**3.49**	**2.68**		
Colocasia esculenta	**2.90**	0.93		**5.85**		**6.27**
Erythrina abyssinica						
Phytolacca dodecandra	0.75		0.44	0.38		
BCF_{Cu} and TF_{Cu}						
Centella asiatica	**3.26**		**3.39**	**3.76**		
Digitaria abyssinica	**3.20**	**6.88**	**7.23**	**2.42**	**1.05**	0.35
Melinis minutiflora	**2.72**	**3.09**	**1.44**	**2.53**	0.47	0.82
Ipomoea batatas	**1.58**	0.49	0.46	0.53	0.94	**1.08**
Crotalaria dewildemaniana	**2.78**		**1.64**	**3.67**		
Sesbania sesban	**1.78**		**12.36**	**18.85**		
Manihot esculenta	**1.36**		**1.53**	0.62		
Ageratum conyzoides	**3.70**	**4.15**	0.49	0.84	0.12	0.20
Pennisetum purpureum	0.27		0.70	0.33		
Polygonum pulchrum	0.28		0.26	0.17		
Cyperus papyrus	0.08		0.06			
Ludwigia abyssinica	0.56		0.54	0.60		
Ipomoea cairica	0.50		0.58	0.50		
Tithonia diversifolia			0.60	0.35		
Colocasia esculenta	0.38			0.53		
Erythrina abyssinica	**2.47**		0.95	**1.62**		
Phytolacca dodecandra	0.32		0.27	0.36		
BCF_{Zn} and TF_{Zn}						

Centella asiatica	**4.87**		**21.06**	**22.39**		
Digitaria abyssinica	**1.26**	**6.94**	**21.69**	**9.90**	**3.13**	**1.43**
Melinis minutiflora	**1.95**	**3.68**	**23.85**	**18.33**	**6.49**	**4.98**
Ipomoea batatas	**30.21**	**5.57**	**7.77**	**5.57**	**1.39**	**1.00**
Crotalaria dewildemaniana	**4.52**		**1.01**	**1.74**		
Sesbania sesban	**3.16**		**2.43**	**3.32**		
Manihot esculenta	**12.30**		**6.14**	**4.39**		
Ageratum conyzoides	**6.77**	**2.01**	**1.47**	**4.19**	0.73	**2.08**
Pennisetum purpureum	0.87		**6.92**	0.74		
Polygonum pulchrum	**1.20**		0.76	0.68		
Cyperus papyrus	0.29		0.30			
Ludwigia abyssinica	**1.83**		**1.64**	**1.90**		
Ipomoea cairica	**3.50**		**3.97**	**2.53**		
Tithonia diversifolia			**10.08**	**5.97**		
Colocasia esculenta	**1.65**	**2.55**		**1.59**		0.63
Erythrina abyssinica	**8.27**		**2.36**	**1.51**		
Phytolacca dodecandra	**4.54**		**3.44**	**3.83**		

The bolded values correspond to bioaccumulation and translocation of trace elements in respective plant species with BCF and TF >1.

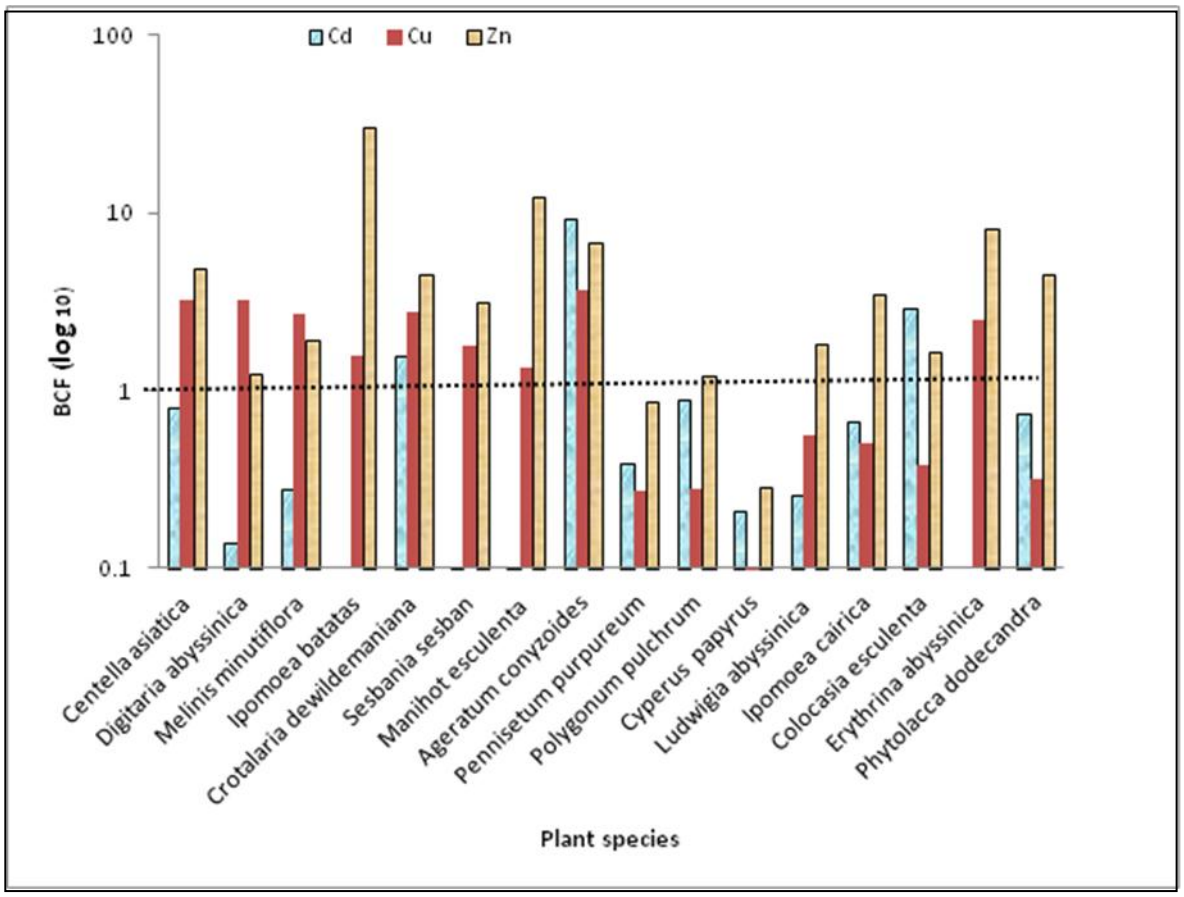

Figure 4. 13: Histogram showing the dry season bioaccumulation factors of the main trace elements in plant shoots in Gatumba mining area. The dotted line shows the threshold value.

Figure 4.13 above shows bioaccumulation of trace elements in shoots in dry season. It revealed that some values presented in Table 4.10 were higher than the threshhold value, which is equal to 1. Such values correspond to plant species that accumulate trace elements from the mining area (like *Crotalaria dewildemaniana* and *Ageratum conyzoides* which accumulate Zn, Cu and Cd).

For the spatial distribution of selected trace elements among the four sites of Gatumba mining area, Figures 4.14 and 4.15 provide the details. As all the trace elements could not be presented on a figure, only Cu, Zn and Cd were selected because they were the salient ones in terms of concentration in soil and plants, and in terms of translocation in different parts of the plant. Concerning their concentration in soil it increases with distance from Ruhanga to Birambo site during the dry and wet seasons, respectively.

The above-mentioned three trace elements were bioacummulated in several parts of plant species. As indicated in Figure 4.14, Zn was found to be lower in soils than in plants during the dry season, and its concentration increases with distance from Ruhanga (mine site) to Birambo site. As for Copper, it has a similar concentration in both soils and plants in Ruhanga, but with a slight increase with distance from Ruhanga towards Birambo site, where it shows a slight increase in soils than in plants. For Cd, it has a slightly lower level in soils than in plants in Ruhanga site, but with a steady distribution towards Birambo site.

With regard to the distribution of plant families in Gatumba mining area, Apiaceae and Grasses grow on technosols that are close to Ruhanga mining site, whereas Cyperacaeae, Onagraceae and Polygonaceae grow on fluvisol which is close to Nyabarongo River, in Birambo site.

During the wet season, Zn and Cd have a similar distribution to the dry season but with difference in concentration, as illustrated in Figure 4.15. However, Cu was found to be at higher level in plants than in soils, with a slight increase from Ruhanga towards Birambo site. In the vicinity of Ruhanga site, Poaceae (grass), Cyperaceae and Onagraceae families grow on technosols, whereas in Birambo site, they grow on fluvisols, as illustrated in Figure 4.15 below.

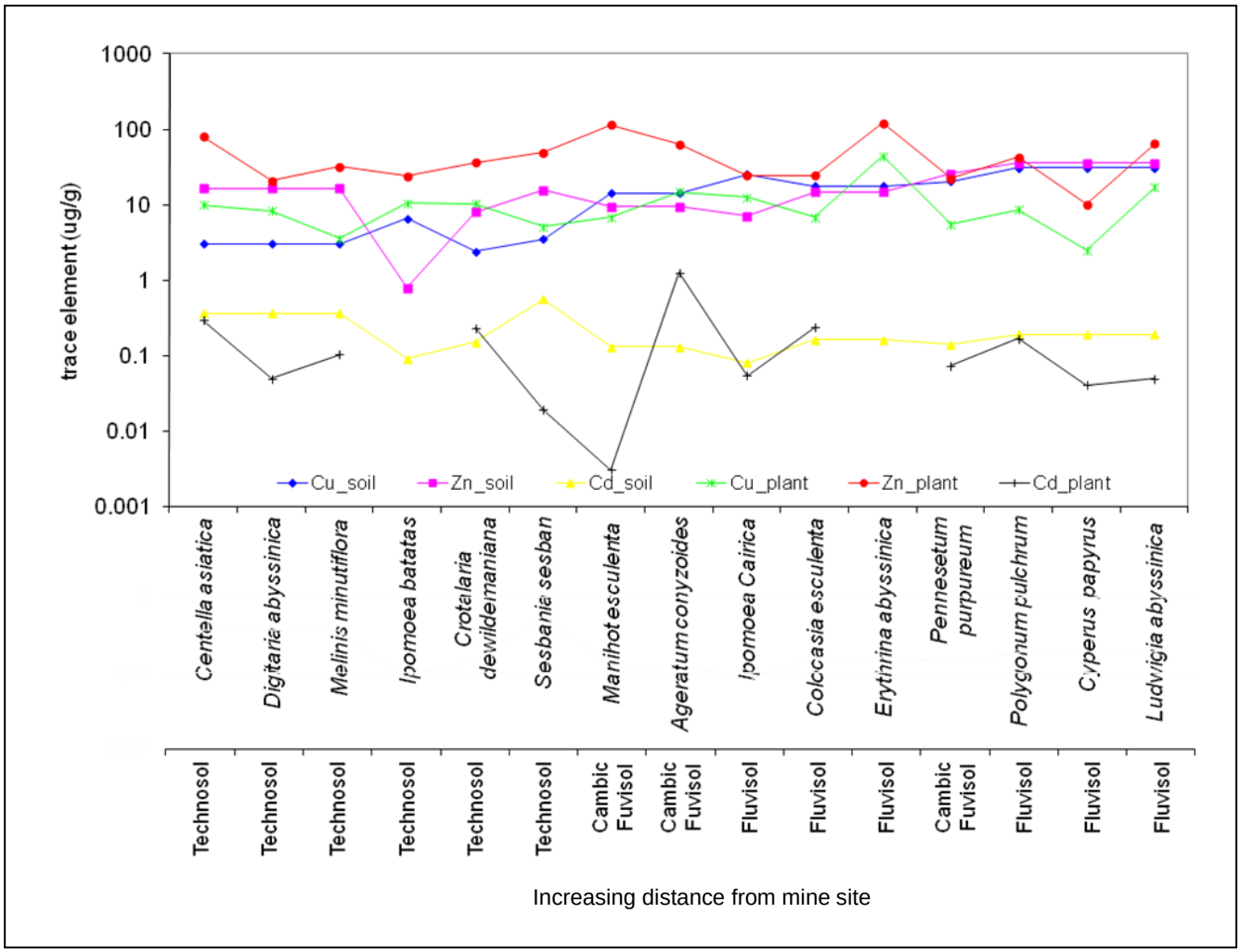

Figure 4. 14: Spatial distribution of selected trace elements in plants and soils at increasing distances from Ruhanga (mine site) to Birambo site during the dry season.

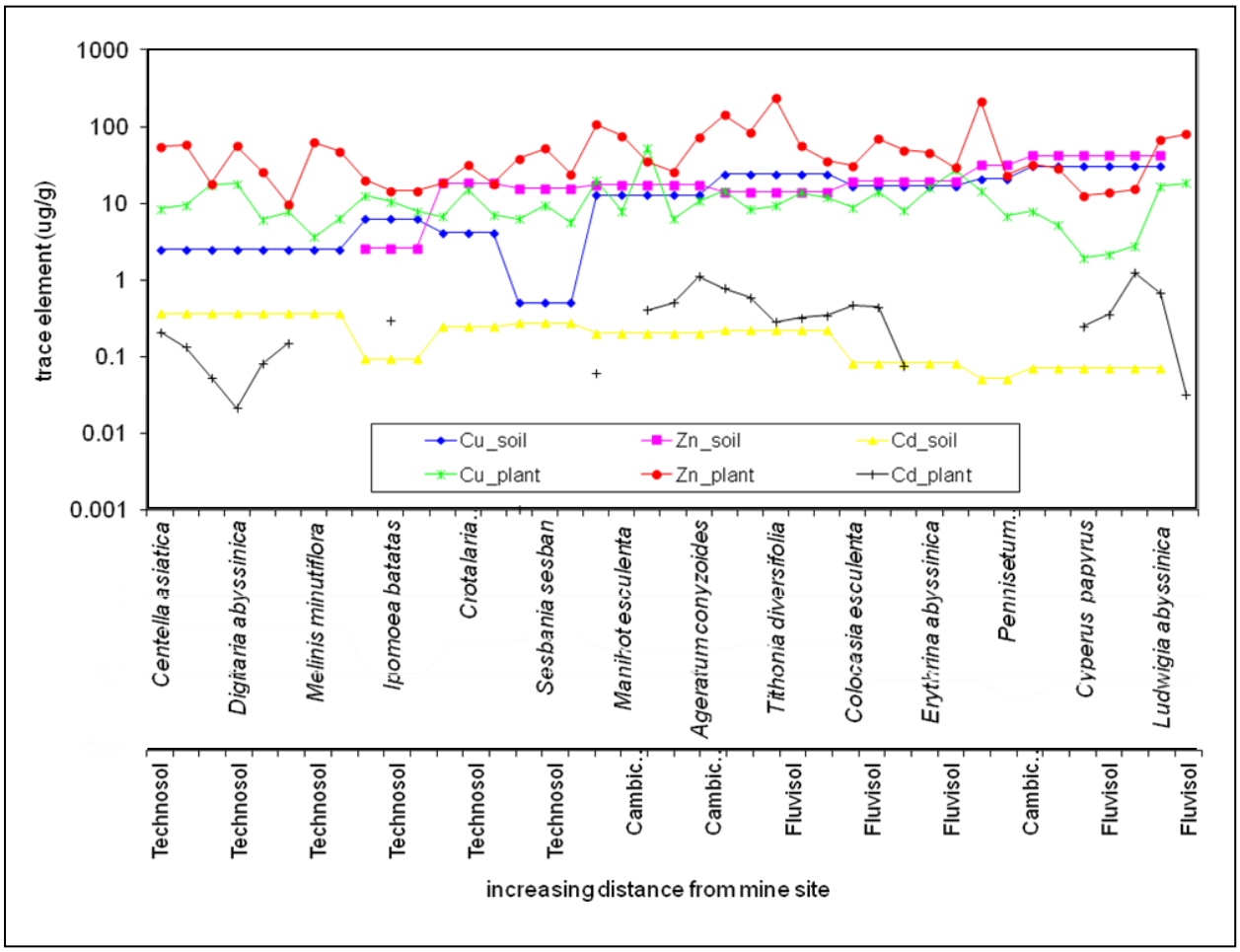

Figure 4. 15: Spatial distribution of selected trace elements in plants and soils at increasing distances from Ruhanga (mine site) to Birambo site during the rainy season

4.8.3 Findings on trace elements Translocation to plants

The translocation factors of trace elements to plant species analyzed were calculated using equation 3.4, and their TF values are shown in Table 4.10 above and in Appendix 7. It is to be reminded that transfer factors (TFs) are used for comparison of element behavior for its absorption by plant, with its partial elimination in the type of soil which contains it (Tlustoš *et al*., 2006)**.** As for Figure 4.16, it shows translocation factors of Cu, Zn, Cd, Pb, U and As trace elements in stems and leaves of selected plant species, namely *Melinis minutiflora, Digitaria abyssinica, Ageratum conyzoides L., Ipomoea batatas* and *Colocasia esculenta,* which were collected during the wet season. It was found that *Digitaria abyssinica* translocates all the analysed trace elements in its parts, with exception for Cu which cannot be translocated in the leaves. *Melinis minutiflora* translocates U, As, Cd and Zn in the leaves and only Cd and Zn in the stem. *Ipomoea batatas* translocates U, As and Cd in the leaves and

U, As and Zn in the stem. *Ageratum conyzoides L*. translocates only Zn in the leaves. *Colocasia esculenta* does not translocate any of the analysed trace elements within its parts, as illustrated in Figure 4.16 below.

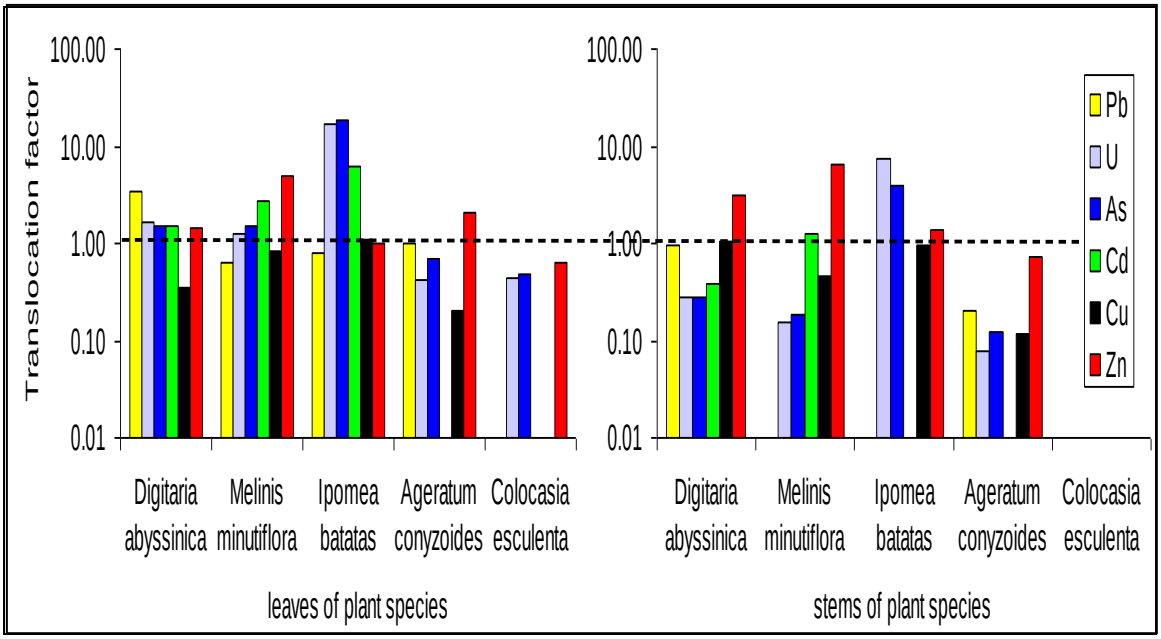

Figure 4. 16: Translocation factors of trace elements in stems and leaves of selected plant species during the wet season in Gatumba mining area.

The findings presented in Figure 4.17 below and in Appendix 7 are related to translocation factors values of minerals which are not heavy metals. These are Sb, Bi, Rb and Li, which were found to be translocated in stems and leaves of the five plant species, namely *Melinis minutiflora, Digitaria abyssinica, Ageratum conyzoides L., Ipomoea batatas* and *Colocasia esculenta,* which were collected during the wet season. It was observed that the storage of these minerals was mainly localized in the leaves of these plants.

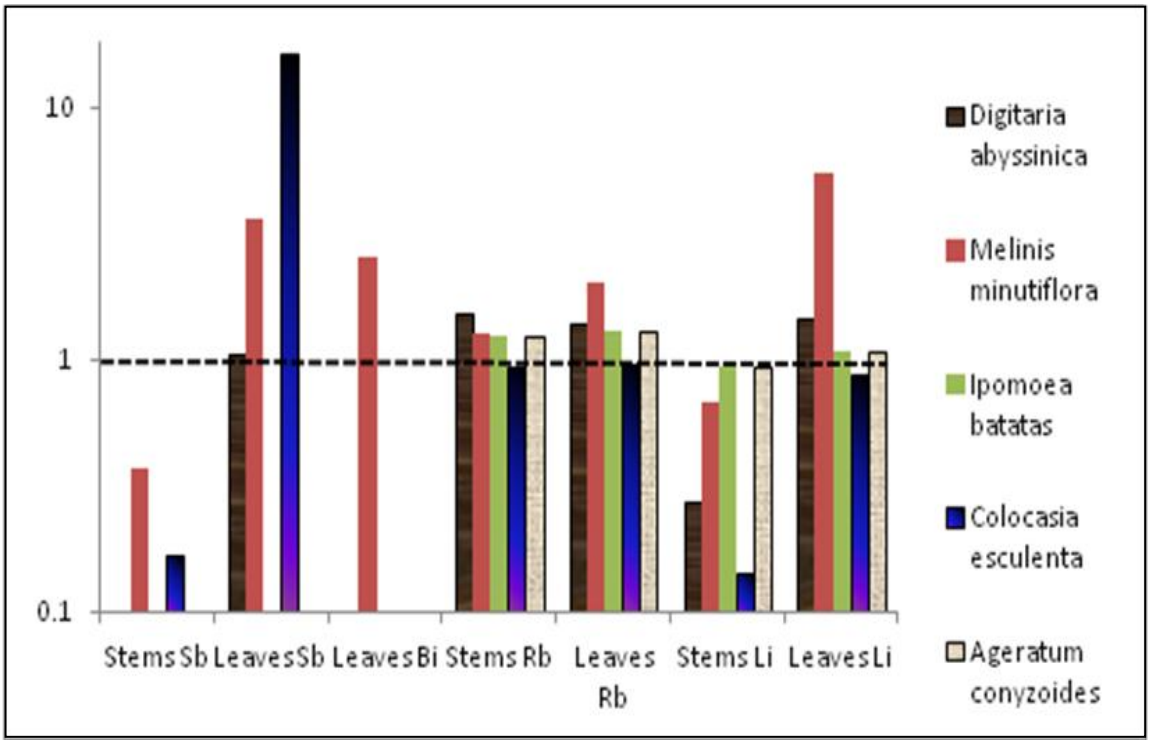

Figure 4. 17: Translocation factors of minerals in stems and leaves of five plant species during the wet season in Gatumba mining area.

4.9 Conclusion

A total of 20 transects were investigated in four sites identified in Gatumba mining area, and these are Ruhanga, Mpare, Rwasare, and Birambo sites. The sampling was conducted in August 2010 for dry season and in March 2011 for wet season. The main types of soils identified in Gatumba mining area included technosol on minespoil, technosol overlaying gleysol in pegmatite material, technosol without soil development, cambic fluvisol, and fluvisol, fluvisol covered by colluvium, strongly disturbed fluvisol and lixisol. Among the overall total of 102 plant species sampled in Gatumba mining area, there were 31 species, 23 genera and 6 families of monocotyledons representing 30,40%. As for dicotyledons, they included 69 plant species, 56 genera and 26 families, representing 65.69%. Gymnosperms and pteridophytes represented 0.98% and 2.94% respectively. The general finding indicated that trace elements show low concentration in plant parts; but with higher concentration of Li, Cu, Zn and Rb; and lower level of concentration for As, Cd, Cs, Pb and U. *Digitaria abyssinica* was found to be a dominant and a tolerant species within several soil types (like technosol and Fluvisol) and profiles. The Jaccard similarity index revealed that Gatumba vegetation is heterogeneous, while the Shannon diversity indices showed that the flora of

Gatumba mining area is diverisified. Some bioaccumulation factors of the analysed trace elements in plant parts were generally lower than the threshold 1, which is a characteristic of plant excluders. Others had BCF which was higher than 1.

CHAPTER 5: DISCUSSION OF RESULTS

5.1 Introduction

This chapter discusses the results on plant communities, types of soil as well as trace elements found in those plants and soils, which were presented in Chapter 4. Trace element concentration in dominant plant species are discussed in relation to their linkage with soil types and profiles. Key findings of the research study are compared with the literature review worldwide. Finally, recommendations are made for appropriate plant species to rehabilitate/restore the degraded soil in Gatumba mining area as well as proposals for further research in the region.

5.2 Discussion

5.2.1. Discussion on plant diversity

Among the dominant plant species identified in the study area, they vary according to the seasons. In this regard, the dominant species during the dry season (August 2010) were *Digitaria abyssinica* (HOCHST. ex A.RICH.) STAPF *(45.55*%), *Cyperus papyrus* L (42.79%), *Lantana camara* L. (22.24%), and *Polygonum pulchrum* BLUME (17.17%). As for the wet season (March 2011), the identified dominant plant species were *Digitaria abyssinica* (HOCHST. ex A.RICH.) STAPF (30.81%), *Leersia hexandra* SWARTZ (35.34%), *Polygonum pulchrum* BLUME (28.34%) and *Ageratum conyzoides* L (23.59%). From the list above, it is evident that two plant species appear in both the dry and wet season, and these are *Digitaria abyssinica* and *Polygonum pulchrum.* The first is a grass which colonises all types of soil. This corresponds to Kulakow *et al*.'s (2000) observation that grasses are predominant during all seasons due to their high level of adaptation to various ecological conditions. Their observation has been reported by stating that rooting system of grasses provides a large surface for soil contact and can stabilize the soil and favour their growth and development.

It was also found that the plant species developing during the dry season are different from the ones developed in the wet season. This state of affairs can reflect what Kulakow *et al*.

(2000) observed during the dry season that high temperatures enhance evapotranspiration that reduce soil moisture which normally favours seed germination.

In addition, *Polyscias fulva* (HEERN.) HARMS was identified as one of the rare plant species remaining in Gatumba mining area. This confirms Ndabaneze *et al*.'s (2008) finding that there is only one indigenous plant species, *Polyscias fulva* in the Gatumba mining area, which indicates that a forest may have existed in the area in the recent past but now it was destroyed by human activities.

Among the identified plant species, we found *Lantana camara* L., which is an invasive plant species. As Gatumba mining site undergoes an increasing concentration in trace elements, this may modify the natural soil composition and helps in the colonization by new plant species. This has been confirmed by Knops *et al.*(1999) when they observed that contaminated soils were more exposed to colonization by invasive plant species propagated easily by birds and with ability to grow on different type of soils due to loss of local biodiversity.

Currently, the study area is mainly cultivated and four plant communities characterize the area which is dominated by grasses and to a lesser spatial extent, by shrubs. Those categories of plant communities include dicotyledons (65.69%) with 68 plant species, monocotyledons (30.40%) with 31 plant species, pteridophytes (2.94%) and gymnosperms (0.98%). Ndabaneze *et al.* (2008) found the same categories of plants although their respective frequencies are relatively different from those found in the current study. In this study, the ratio of monocotyledons to dicotyledons is 1/2.2, which is similar to observations made in Platberg, South Africa where the ratio between the two plant categories was also 1/2.5 (Brand *et al*., 2007).

The study revealed that the investigated site is a disturbed area. This is manifested by the mixture of dominant plant families. In fact, Asteraceae (15%) was found to be dominant among dicotyledons while Poaceae (19.6%) was found to be dominant among monocotyledons. According to Ye *et al.* (2008) Gramineae and Compositae manifest universal high tolerances and adaptations to unfavorable conditions. The Poaceae family was

also reported by Shu *et al.* (2005) to be one of the colonizing vegetation in mine tailings with high metal concentration and low fertility.

Jaccard similarity indices calculated for Gatumba vegetation were less than 0.5, which characterise heterogeneous vegetation. This coefficient of 0.5 has been discussed by Gillet (2000) to distinguish heterogeneous and homogeneous vegetation. Such heterogeneous status represents the dissimilarity between Gatumba vegetation, and may be due to the variability of the types of soil and to the degree of soil degradation caused by mining activities, other human activities and other factors such as soil erosion. Furthermore, the Shannon diversity index calculated for Gatumba vegetation indicates that the flora is diversified. Such diversification might have resulted from the diversity of soils and human activities particularly diversified crops.

5.2.2 Variability of trace element concentration in plant species and soils

The study revealed that Gatumba mining area is made of about 8 different types of soils, including technosol on minespoil (P1 and P2), technosol overlaying gleysol in pegmatite material (P3), technosol without soil development (P4 and P5), cambic fluvisol (P10), fluvisol (P11), fluvisol covered by colluvium (P12), strongly disturbed fluvisol (P13) and lixisol (P14). Such a classification followed the international denominations of types of soils, that why it relied on names put forward by WRB (2006). The types of soils identified by this study for Gatumba mining area also confirm Reetsch's (2008) findings which mention that the types of soils found in Gatumba mining area are of tropical highlands.

As for physical characteristics of those types of soil, it was found that the mining area is mainly dominated by technosols which are acidic, poor in nutrients (like P, K, B, N and C) and with variable physical texture which is influenced by pH (pH of 4.4-6.4). Such acidic characteristic of soil implies that nutrients decrease accordingly; and this was demonstrated by Jones and Jacobsen (2001) and Reetsch (2008) when they stated that when pH decreases in the soil, the soil becomes poor in nutrients. An illustrating example is that P which is commonly known to be bioavailable to plants at soil pH of 5.5 to 7.5 (Figure 2.2). Our findings revealed that P is not bioavailable in investigated soils as the pH values in almost all these sites is below 5.5 (Table 4.7).

With regard to trace elements concentration in different types of soil identified, it was found that higher levels of concentration were for Li, Cr, Cu, Ni, Zn, Rb and Cs, while lower levels of concentration were for As, Cd, Sb, Pb, Bi and U. However, the discussion is limited to five trace elements whose indicators helped to identify the level of toxicity in the study area. Those trace elements are Cu, Zn, Cd, As and Pb and their concentration occurrence varies according to seasons. For Cu, its level of concentration in soil during dry season ranges from 2.41 to 38.12 µg/g; while in wet season, it ranges between 2.50 and 30.48 µg/g. For Zn, the level of concentration in soil during dry season ranges from 7.01 to 35.34 µg/g; while in wet season, it ranges from 2.58 to 41.80 µg/g. For As, the level of concentration in soil during dry season ranges from 1.76 to 10.71 µg/g; while in wet season, it ranges from 0.54 to 10.45 µg/g. For Cd, the level of concentration in soil during dry season ranges from 0.08 to 0.56 µg /g; while in wet season, it ranges from 0.08 to 0.36 µg/g. As for Pb, the level of concentration in soil during dry season ranges from 4.87 to 17.21 µg /g; while in wet season, it ranges from 3.62 to 14.11µg/g. If we compare the level of concentration in soil for the five trace elements mentioned above with the values indicating the level of soil toxicity put forward by Ross (1994), as indicated in Table 2.2, we can conclude that the level of concentration of the five trace elements in Gatumba soil does not reach the level of toxicity.

Concerning the trace element concentration in plants, the study revealed that the highest metal element concentration in plants was for Li, Cu, Zn and Rb; whereas the lowest level of concentration was for As, Cd, Cs, Pb and U. For Copper (Cu), the level of concentration in plant during dry season ranges from 2.5 to 43.92 µg/g; while in wet season, it ranges from 1.95 to 52.91 µg/g. Its concentrations in most of the dominant plant species identified varied with its more accumulation in shoots than in roots. This confirms Fernandes and Henriques's (1991) and Gardea-Torresdey *et al.*'s (2003) findings that chloroplasts are the main site for Cu accumulation in higher plants. Thus, Cu concentration found in the identified plants were low, meaning that plants were not contaminated by Cu because Cu toxicity for many plant species is about 30 mg/kg as demonstrated by Marschner (1995). However, it is to be mentioned that the hyperaccumulation of Cu is fixed at 1000 mg/kg for some hyperaccumulators plants, as demonstrated by Reeves and Baker (2000) as well as Zavoda *et al*. (2010).

For zinc (Zn), the findings have indicated that the level of concentration in plant during dry season ranged from 10.16 to 121.6 µg/g; while in wet season, it ranged from 9.49 to 236.41 µg/g. It was also revealed that a great amount of zinc is found in shoots and in leaves of all

plant samples. This confirms Hu *et al.*'s (2009) findings that the major storage site for Zn and Cd in plants is the cell wall of roots, vacuoles of epidermis and bundle sheath of leaves. Illustrating examples showing that the largest amount of Zn is accumulated in aerial parts of plants are *Tithonia diversifolia* which accumulates Zn in stems (Zn=141.84 µg/g) and in flower (236.41 *µg/g)* and *Ageratum conyzoides L.* in leaves (Zn=72.79 *µg/g*). The findings show that there is no Zn toxicity in plants. This conclusion was drawn in comparison with Kbata-Pendias and Pendias's (1986) statement that Zn is an essential trace element in plants in normal sufficient amounts of 27-150 mg/kg in plant tissue (dry weight), 400 mg/kg being considered as toxic (Table 2.3). Moreover, according to Maestri *et al*. (2010), the average range of Zn in plant tissues is fixed to 15-150 mg/kg dry weight, which confirm that the Zn concentration in plant tissues in our study area are normal. Other dominant plant species which accumulate Zn are *Phytolacca dodecandra* (62.25 µg/g) in leaves, *Sesbania sesban* (51.75 µg/g) in leaves, and *Digitaria abyssinica* (55.94 µg/g) in stems.

For Cd, the findings have indicated that the level of concentration in plant during dry season ranged from 0 to 1.25µg/g; while in wet season, it ranged from 0.02 to 1.24µg/g. It is therefore evident that Cd concentration in plant is low, which means that there is no plant toxicity, according to Anderson *et al.* (2004) who confirm that Cd has some toxic effects on plants when its concentration values range betweeen 5 and 20 ppm. However, Kabata-Pendias and Pendias (1986) suggest that higher Cd mobility leads to translocation of Cd on the the tips of the plant as illustrated in Figure 2.4.

As the findings indicate that Zn and Cd are found in the same plant species, they can be in competition. In this regard, Babula *et al.* (2008) states that the similarity of certain trace metals to essential heavy metals (specifically Cd–Zn couples) is the origin of their high toxicity due to the possibility for one particular element to replace essential metals in enzymatic systems. Gardea-Torresdey *et al.* (2003) state that the possible explanation for high Cd levels in plants could be found in the competition of Cd with Zn for the same organic molecule compounds (ligand) inside the plants. As effect of such a competition, Lagerwerff and Biersdorf (1972) and Das *et al*. (1997) indicate that this competition causes various changes in biological activities, such as a reduction in photosynthetic content as well as a reduction in Calcium uptake. Arogunjo (2007) adds that Cd particles in the air can travel long

distances before falling to the ground or water, and Cd stays in the plant body for a very long time. Zhao *et al.* (2002) has also reported that Cd has rare hyperaccumulation.

For Pb, the level of concentration in plant during dry season ranged from 0.21 to 1.91 µg/g; while in wet season, it ranged from 0.09 to 30.16 µg/g. It is observed that the level of concentration tends to toxicity during the wet season, since it reaches the threshold range of 30 to 300 ppm suggested by Kabata-Pendias and Pendias (1986). It is to be clarified that high concentration of Pb (30.16 µg/g) was found in the flower of *Cyperus papyrus*, but it was low in other parts of all plants investigated. The possible explanation for their lower occurrence in plant parts would be the unavailability of Cd and Pb, due to their high affinity to organic matter, as observed by Kabata-Pendias and Pendias (1991); Strawn and Sparks (2000); McBride (2001); Nigam *et al.* (2001) and Merritt and Erich (2003).

For As, the level of concentration in plant during the dry season ranged from 0.02 to 0.23 µg/g; while in wet season, it ranged from 0.01 to 0.75 µg/g. Thus, its level of concentration is low, implying that there is no toxicity for this trace element, as it does not reach the threshold range of 5 to 20 ppm suggested by Kabata-Pendias and Pendias (1986).

Regarding the distribution of trace elements in top soil of the four sites constituting Gatumba mining area, three salient trace elements, namely Cu, Zn and Cd, are discussed. For Cu and Zn, the findings indicate that there is slight increase from Ruhanga towards Birambo site, crossing Rwasare and Mpare sites. However, there is a slight decrease of Cd concentration in soils from dry to wet seasons. These variations of levels of trace element concentration in soils are similar to the levels of trace elements concentration which were reported by Escarré *et al. (*2011) for "Les Malines and Les Avinières" areas located in France. Escarré *et al*. (2011) further noted that the mining activities generate spoils and effluents with extremely high concentrations of trace metals deposited into the soil at variable concentrations from a mining site downwards.

As for the distribution of trace elements in plants, the higher the trace element concentrations for Zn, Cd and Cu in the soil, the higher their concentration in plants. This is because they are highly mobilised within plants as demonstrated by Kabata-Pendias and Pendias (1986). In different plant parts investigated, Zn, Cd and Cu were found to be more concentrated in plant tissues than in other parts of the plant and this concentration depends on elements that occur in the soil as reported by Adriano (2001). Other observations from Malaisse *et al*. (1999) and

Strandberg *et al*. (2006) indicate that plant trace element concentration vary with the severity of soil trace element levels, the type of plant families as well as the plant species which induce dynamic changes in vegetation. Illustrating examples from this study are *Centella asiatica* (Apiaceae), *Digitaria abyssinica* (Poaceae) and *Crotalaria dewildemaniana* (Fabaceae) which grow on technosols in the vicinity of Ruhanga site, whereas *Cyperus papyrus* (Cyperacaeae), *Ludwigia abyssinica* (Onagraceae) and *Polygonum pulchrum* (Polygonaceae) grow on fluvisol in Birambo site, during both seasons.

5.2.3 Plant bioaccumulation and tolerance to trace elements

The findings indicate that the spatial distribution of selected trace elements (Cu, Zn and Cd) that are bioaccumulated in plant parts shows a slight seasonal decrease in concentration between the dry and wet seasons. This is a manifestation of the flushing and dilution effect of the rains which reduces the concentration of bioavailable elements in soils uptaken by plant roots.

In this study, Cu is mainly accumulated in *Centella asiatica* with (BCF_{cu} =3.26) especially in shoot during the dry season and in leaves (BCF_{cu} =3.76) during the wet season. Zn is mainly accumulated in *Ageratum conyzoides L.,* especially in shoot *(BCF_{Zn} =6.77)* during the dry season and in leaves (BCF_{Zn} =4.19) during the wet season. Cd is mainly bioaccumulated by the dominant species of *Cyperus papyrus* L. with (BCF_{Cd} = 3.57) in leaves, *Ageratum conyzoides L.* in leaves *(BCF_{Cd} =2.49)* during wet season, while *Ageratum conyzoides L.* in shoot *(BCF_{Cd} =9.39)* during dry season. *Tithonia diversifolia* in leaves *(*BCF_{Cd}*=5.97)* during wet season, and *Ludwigia abyssinica* in stems *(BCF_{Cd}=1.64)* during wet season.

For other plants investigated, Rubidium bioaccumulation was noted in *Crotalaria dewildemaniana* with (BCF_{Rb} =2.08*)* in stem during wet season*; Centella asiatica* with (BCF_{Rb} =2.90) in stem during wet season; and *Erythrina abyssinica* with (BCF_{Rb}=1.82) in stem during wet season, as described in appendix 7. These results show that many plant species found in the study area are accumulators for some of the selected metals.

The study findings include 7 plant families, namely Asteraceae, Cyperaceae, Convolvulaceae, Fabaceae, Lamiaceae, Poaceae and Euphorbiaceae which are found in the four sites of Gatumba mining area and at the same time being included in the list of 101 plant families making up 500 plant species of hyperaccumulators identified worldwide by Sarma *et al.* (2011). According to Xian and Shokohifard (1989); Otte *et al*. (1993); Barman *et al*. (2001)

and Spinoza-Qinones *et al*. (2005) hyperaccumulation of trace elements depends on the plant species, the soil conditions (like pH, organic matter content, and cation exchange capacity) and the types of trace metals.

In Gatumba mining area, two plant categories were distinguished among the list of plant species identified. Those two categories were selected using bioaccumulation factors of all trace elements analysed. The first category is characterised by plant accumulators (BCF>1) for some trace elements (like Cd, Cu and Zn) and the second category is made up of plant excluders (BCF<1) of trace elements (like Rb, Sb, Bi, As, U, and Pb).

The findings showed that most plants collected do not tolerate or accumulate high Arsenic (As) contents into their plant tissues. It was also found that the lowest accumulation of As in plant parts identified is seen in *Tithonia diversifolia*, *Crotalaria dewildemaniana* and *Pennisetum purpureum* and these plants can be considered as excluders.

As for Cs, the findings showed that it was not tolerated by plants as indicated by the very low concentration values in plants compared to the soil concentrations. In fact, our findings show that the Cs concentration range in the soil was 4.37-45.95 µg/g during dry season and 3.52-46.05 µg/g in wet season. The low concentration values for this element are especially evident in *Melinis minutiflora* with Cs of 0.794 µg/g in stems, *Digitaria abyssinica* with Cs of 0.773 µg/g in stems, and *Ageratum conyzoides L* with Cs of 0,442µg/g in stems. Those weak concentrations of Cs in plants have been observed in both dry and wet seasons in Gatumba mining area.

For Pb, Baker *et al*. (2000) indicate that it is not accumulated in plant aerial parts. The threatening values for the hyperaccumulation of Pb are fixed at 1000 mg/kg. Thus, low Pb accumulation is shown by *Phytolacca dodecandra, Erythrina abyssinica* and *Ludwigia abyssinica* where Pb are below instrument detection limits. Therefore, Lead is almost unavailable to plants due to its low solubility and strong interactions with soil particles (Nriagu and Pacyna, 1988).

For U, the highest concentration was found in leaves for many plant samples despite having very low bioaccumulation values. There were plant species which could accumulate U in their tissues but some species of Poaceae, Asteraceae, Apiaceae and Convolvulaceae seemed to store it in traces during rainy periods. Low storage was found for example in *Melinis minutiflora* with 0.278µg/g of U storage; *Ageratum conyzoides* with 0.085 µg/g of U;

Centella asiatica with 0.08 µg/g of U; and *Ipomoea batatas* with 0.102 µg/g of U stored in their leaves.

As for Li, it was mostly abundant in Technosols especially in Ruhanga sites where Fabaceae, Poaceae, Convolvulaceae and Asteraceae showed a great concentration of Li in their tissues. According to Bingham, *et al*. (1964), lithium-tolerant plants, such as cotton, red beets, and Rhodes grass, accumulate larger amounts of lithium. Among the findings, no plant sampled were true excluders for Li because all plant sampled and analyzed had very low concentration of Li in their tissues. High translocation factors were found in leaves of species for certain families of Poaceae (*Digitaria abyssinica* with TF_{Cd} of 1.51), Asteraceae (*Ageratum conyzoides* with TF_{Cd} of 2.74) and Convolvulaceae (*Ipomoea batatas* with TF_{Cu} of 1.08). In this regard, Antonovics *et al.* (1971) indicate that trace elements tolerance has been demonstrated in many families of vascular plants throughout the world.

For Bi, Babula *et al. (*2008) observed that it is an uncommon trace element that chemically resembles As and Sb. The lowest bioaccumulation for Bi in Gatumba mining area is realized in *Cyperus papyrus*, *Tithonia diversifolia* and *Polygonum pulchrum.* Li and Thornton (1993) and Babula *et al*. (2008) indicated that pH seems to be a very important factor for Bi uptake from soil containing trace elements.

As for translocation factors (TF), they were calculated for only five plant species during the wet season. Zn is the most translocated trace element in both leaves and stems of the five plant species (*Melinis minutiflora, Digitaria abyssinica, Ageratum conyzoides L*., *Ipomoea batatas* and *Colocasia esculenta*) because $TF_{Zn}>1$. Zn and Cd are better translocated to leaves than to stems since their TF>1, particularly in *Ipomoea batatas. Colocasia esculenta* does not tolerate any of the trace elements analysed because TF of those trace elements are less than 1. According to Tlustós *et al*. (2006), the knowledge of transfer factor of different trace elements is used to compare the type of soil with the plants which grow and develop on that soil**.** Thus, the trace elements present in soil are selectively absorbed by plants growing in that area as shown by model of relative uptake and bioaccumulation potential proposed by Adriano (2001).

5.3 Conclusions

The study revealed that the current vegetation in Gatumba mining area is made of grasses with dispersed shrubs where four categories of plants were represented (Dicotyledons, monocotyledons, pteridophytes and gymnosperms. Gatumba vegetation is heterogeneous according to Jaccard similarity index, but plant species are diversified as shown by the Shannon index. For the plant communities in Gatumba mining area, it was observed that the area has been deforestated, which led to the colonization of the wasteland by new adapted plant species.

Gatumba mining area has technosol on minespoil, technosol overlaying gleysol in pegmatite material, technosol without soil development, cambic fluvisol, fluvisol, fluvisol covered by colluvium, strongly disturbed fluvisol and lixisol. The mine area is mainly dominated by technosols which are acidic, with low nutrients (like P, K and C) and a variable physical texture. The highest metal element concentration in soil are Rb, Li, Cr, Cs, Zn, Ni and Cu, whereas Pb, As, U, Bi, Cd and Sb showed the lowest concentration. Some trace elements (like Cu, Zn, As and Pb) show an increase in concentration with distance from mining site. There is also a slight seasonal decrease in trace element concentration (like Cd) in soils from dry to wet seasons. Trace element concentrations in plant parts are variable depending on the plant species and their tolerance towards the trace elements present in the soil. Apiaceae and Poaceae plant families are developed on technosols that are close to the mine site, whereas Cyperacaeae, Onagraceae and Polygonaceae plant families are developed on fluvisol that are close to the Nyabarongo River in Birambo site during the dry season, but have Cyperaceae and Onagraceae families growing on fluvisols in the wet season. No toxic concentration was found in Gatumba for any trace element.

Bioaccumulation factors of analysed trace elements in plant parts were generally low ($BCF<1$), except for Cd, Cu and Zn which are relatively highly accumulated ($BCF>1$). The spatial distribution of selected trace elements (Cu, Zn and Cd) that are bioaccumulated in plant parts show a slight seasonal decrease in concentration between the dry and wet seasons.

Gatumba mining area shows two plant categories in terms of bioaccumulation. The first category consists of plant accumulators for trace elements (like Cd, Cu and Zn) and the second category is made up of plant excluders of trace elements (like Rb, Sb, Bi, As, U, and

Pb). Cu is mainly accumulated by *Digitaria abyssinica, Crotalaria dewildemaniana, Sesbania sesban,* and *Centella asiatica.* Zn is mainly accumulated by *Tithonia diversifolia, Ageratum conyzoides, Phytolacca dodecandra, Sesbania sesban,* and *Digitaria abyssinica.* Cd is mainly accumulated by *Cyperus papyrus, Ageratum conyzoides, Tithonia diversifolia,* and *Ludwigia abyssinica.* Most of the plant species, like *Crotalaria dewildemaniana, Centella asiatica* and *Erythrina abyssinica* showed Rb bioaccumulation

Concerning plant excluders, the lowest bioaccumulation of As in plant parts is shown by *Tithonia diversifolia, Crotalaria dewildemaniana* and *Pennisetum purpureum* (Appendix 7*).* Cs has low values especially in *Melinis minutiflora, Digitaria abyssinica,* and *Ageratum conyzoides.* Low Pb accumulation is shown by *Phytolacca dodecandra, Erythrina abyssinica* and *Ludwigia abyssinica.* No plant species analyzed bioaccumulated U in their tissues. No plant species were true excluders of Li since all plant samples had very low concentration in their tissues. The lowest Bi bioaccumulation was observed in *Cyperus papyrus, Tithonia diversifolia* and *Polygonum pulchrum.* All the identified plants excluded Sb especially *Polygonum pulchrum, Tithonia diversifolia* and *Centella asiatica (*Appendix 7).

Zn was the most translocated trace element in both leaves and stems of the five plant species (*Melinis minutiflora, Digitaria abyssinica, Ageratum conyzoides, Ipomoea batatas* and *Colocasia esculenta*). Zn and Cd are better translocated to stems particularly for *Ipomoea batatas* (Fig. 4.16). Thus, based on Zehra *et al*.'s (2009) observation, the plant species having trace element resistance may be a better choice in revegation and the plants that are already growing on a soil contaminated with specific trace elements can be a better choice due to their tolerance.

In regard to the above-mentioned considerations, the most useful plant species for the revegetation/restitution of Gatumba mining area should be *Sesbania sesban, Crotalaria dewildemaniana* and *Tithonia diversifolia* because they have capacity to bioaccumulate and tolerate most of the highest trace element concentrations. The study verified and confirmed the stated hypotheses, which are the following:

- Plant communities in Gatumba mining area are characteristic and related to the soil mineral composition.
- Trace elements uptake depends on the type of soil and plant species.

- The vegetation of Gatumba mine site has natural sensitivity to the accumulated trace elements.

5.4 Recommendations

In order to contribute to the rehabilitation of the degraded Gatumba mining area in regard to the conservation, protection and management of the vegetation, this study proposes the following recommendations:

- All mining companies should prepare and implement a rehabilitation programme after the mining activities as it is required by the Rwandan Law;
- Local administration and population should be involved in the management of the rehabilitation programme;
- The rehabilitation programme should take into consideration local plant species or if needed introduce adapted plant species such as those suggested by the actual study;
- A buffer zone needs to be created between mining area and residential places, this will facilitate conservation and reclamation activities in these areas;
- Local administration and NGOs should encourage establishment of new activities other than mining activities to generate income so as to reduce pressure on land.

LIST OF REFERENCES

Adriano DC 2001: *Trace elements in terrestrial environments*. Biogeochemistry, bioavailability and risks of metals. Books google. Com. Accessed date: 16/10/2010.

Adriano DC 1986: *Trace elements in the terrestrial environment*. New York, Springer, Pp.533.

Kabata-Pendias A 2001: *Trace Elements in Soils and Plants*. 3rd edition, New York, CRC Press.

Alloway BJ 1990: *Heavy metals in soil*. New York, Wiley and Sons.

Anderson AK, Raulund-Rasmussen K, Strobel BW and Hansen HCB 2004: The effect of tree species and site on the solubility of Cd, Cu, Ni, Pb and Zn in soils. *Water Air Soil Pollution.* 154, 357-370.

Antonovics J, Bradshaw AD and Turner RG 1971: Heavy metal tolerance in plants. *Advances in Ecological Research.* 7, 1-85.

Arogunjo AM 2007: Heavy metal composition of some solid minerals in Nigeria and their health implications to the environment. *Biology Sciences*. 10, 4438-4443.

Asherc J and Reay PF 1979: Arsenic uptake by barley seedlings. *Plant Physiology.* 6, 459-466.

Babula P, Vojtech Adam Æ, Radka Opatrilova Æ, Josef Zehnalek Æ, Ladislav Havel Æ and Rene Kizek Æ 2008: Uncommon heavy metals, metalloids and their plant toxicity. *Environment Chemistry Letter*. 6, 189–213.

Baker AJM, McGrath SP, Reeves RD and Smith JAC 2000: Metal hyperaccumulator plants: a review of the ecology and physiology of a biochemical resource for phytoremediation of metal-polluted soils. In N. Terry and G. Bañuelos (Eds.), *Phytoremediation of Contaminated Soil and Water. Pp. 85–107.*

Baker AJM, Reeves RD and Hajan ASM 1994: Heavy metal hyperacculation and Tolerance in British population of the metalophyte *Thlaspi caerulescens*. *New Phytologist*. 127, 61-68–567.

Baker AJM and Walker PL 1989: Ecophysiology of metals uptake by Tolerant plants in heavy metals tolence in plants. *Boca Raton, Plant science.* Pp. 155-177.

Baker AJM 1981: Accumulators and excluders strategies in the response of plants to heavy metals. *Plant Nutrition*. 3, 1–4.

Baker AJM 1987: Metal tolerance. *New Phytologist*. 160, 93-111.

Barman SC, Kisku GC, Salve PR, Misra D, Sahu RK and Ramteke PW 2001: Assessment of industrial effluent and its impact on soil and plants. *Environmental Biology*. 22, 251-256.

Becker AJM, Reeves RD and Hajar ASM 1994: Heavy metal accumulation and tolerance in British population of the metallophyte. *Thlaspi caerulensces* J. and Prsl. *New Phytologist*. 127, 61-68.

Bednar AJ, Medina VF, Ilmer-Scholle DS, Frey BA, Johnson BL, Brostoff, W.N and Larson SL 2007: Effects of organic matter on the distribution of uranium in soil and plant matrices. *Chemosphere*. 70, 237-247.

Biggelaar DC 1996: Farmer Experimentation and Innovation. A case study of knowledge generation processes in agroforestry systems in Rwanda. Food and Agricultural Organization of the United Nations, Community Forestry, Case Study Series, 12.

Bingham FT, Paige AL and Bradford GR 1964: *Toxicity of Lithium to plants*. Californ Agriculture Report, USA.

Boyd RS 2004: Ecology of metal hyperaccumulation. *New Phytologist.* 162, 563-567.

Brady N and Weil R 2002: *The nature and properties of soils*. 13th ed. New Jersey, Upper Saddle River, Pearson Education, Pp. 960.

Brand RF 2007: Phytosociology of Platberg mountain, eastern Free State, South Africa', PhD thesis, University of the Free State.

Braun Blanquet J 1934: *Plant sociology*. New York. Reprinted in 1966.

Brooks RR 1998: *Plants those hyperaccumulate heavy metals*. UK, CAB Intern.

Brow SL, Chaney RL, Angle JS and Baker AJM 1994: Phytoremediation potential of *Thlaspi caerulescens* and bladder campion for zinc- and cadmium-contaminated, *Environmental Quality*. 23, 1151-1157.

Bucagu C 2007: *Mining activity and Agriculture in Muhororo*. Butare: National University of Rwanda.

Byiringiro V and Biryabarema M 2007: Geomorphologic Processes in Gatumba Mining Area, Butare. *Études Rwandaises*.

Calvin and Hamilton R 2008: Information adapted from "Minerals in Your World", a cooperative effort betweeen the U.S. Geological Survey and the Mineral Information Institute.

C.A.S.M 2008: Communities and artisanal and small-scale mining (CASM). A global partnership for action. Accessed date: 8/ 6/ 2011.

Cataldo DA and Wildung RE 1978: Soil and Plant factors influencing the Accumulation of heavy metals by plants. *Environment Health Perspectives*. 27, 149-159.

Casado M, Anawar HM, Garcia-Sanchez A and Regina IS 2007: Antimony and arsenic uptake by plants in an abandoned mining area. *Soil Science and Plant Analysis*. 38, 1255–1275.

Chemonics International Inc. 2003: Rwanda Environmental Threats and Opportunities Assessment. Report for USAID. Rwanda.

Das P, Samantaray S and Rout GR 1997: Studies on cadmium toxicity in plants: a review. *Environmental Pollution*. 98, 29–36.

Davey BG and Wheeler RC 1980. Some aspects of the chemistry of lithium in soils, *Plant Soil*. 5, Pp.49.

Davis ND, Stoker DG, Windsor DE, Ashcroft MT, Coburn MC and Andrews WA 1973: Field and laboratory studies.*In:* A guide to the study of soil ecology. (ed. Andrews WA), Prentice Hall of Canada, Ltd. Pp. 101-102.

Deuel LE and Swoboda AR 1972: Arsenic toxicity to cotton and soybeans. *Environmental.Quality*. 13, 17-320.

Dewaele S 2007: Geology and mineralization of the Gatumba area, Rwanda (Central Africa). Report on Coltan Project Meeting in Kigali.

Dietz KJ, Baier M and Krämer U 1999: Free radicals and reactive oxygen species as mediators of heavy metal toxicity in plants. In: Prasad MNV, Hagemeyer J, eds. Heavy metal stress in plants: from molecules to ecosystems. *Berlin: Springer-Verlag, 73–97.*

DVWK 1988: (Deutscher Verband für Wasserwirtschaft und Kulturbau e.V.) (Hrsg.) zur Wasserwirtschaft, 212, Hamburg und Berlin (German Association for Water and Wastewater).

Ebbs SD, Brady DJ and Kochian LV 1998: Role of uranium speciation in the uptake and translocation of uranium by plants. *Experiment Botany*. 49, 1183-1190.

Escarré JC, Lefèbvre S, Raboyeau A, Dossantos W, Gruber JC, Cleyet M, Frérot H, Noret N, Mahieu S, Collin C and Folkert van Oort 2011: Heavy Metal Concentration Survey in Soils and Plants of the ‘ Malines Mining District’ (Southern France): Implications for Soil Restoration.*Water Air Soil Pollution. 11270*, 010 - 0547.

Farrah H and Pickering W 1978: The sorption of mercury species by clay minerals, *Water Air Soil Polluion.* 9, Pp.23.

Faostat 2007: Statistics by Food and Agriculture Organization of the United Cations Report. Accessed date: 12/12/2010.

Fetherston 2004: International Tantalum Resources – Exploration and Mining.Mineral Resources Bulletin 22 Geological Survey ofWestern Australia, Department of Industry and Resources, Perth, Australia. Accessed date: 10/12/2010.

Fernandes JC and Henriques FS 1991: Biochemical, physiological and structural effects of access copper in plants. *Botanical Review. 57, 246-273.*

Fischer E 1997: *Vegetation on Rwanda:* Zur Biodiversität und Ökologie eines zentralafrikanischen Landes. Akademie der Wissenschaften under Literatur, Mainz, Germany.

Fischer and Killmann 2008: Illustrated field guide to the plants of Nyungwe National Park, Kigali, (ISBN 978.3.941326.00.2).

Gardea-Torresdey, Peratla-Videa JR, Montes M, G de la Rosa and Corral-Diaz B 2003: Bioaccumulation of Cadmium, chromium and Copper by *Convolvulus arvensis* L. Impact on plant growth and uptake of nutritional elements. *Bioresource Technology*. 92, 229-235.

Mining Geology Department of Rwanda 2006: Annual Raport annuel on the economic growth of Rwanda. Kigali, Rwanda.

Gillet F 2000: La *phytosociologie synusiale intégrée: guide méthodologique* [1]. Document du laboratoire d'écologie végétale et de phytosociologie, Neuchâtel : Université de Neuchâtel.

Gisenyi meteorological center 2010: Annual Report of meteorological data. Kigali. Rwanda.

Greene D 1993: Interim report on Effects of lead on the environment. Lead Education ans abatement Design.

Habiyaremye MK 1995: *Etude Phytocenologique de la dorsale orientale du Lac Kivu*[2]. Faculté des Sciences. Bruxelle: Université Libre de Bruxelle.

Hu PJ, Qiu RL, Senthilkumar P, Jiang D, Chen ZW, Yang YT and Liu FJ 2009: Tolerance, accumulation and distribution of Zinc and Cadmium in plant hyperaccumulator Potentilla griffithii. *Environmental and Experimental, Botany. 66, 317-325.*

Hussain F 1989: *Field and Laboratory Manual of Plant Ecology*. Islamabad: University Grants Commission.

[1]: *Integrated synusial phytosociology: methodological guide*
[2]: *Phytocenological study of the eastern line of Kivu Lake*

IRIN 2002: United Nations office for the coordination of Humanitarian affairs-Integrated Regional Information Networks.Two groups critical of Coltan mining in the east Democratic Republic of Congo. Accessed date: 10/12/2010.

Institute for Security Studies 2008: Report of Institute for Security Studies (ISS). Accessed date: 10/08/2010.

Jaccard P 1908: Nouvelles recherches sur la distribution florale. Bull. Soc. Vaudoise, *Science Naturelle*. 44, 223-270.

Jackson MA 1962: *Soil Chemical Analysis*. London: Constable and Co, Ltd.

Jones SB and Luchsinger AE 1987: *Plant Systematics*. 2nd ed. Singapore: McGraw-Hill.

Kabata-Pendias, A and Pendias, H 1991: *Trace Elements in Soils and Plants,* 2nd ed. Florida, CRC Press.

Kabata-Pendias A and Pendias H 1986: *Trace elements in soils and plants*. Florida, CRC Press, Inc. Boca Raton.

Kamal M, Ghalya AE, Mahmouda N and Côté R 2003: Phytoaccumulation of heavy metals by aquatic plants. *Environment International*. 29, 1029-1039.

Knops JMH, Tilman D, Haddad NM, Naeem S, Mitchell CE, Haarstad J, Ritchie ME, Howe KM, Reich PB, Siemann E and Groth J 1999: Effects of plant species richness on invasion dynamics, disease outbreaks, insect abundances and diversity. *Ecology Lett.* 2, 286–293.

Koptsik S, Koptsik G, Livantsova S, Eruslankina L, Zhmelkova T and Vologdina Z 2003: Heavy metals in soils near the nickel smelter: chemistry, spatial variation, and impacts on plant diversity. *Environment Management.* 5, 441–450.

Kovach WL 1993: Multivariate techniques package statistic (MVSP) for biostratigraphical correlation. London. *Journal of the Geological Society*. 150, 697-705.

Kovalevskii AL 2007: Radium in plants as prospectingfeature of uranium ores Siberian Branch of the Russian Academy of Sciences, Ulan-Ude, Russia. Accessed date: 10/9/2011

Kulakow PA, Schwab AP and Banks MK 2000: Screening Plant species for growth on weathered, petroleum hydrocarbon*contaminated sediments. *International Journal of Phytoremediation*. 2, 297-318.

Lagerwerff JV and Biersdorf GT 1972: Interaction of Zinc with uptake and translocation of cadmium in radish. *New Phytologist*. 5, 512-515.

Läuchli A and Epstein E 1970: Transport of Potassium and Rubidium in Plant Roots, The Significance of Calcium. *Plant Physiology*. 45, 639–641.

Lehmann BF, Melcher M, Sitnikova J and Ruzindana 2008: The Gatumba rare metal pegmatites: chemical signature and environmental impact. *Études Rwandaises.* 16, 25-40

Leo M, Walsh Malcolm, Sumner E, Dennis R and Keeney 1977: Occurrence and distribution of arsenic in soils and plants. *Environmental Health Perspective.* 19, 67–71.

Levetin E and McMahon K 1999: *Plants and Society*, 2nd Edition. Tulsa: Univerty of Tulsa.

Li XD and Thornton I 1993: Arsenic, antimony and bismuth in soil and pasture herbage in some old metalliferous mining areas in England. *Environmental Geochemistry Health.* 15, 135–144.

Macnair MR, Tilstone GH and Smith SE 2000: The genetics of metal tolerance and accumulation in higher plants. In: Terry N, Banuelos G, eds. *Phytoremediation of contaminated soil and water. CRC Press, LLC, 235–250.*

Maestri E, Marmiroli M, VisiolI G and Marmiroli N 2010: Review on Metal tolerance and hyperaccumulation: Costs and trade-offs between traits and environment. *Environmental and Experimental Botany. 68, 1–13.*

Magma Coltan, 2012: Will The Price Of Tantalum Remain Stable? http://www.magmacoltan.com. Website accessed: 10th September 2012.

Malaisse F, Baker A and Ruelle S 1999: Diversity of plant communities and leaf heavy metal content at Luiswishi copper/cobalt mineralization, Upper Katanga, Dem. Rep.Congo. *Biotechnol Agronomic Social Environment.* 3, 104–114. Accessed date: 12/10/2010

Marschner H 1995: *Mineral nutrition of higher plants*. London: Academic Press.

Martens DC and Westermann 1991: *Fertilizer applications for correcting micronutient deficiencies*. Micronutrients in agriculture. 2nd edition. Madivon: SSSA. WI.

Martin RF and Cerny P 1992: Granitic pegmatites.*Canadian Mineralogist*. 30, 499-954.

Mattina MJI, Lannucci- Berger W, Musante C and White JC 2003: Concurrent plant uptake of heavy metals and persistent organic pollutants from soil. *Environmental Pollution, 124, 375-378.*

McBride MB 2001: Cupric ion activity in peat soil as a toxicity indicator for maize. *Environmental Quality*. 30, 78-84.

Miltmore JE and Mason JL 1971: Copper to molybdenum ratios and molybdenum and copper concentrations in ruminant feds. *Can. J. Animal Science*. 51, 193-200.

Merritt KA and Erich MS 2003: Influence of organic matter decomposition on soluble carbon and its copper-binding capacity. *Environmental Quality*. 32, 2122-2131.

MINAGRI 2009: Joint Sector Review for the Agriculture Report. Ministry of Agriculture end Animal Resources. Kigali, Rwanda.

Mingorance MD, Valde´B and Rossini Oliva S 2007: Strategies of heavy metal uptake by plants growing under industrial emissions. *Environmental International. 3, 514–520.*

MINITERE 2006: National adaptation programme of action to climatechange. Minisry of Lands, Environment, Forestry, Water and Mines (MINITERE). Kigali, Rwanda.

MINITERE 2003: Report, National Strategy and Action Plan for the Conservation of Biodiversity in Rwanda.

Mouton J 2001: *How to succeed in your Master's and Doctoral studies*. A South Africa Guide and Research Book. Pretoria. Van Schaik.

Ndabaneze P, Muhongere C and Habarugira I 2008: Sustainable Restitution/Recultivation of artisanal Tantalum Mining wastelands in Central Africa: Gatumba flora and vegetation study. Mining Wetland in central Africa *Études Rwandaise 1*.45-47.

Ndagijimana S 2006: Plan d'action Hopital Muhororo at Gatumba sector. Ngororero-Rwanda.

Nigam R, Srivastava S, Prakash S and Srivastava MM 2001: Cadmium mobilization and plant availability—the impact of organic acids commonly exuded from roots. *Plant Soi. l230, 107-113.*

Nriagu J and Pacyana J 1988: Quantitative assessment of worldwide contamination of air, water and soils by trace metals. *Nature.* 333, 134-139.

National Institute of Statistics 2006: General Census of Population. Kigali, Rwanda.

Otte ML, Haarsma MS, Broekman RA and Rozema J 1993: Relation between heavy metal concentrations in salt marsh plants and soil. *Environmental Pollution*. 82, 13-22.

Pohl W 1994: Metallogeny of the northeastern Kibara belt, Central Africa - recent perspectives. *Ore Geology Review*. 9, 105-130.

Pond U, Beesley BB, Brown LR and Bezuidenhout H 2002: Floristic analysis of the Mountain ZebraNational Park, Eastern Cape. *Koedoe. 45*, 35–57. Pretoria.

Porter EK and Peterson PJ 1977: Arsenic tolerance in grasses growing on mine waste. *Environmental Pollution*. 14, 255-265.

Prasad MNV, Freitas H, Fraenzle S, Wuenschmann S and Markert B 2009: K nowledge explosion in phytotechnologies for environmental solutions. *Environmental Pollution.* 158, 18–23.

Raskin I, Kumar PBAN, Dushenkow S and Salt DE 1994: Bioconcentration of heavy metals by plants. *Curr.Opin. Biotechnology.* 8, 285-290.

Raven JA, Evans, MCW and Korb RE 1999: The role of trace metals in photosynthetic electron transport in O_2-evolving organisms. *Photosynthesis Research*. 60, 111-149.

Reetsch A 2008: Effects of Coltan Mining on Properties and Quality of Soils of the Open-Cast Mining District Gatumba, Thesis, Germany.

Reeves RD and Baker AJM 2000. Metal-accumulating plants. Pp. 193–229, *In* I. Raskin and B.D. Ensley (Eds.). Phytoremediation of Toxic Metals: Using Plants to Clean Up the Environment. New York: John Wiley and Sons Inc. USA.

Raskin I and Ensley B 1994: *Phytoremediation of toxic metals*: using plants to clean up the environment. New York: Wiley and Sons.

REMA 2009: Rwanda State of Environment and Outlook Report.Kigali, Rwanda

REMA 2006: Report on Rwanda Environment Management Authority (REMA). Kigali, Rwanda.

REMA 2003: National Environmental Policy. Kigali Rwanda.

Roose E 1996: Land Husbandry – Components and Strategy. FAO, Rome, Italy. Accessed date: 10/12/2010.

Ross SM 1994: *Toxic Metals in Soil- Plant Systems*. New York: John Wiley and Sons., USA.

Souty N, Guennelon R and Rode C 1975**:** Quelques observations sur l'absorption du potassium, du rubidium-86 et du césium-137 par des plantes cultivées sur solutions nutritives, *Ann. Agron.*, 26, Pp.58.

Rufyikiri G, Thiry Y, Wang L, Delvaux B and Declerck S 2002: Uranium uptake and translocation by the arbuscular mycorrhizalfungus, Glomus intraradices, under root-organ culture conditions. *New Phytologist.* 156, 275–281.

Sadiq M 1986: Solubility relationships of arsenic in calcareous soils and its uptake by corn. *Plant Soil*. 91, 241-248.

Sarma H 2011: Metal hyperaccumulation in Plants. A Review Focusing on Phytoremediation Technology. *Environmental Science and Technology*. 4, 118-138.

Shakuri BK 1976: Lithium content in soils of Nakhichevan Azerbaizhan, SSR, *Pochvovedenie.* 8, Pp.130.

Sievers ML and Cannon HL 1973: Disease patterns of Pima Indians of the Gila River Indian Reservation of Arizona in relation to the geochemical environments, in *Trace Subst. Environ. Health.* 7, Pp.57. Hemphill, D. D., Ed., University of Missouri, Columbia

Shannon CE 1948: A mathematical theory of communication. *Bell system technical.* 27, 379-423 and 623-656. Accessed date: 12/10/2011.

Shu WS, Ye ZH, Zhang ZQ, Lan CY and Wong MH 2005: Natural colonization of plants on five lead/zinc mine tailing in Southern China. *Restoration Ecology*. 13, 49-60.

Sinha RK 2004: *Modern Plant Physiology*. Patna: Department of Botany Science College. India.

Smolders E 2001: Cadmium uptake by Plants.International. *Journal of Occupational Medicine and Environmental Health*. 2, 177-183.

Spinoza-Quinones FR, Zacarkim CE, Palacio SM, Obregon CL and Zenatti DC 2005: Removal of heavy metal from polluted river water using aquatic macrophytes Salvinia sp. Braz. *Journal. Physiolologist. 35, 744-746*.

Strandberg B, Axelsen JA, Bruus Pedersen M, Jensen J and Attrill MJ 2006. Effect of a copper gradient on plant community structure. *Environment Toxicology Chemestry*. 25,743–753.

Strawn DG and Sparks DL 2000: Effects of soil organic matter on the kinetics and mechanisms of Pb(III) sorption and desorption in soil. *Soil Sciences*. 64, 144-156.

Subhuti Dharmananda 2007: Lead Content of Soil, Plants, Foods, Air, and Chinese Herb Formulas Ph.D. Institute for Traditional Medicine, Portland, Oregon. Accessed date: *1/10/2011*

Troupin G 1966: *Etude Phytocénologique du Parc National de l'Akagera et Rwanda Oriental*[1]. Recherche d'une method d'analyse appropriée å la vegetation d'Afrique intertropicale. Tervuren: Belgique

Troupin G 1978 : *Flore du Rwanda. Spermatophytes*[2]. Volume I. Musée royal de l'Afrique central, Tervuren: Belgique

[1] : *Phytocenological study of Akagera National Park and Eastern Rwanda*

[2] : *Flora of Rwanda. Spermatophytes*

Troupin G 1982: *Flore des Plantes ligneuses du Rwanda*. Institut National de Recherche scientifique. Tervuren : Belgique.

Troupin G 1985: *Flore du Rwanda, Spermatophytes.* Volume III. Musée Royal de l'Afrique Central, Tervuren: Belgique.

Troupin G 1988: *Flore du Rwanda, Spermatophytes*, volume IV. Musée Royal de l'Afrique Central, Tervuren: Belgique.

Troupin G and Nicole G 1975: *Plantes ligneuses du parc national de l'Akagera et des savanes orientales du Rwanda*[1]. Clés pratiques de determination scientifique, Musée Royal de l'Afrique Centrale, Tervuren: Belgique.

Tlustoŝ P, Pavlikova D, Szakova J and Balik J 2006: Plant accumulation capacity for potentially toxic elements. Czech University of Agricultue in Prague, 165 21 Prague-Suchdol, *Czech Republic.* 53-84.

Van Assche F and Clijsters H 1990: Effects of metals on enzyme activity in plants. *Plant, Cell and Environment.* 13, 195–206.

Van der Maarel E 1975: The Braun-Blanquet approach in perspective. *Plant Ecology.* 30, 213-219.

Varlamoff N 1968: Die Beryll- und Lithium pegmatite Rwanda, des Kongo und Madagaskars. *Erzmetall.* 21, 261-269.

Verdoot A and van Ranst E 2003: *Land Evaluation for Agricultural Production in the Topics.* A Large-Scale Land Suitability Classification for Rwanda", Ghent University, Laboratory of Soil Science, Belgium. Accessed date: 14/6/ 2010

Weiersbye IM, Straker CJ and Przybylowicz WJ 1999: Micro-PIXE mapping of elemental distribution in arbuscular mycorrhizal roots of the grass, *Cynodon dactylon*, from gold and uranium mine tailings. *Physiology Research*. 158, 335-343.

Wickens J 2004: *Development in the Tantalum Markets. Secretary of Tantalum – Niobium International.* Brussel: Study Centre (T.I.C.), Belgium.

[1] : *Woody plants of Akagera National Park and Eastern savannah of Rwanda*

Wong MH 2003: Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. *Chemosphere.* 50, 775-780.

WRB 2006: World reference base for soil resources, World Soil Resources Reports, 103, Food and Agriculture Organization of the United Nations, IUSS Working Group. Rome, Italy.

Xian X and Shokohifard G 1989: Effect of pH on chemical forms and plant availability of cadmium, zinc and lead in polluted soils. *Water Air Soil Pollution.* 45: 265-273

Ye M, Li JT, Tia SN, Hu M, Yi S and Liao B 2008: Biogeochemical studies of metallophytes from copper-enriched sites along the Yangtze River, Chine. *Environment Geology.* 56, 1313-1322.

Yudintseva EV, Mamontova LA and Levina EM 1979: Accumulation of radiocesium in the yield of plants depending on the application of lime, peat and peat ashes, *Dokl. Vses. Akad. Skh. Nauk.* 8, Pp. 27.

Zavoda J, Cutright T, Szpak J and Fallon E 2010: Uptake, selectivity, and inhibition of hydroponics treatment of contaminants. *Environmental Eng.* 127, 502– 8.

Zehra SS, Arshad M, Mahmood T and Waheed A 2009: Assessment of heavy metal accumulation and their translocation in plant species. *African Journal of Biotechnology*. 8, 2802-2810.

Zhao FJ, Hamon RE, Lombi E, McLaughlin MJ and McGrath SP 2002: Characteristics of Cadmium uptake in two contrasting ecotypes of the hyperaccumulators.*Thlaspi caerulescens*. J. Exp. Botany. 53, 535-543.

Zhenli L, He E, Xiaoe Yang P and Stoffella J 2005: Trace elements in agroecosystems and impacts on the environment. *Trace Elements in Medecine and Biology.* 19, 125-140.

Zogbi D 2005: Tantalum Ores and Concentrates: Oversupply in 2005. Accessed date: 12/10/2009

APPENDICES

Appendix 1: Abondance - dominance coefficients of plant species sampled in all four sites in August 2010 in dry season

RUHANGA SITE1										
SPECIES P1 T1	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**
Biophytum petersianum.	1			+						
Helichrysum mechoianum	2	2		+						
Digitaria abyssinica	2	1	1	+	1					
Melinis minutiflora	1		+							
Ageratum conyzoides		+		+						
Centella asiatica		1	1		+					
Antherotomma naudinii		+								
Acanthus pubescens	1		1	+						
Conyza wewitschii				+						
Crassocephalum vitellinum					+					
Hoslundia opposita					+					
P2 T2										
Indigofera arrecta	+	+								
Digitaria abyssinica	2	2		3						
Paspalum conjugatum	+	+								
Conyza welwitschii	+	+	1							
Centella asiatica	+	+	1	+		+				
Hyparrhenia collina	1									
Hyparrhenia rufa	+					+				
Hyparrhenia filipendula		+								
Sporobolus pyramidalis		+								
Crassocephalum vitellinum		+								
Melinis minutiflora			1							
Bidens pilosa				+						
Panicum chionachne				1		+				
Ipomoea batatas				+						
Myrica salicifolia				+		+				
P3 T3										
Vernonia amygdalina	2				1					
Acanthus pubescens	1			+	1					
Centella asiatica	+	+								
Eriosema montanum	+									
Crotalaria arrecta	+	+	+		+					
Crotalaria		1		1	2					

dewildemaniana										
Indigofera arrecta	+									
Digitaria abyssinica		3	1							
Hibiscus noldeae			+		1					
Paspalum conjugatum			+		+					
Sesbania sesban		1		1	2					
P4 T4										
Lantana camara	4	3	2	2	3					
Digitaria abyssinica	2	3	2	3	3					
Vernonia amygdalina	2		1		1					
Senseviera dawei	1		1							
Cupressus sp	1									
Phytolacca dodecandra		2		2	1					
Pennisetum purpureum		+								
Hibiscus noldeae		+								
Caesalpinia decapetala			1							
Hoslundia opposita			1							
Clerodendron rotundifolium			+		1					
Erythrina abyssinica			3							
Ageratum conyzoides			2		1					
Passiflora ligularis			1							
Cassia singueanna				+						
Crassocephalum vitellinum				1	2					
Triumfetta cordifolia				†						
Acanthus pubescens	1	1		1	2					
Rubus rigidus			1	2	3					
Crotalaria arrecta					†					
P5 T5										
Clerodendrum rotundifolium		+		+	+					
Psidium guajava	+			+						
Myrica salicifolia.	+		+	+	+					
Clerodendru myricoides		+		+						
Lantana camara	+			+	+					
Bridelia bridellifolia	1	1		+						
Maesa lanceolata	1		1	+	+					
Phytolaca dodecandra	1		2	+						
Bridelia micrantha	1		2	+						
Panicum chionachne	+	+		+						
Ludwigia abyssinica	1		1	+						
Manihot esculenta	2		2		+					

Ageratum conyzoides	1		1		+					
Digitaria velutina	2		2	1	+					
MPARE SITE 2										
P9 T6										
Rubus rigidus	1									
Pteridium aquilinum	+									
Vernonia amygdalina	1		1		1					
Bidens pilosa	+	1	1							
Digitaria abyssinica	1	1		+						
Manihot esculenta	1	1								
Musa sapientum	2			2						
Ipomoea batatas	1	3	3	2	+					
Oxalis latifolia	+									
Leonotis nepetaefolia	1		+		+					
Dracoena afromontana	+	1		+						
Ageratum conyzoides		+	2	1						
Euphorbia tirucalli			1		1					
Mangifera indica			1	1						
Hyparrhenia filipendula			+							
Conyza welwitschii			+	1						
Psidium guajava			2	2						
P12 T7										
Eragrostis exasperata.	3									
Digitaria abyssinica	5	2	5	4						
Lantana camara	1									
Psidium guajava	2									
Eucalyptus ficifolia	3	1								
Hoslundia opposita	2		1							
Spermacoce princae	1	+	+							
Cupressus sp.		+	1							
Psidium guajava		1								
Helichrysum globosum		2								
Ageratum conyzoides			+	2						
Crassocephalum vitellinum			+							
Pteridium aquilinum				1						
Rubus rigidus				+						
Commelina benghalensis				+						
Manihot esculenta				3						
Passiflora ligularis				+						
BIRAMBO SITE 4										
P10 T8										
Nephrolepis cordifolia	5	5								
Melinis minutiflora	1	1		+						

Imperata cylindrica	1		2	+						
Digitaria abyssinica	+	2	3		+					
Bridelia micrantha		2	3	+	1					
Lantana camara		1		+						
Helichrysum mechoianum			+							
Polyscias fulva	1		1	+	1					
Desmodium intortum					+					
Pennisetum purpureum1					+					
Rhyncholytrum repens					+					
Paspalum scrobiculatum					+					
P10 T9										
Digitaria abyssinica	5	5	5	5	5	5				
Dyschoriste trichocalyx	1									
Acalypha racemosa	+	+		1	1					
Ludwigia abyssinica	+	+	1		1	+	+			1
Centella asiatica	1									
Pennisetum purpureum	+									
Polygonum pulchrum		+		+	1	1	2	4	2	4
Triumfetta cordifolia		+					1			
Leersia hexandra		+		+		+	3	2	3	5
Commelina benghalensis			1	+			†			
Ageratum coyzoides			+							
Cyperus latifolia	1			1		1	+	+		1
Cyperus papyrus										1
P11 T10										
Cyperus papyrus	5	5	5	5	5					
Polygonum pulchrum	4	3	2	1	1					
Leersia hexandra	2	1		2	2					
Dyschoriste trichocalyx		1	+							
Ludwigia abyssinica		+	2	1	+					
Commelina benghalensis		+								
Bridelia micrantha		2								
Triumfetta cordifolia			1							
Bridelia bridellifolia				1						
RWASARE SITE3										
P13 T11										
Cynodon nlemfuensis	1									
Digitaria abyssinica	+	1	2	1	2					
Ageratum conyzoides	1	2		3	2					
Pennisetum purpureum	2	2	2	2						
Ipomoea batatas	2	2	2	2						
Eleusine indica	1									

Melinis minuflora	1	1								
Colocasia esculenta	2	2	+							
Commelina benghalensis	1									
Bidens pilosa		1		1						
Gynura scandens		1								
Hibiscus ludwigii			2			+				
Hoslundia opposita				1						
Bambusa vulgaris				3		**2**				
Pteridium aquilinum					1					
Polygonum pulchrum					+					
Leonotis nepetaefolia					2					
Ipomoea cairica					2	**3**				
Passiflora edulis					2	**1**				
Erythrina abyssinica		1	1		1	**1**				
Triumfetta cordifolia						**1**				
Dasylepis racemosa						**1**				
Dyschoriste trichocalyx						**1**				

Appendix 2: Abondance - dominance coefficients of plant species sampled in all sites in March 2011 in wet season

Ruhanga site1					
Species P1 T12	R1	R2	R3	R4	R5
Ageratum conyzoides	1				
Digitaria abyssinica	+	2	5	5	4
Centella asiatica	2		1		1
Hoslundia opposita	1	+			
Melinis minutiflora	1	2			
Bidens pilosa	+				+
Gynura scandens	+	+	+	+	
Microglossa pyrifolia	+	+		+	
Selaginella sp	+				
Crassocephalum vitellinum	+				+
Rhynchosia luteola	+	1			
Helichrysum newll	+		+		
Indigofera arrecta	+				
Bidens grantii	+				
Cynodon nlemfuensis		3	1	1	2
Acanthus pubescens		3		+	1
Crotalaria dewildemaniana		2	+		
Acanthus repens		+			
Cupressus sp		2			
Biophytum petersianum		2			
Ipomoea batatas			+		
Spermacoce princae			+	+	1
Eucalyptus ficifolia.				3	
Commelina benghalensis				+	+
Pteridium aquilinum					+
Rubus rigidus					+
P2 T13					
Ageratum conyzoides	1		+		1
Bidens pilosa	+	+	+	+	
Ipomoea batatas	2		1	1	
Ipomoea cairica	1				
Manihot esculenta	1				
Digitaria abyssinica	4	3	2		3
Pteridium aquilinum	3	1			2
Acanthus pubescens	+			1	
Myrica salicifolia	+				
Spermacoce princae		2	+	+	
Centella asiatica		2	2		1

Rhynchosia luteola		2			
Erythrina abyssinica		1		1	
Impatiens bequartii		1			
Leersia hexandra		+			
Gynura scandens		1		+	
Tithonia diversiflora		1			
Acanthus repens		+			
Melinis minutiflora			1	1	2
Crassocephalum vitellinum			+	1	
Triumfetta cordifolia			+		
Hoslundia opposite			1	1	
Commelina benghalensis				+	
Oxalis lafifolia				1	+
Clerodendrom rotundifolium					1
Cyperus distans					+
Biophytum petersianum					+
Bridelia micrantha					1
Hyparrhenia collina					1
P3 T14					
Ipomoea batatas	2				
Ipomoea cairica	+				
Digitaria abyssinica	4	2	1	+	
Acanthus pubescens	+	+	+		1
Rhynchosia minima	+				
Triumfetta cordifolia	+				
Centella asiatica	1	2			
Pteridium aquilinum	+		1		1
Cassia singueanna		1	1	2	2
Tephrosia pumila	1				
Acanthus repens		+			+
Bidens grantii		1			
Hoslundia opposite		1			
Spermacoce princae		+		+	+
Rubus rigidus		+			
Melinis minutiflora		2	1	1	
Hyparrhenia collina		+			
Aspilia kotschyii		1			
Hibiscus ludwigii			2		
Commelina benghalensis			+		+
Ageratum conyzoides			+		+
Cynodon nlemfuensis				1	1
Crotalaria dewildemaniana				2	
Sesbania sesban				+	

Crossocephalum vitellinum				+	
Gynura scandens		+	+	+	
Biophytum petersianum.				+	
Selaginella sp.					+
Cyperus distans					+
P4 T15					
Crotalaria dewildemaniana	5		1		1
Sesbania sesban	2			1	
Polygonum pulchrum	+	1	+	+	
Digitaria abyssinica	2	2	3	1	2
Ageratum conyzoides	+			+	+
Crassocephalum vitellinum	+				
Cassia singueanna	+			+	
Gynora scandens	+	+	+		1
Centella asiatica	+		+		1
Rhynchosia luteola		+			
Tithonia diversiflora			+		
Hyparrhenia collina			1		
Triumfetta cordifolia				+	
Bidens grantii				+	
Melinis minutiflora					+
P5 T16					
Digitaria velutina	5	2	3	3	2
Ageratum conyzoides	3	3	2	+	
Manihot esculenta	+	+	+	3	1
Gynura scandens	+	+		1	
Oxalis latifolia	1		2		
Cassia singueanna			+		
Cyperus distans	+			+	1
Pennisetum purpureum			2		
Crassocephalum vitellinum			+		
Cyperus pseudoleptocladus					2
Brachiaria semiundulata					1
Bothriocline longipes			1	+	+
Mpara site2					
P12 T17					
Vernonia amygdalina	+				
Crossocephalum vitellinum	+				1
Hyparrhenia filipendula	+				
Triumfetta cordifolia	1	1	1		+
Manihot esculenta	3	2	1	3	3
Ageratum conyzoides	1	2	2	+	1
Digitaria velutina	2	2	3		+

Ipomoea cairica	2		1	1	1
Ipomoea batatas		1	1	3	1
Brachiaria semiundulata		+			
Spermacoce princae		+			
Erytrina abyssinica		1			
Galinsoga parviflora		+			
Gynura scandens			1		
Sesbania sesban			+		
Eucalyptus ficifolia.				1	
Bidens grantii				+	1
Melinis minutiflora				+	
Centella asiatica					1
Bidens pilosa					+
Rwasare Site 3					
P13 T18					
Passiflora edulis	1				
Bambusa vulgaris	2				
Triumfetta cordifolia	+				1
Commelina benghalensis	+				
Ageratum conyzoides	1		1	+	+
Pennisetum purpureum	1		1	1	
Impatiens burtonii					
Melinis minutiflora	+				+
Colocasia esculenta	1			1	
Erythrina abyssinica		3		1	1
Bridelia brideliifolia		1	+		
Crassocephalum vitellinum		+	+		+
Nephrolepis cordifolia		+			
Achyranthes aspera		+			
Leonotis nepetaefolia		+			
Dissotis ruandensis			+		
Zea mays			3	3	
Digitaria abyssinica			1	+	2
Galinsoga parviflora			1	+	
Acanthus pubescens				+	
Cyperus distans				+	
Ipomoea batatas					1
Gynura scandens					+
Brachiaria semiundulata					1
Ipomoea cairica					1
Birambo Site 4					
P10 T19					
Leersia hexandra	4	1	4	2	1

Cyperus latifolia	+				
Ageratum conyzoides	+		1	1	2
Dissotis ruandensis	+	1			
Commelina benghalensis					
Ludwigia abyssinica	+				+
Gynura scandens	+	+			
Triumfetta cordifolia	+				+
Indigofera arrecta	+				
Bidens grantii	+	+			+
Pennisetum purpureum		4			
Crotalaria dewildemaniana		+			
Biophytum petersianum			+		
Nephrolepis cordifolia		+			
Brachiaria semiundulata			1	+	
Crassocephalum vitellinum			+	+	+
Cassia singueanna			1	1	
Helichrysum globosum			1		
Galinsoga parviflora				+	1
Panicum chionachne				+	
Polygonum pulchrum					+
Leonotis nepetaefolia					+
P11 T20					
Polygonum pulchrum	4	3	2	3	4
Leersia hexandra	2	2	2	2	
Cyperus papyrus	3				
Ageratum conyzoides	+	+	+	+	
Hyparrenia rufa	+	+	1	+	+
Ludwigia abyssinica	2	1			1
Commelina benghalensis		+			+
Cyperus latifolia		+		1	1
Cyperus papyrus		3	3	4	3
Galinsoga parviflora			+	+	

Appendix 3: Different phytosociological parameters calculated using of coefficientgiven in table 3.4

Aug-10

RUHANGA SITE1

SPECIES P1 T1	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Biuophytum petersianum.	2	2.7	33.33	3.86	8.33	12.20	6.10
Helichrysum mechoianum	3	30.2	50.00	43.20	12.50	55.70	27.85
Digitaria abyssinica	5	22.7	83.33	32.47	20.83	53.31	26.65
Melinis minutiflora	2	2.7	33.33	3.86	8.33	12.20	6.10
Ageratum conyzoides	2	0.4	33.33	0.57	8.33	8.91	4.45
Centella asiatica	3	5.2	50.00	7.44	12.50	19.94	9.97
Antherotomma naudinii	1	0.2	16.67	0.29	4.17	4.45	2.23
Acanthus pubescens	3	5.2	50.00	7.44	12.50	19.94	9.97
Conyza wewitschii.	1	0.2	16.67	0.29	4.17	4.45	2.23
Crassocephalum vitellinum	1	0.2	16.67	0.29	4.17	4.45	2.23
Hoslundia opposita	1	0.2	16.67	0.29	4.17	4.45	2.23
P2 T2	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Indigofera arrecta	2	0.4	33.33	0.48	7.14	7.61	3.81
Digitaria abyssinica	3	67.5	50.00	80.36	10.71	91.06	45.55
Paspalum conjugatum	2	0.4	33.33	0.48	7.14	7.61	3.81
Conyza welwitschii	3	2.9	50.00	3.45	10.71	14.16	7.08
Centella asiatica	5	3.3	83.33	3.93	17.84	21.77	10.89
Hyparrhenia collina	1	2.5	16.67	2.98	3.57	6.55	3.27
Hyparrhenia rufa	2	0.4	33.33	0.48	7.14	7.61	3.81
Hyparrhenia filipendula	1	0.2	16.67	0.24	3.57	3.81	1.90
Sporobolus pyramidalis	1	0.2	16.67	0.24	3.57	3.81	1.90
Crossocephalum vitellinum	1	0.2	16.67	0.24	3.57	3.81	1.90
Melinis minutiflora	1	2.5	16.67	2.98	3.57	6.55	3.27
Bidens pilosa	1	0.2	16.67	0.24	3.57	3.81	1.90
Panicum chionachne	2	2.7	33.33	3.21	7.14	10.35	5.18
Ipomoea batatas	1	0.2	16.67	0.24	3.57	3.81	1.90
Myrica salicifolia	2	0.4	33.33	0.48	7.14	7.61	3.81
P3 T3	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Vernonia amygdalina	2	17.5	40	16.36	8.00	24.36	12.16
Acanthus pubescens	3	5.2	60	4.86	12.00	16.86	8.41
Centella asiatica	2	0.4	40	0.37	8.00	8.37	4.18
Eriosema montanum	1	0.2	20	0.19	4.00	4.19	2.09
Crotalaria arrecta	4	0.8	80	0.75	16.00	16.75	8.36
Crotalaria dewildemaniana	3	20	60	18.69	12.00	30.69	15.32
Indigofera arrecta	1	0.2	20	0.19	4.00	4.19	2.09
Digitaria abyssinica	2	40	40	37.38	8.00	45.38	22.65
Hibiscus noldeae	2	2.7	40	2.52	8.00	10.52	5.25

Paspalum conjugatum	2	0.4	40	0.37	8.00	8.37	4.18
Sesbania sesban	3	20	60	18.69	12.00	30.69	15.32
P4 T4	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Lantana camara	5	167.5	100	32.27	12.20	44.47	22.24
Digitaria abyssinica	5	142.5	100	27.46	12.20	39.65	19.83
Vernonia amygdalina	3	20	60	3.85	7.32	11.17	5.59
Sensiviera dawei	2	5	40	0.96	4.88	5.84	2.92
Cupressus sp	1	2.5	20	0.48	2.44	2.92	1.46
Phytolacca dodecandra	3	32.5	60	6.26	7.32	13.58	6.79
Pennesetum purpureum	1	0.2	20	0.04	2.44	2.48	1.24
Hibiscus noldeae	1	0.2	20	0.04	2.44	2.48	1.24
Caesalpina decapetala	1	2.5	20	0.48	2.44	2.92	1.46
Hoslundia opposite	1	2.5	20	0.48	2.44	2.92	1.46
Clerodendron rotundifolium	2	2.7	40	0.52	4.88	5.40	2.70
Erythrina abyssinica	1	37.5	20	7.23	2.44	9.66	4.83
Ageratum conyzoides	2	17.5	40	3.37	4.88	8.25	4.13
Passiflora ligularis	1	2.5	20	0.48	2.44	2.92	1.46
Cassia singueanna	1	0.2	20	0.04	2.44	2.48	1.24
Crassocephalum vitellinum(	2	17.5	40	3.37	4.88	8.25	4.13
Triumfetta cordifolia	1	0.2	20	0.04	2.44	2.48	1.24
Acanthus pubescens	4	10	80	1.93	9.76	11.68	5.84
Rubus rigidus	3	55	60	10.60	7.32	17.91	8.96
Crotalaria arrecta.	1	0.2	20	0.04	2.44	2.48	1.24
P5 T5	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Clerodendrum rotundifolium	3	0.6	60	0.49	6.98	7.46	3.74
Psidium guajava	2	0.4	40	0.33	4.65	4.98	2.49
Myrica salicifolia.	4	0.8	80	0.65	9.30	9.95	4.98
Clerodendron Myricoides	2	0.4	40	0.33	4.65	4.98	2.49
Lantana camara	3	0.6	60	0.49	6.98	7.46	3.74
Bridelia bridellifolia	3	5.2	60	4.23	6.98	11.20	5.61
Moesa lanceolata	4	5.4	80	4.39	9.30	13.69	6.85
Phytolaca dodecandra	3	17.7	60	14.39	6.98	21.37	10.70
Bridelia micrantha	3	17.7	60	14.39	6.98	21.37	10.70
Panicum chionachne	3	0.6	60	0.49	6.98	7.46	3.74
Ludwigia abyssinica	3	5.2	60	4.23	6.98	11.20	5.61
Manihot esculenta	3	30.2	60	24.55	6.98	31.53	15.78
Ageratum conyzoides	3	5.2	60	4.23	6.98	11.20	5.61
Digitaria velutina	4	32.7	80	26.59	9.30	35.89	17.97
Mar-11							
P1 T12	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Ageratum conyzoides	1	2.5	20	0.51	1.92	2.44	1.22
Digitaria abyssinica	5	252.7	100	52.00	9.62	61.61	30.81

Centella asiatica	3	20	60	4.12	5.77	9.88	4.94
Hoslundia oposita	2	2.7	40	0.56	3.85	4.40	2.20
Melenis minutiflora	2	17.5	40	3.60	3.85	7.45	3.72
Bidens pilosa	2	0.4	40	0.08	3.85	3.93	1.96
Gynura scandes	4	0.8	80	0.16	7.69	7.86	3.93
Microglossa pyrifolia	3	0.6	60	0.12	5.77	5.89	2.95
Selaginella sp	1	0.2	20	0.04	1.92	1.96	0.98
Crassocephalum vitellinum	2	0.4	40	0.08	3.85	3.93	1.96
Rhynchosia luteola	2	2.7	40	0.56	3.85	4.40	2.20
Helichrysum newll	2	0.4	40	0.08	3.85	3.93	1.96
Indigofera arrecta	1	0.2	20	0.04	1.92	1.96	0.98
Bidens grantii	1	0.2	20	0.04	1.92	1.96	0.98
Cynodon nlemfuensis	4	57.5	80	11.83	7.69	19.52	9.76
Acanthus pubescens	3	40.2	60	8.27	5.77	14.04	7.02
Crotalaria dewildemaniana	2	15.2	40	3.13	3.85	6.97	3.49
Acanthus repens	1	0.2	20	0.04	1.92	1.96	0.98
Cuprecus sp	1	15	20	3.09	1.92	5.01	2.51
Biumphetum petersianum	1	15	20	3.09	1.92	5.01	2.51
Ipomoea batatas	1	0.2	20	0.04	1.92	1.96	0.98
Spermacoce princae	3	2.9	60	0.60	5.77	6.37	3.18
Eucyptus ficifolia.	1	37.5	20	7.72	1.92	9.64	4.82
Commelina benghalensis	2	0.4	40	0.08	3.85	3.93	1.96
Pteridium aqualinum	1	0.2	20	0.04	1.92	1.96	0.98
Rubus rigidus	1	0.2	20	0.04	1.92	1.96	0.98

P2 T13	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Ageratum conyzoides	3	5.2	60	1.46	5.66	7.12	3.56
Bidens pilosa	4	0.8	80	0.22	7.55	7.77	3.89
Ipomoea batatas	3	20	60	5.62	5.66	11.28	5.64
Ipomoea cairica	1	2.5	20	0.70	1.89	2.59	1.29
Manihot esculenta	1	2.5	20	0.70	1.89	2.59	1.29
Digitaria abyssinica	4	152.5	80	42.84	7.55	50.38	25.19
Pteridium aqualinum	3	55	60	15.45	5.66	21.11	10.55
Acanthus pubescens	2	2.7	40	0.76	3.77	4.53	2.27
Myrica salicifolia	1	0.2	20	0.06	1.89	1.94	0.97
Spermacoce princae	3	15.4	60	4.33	5.66	9.99	4.99
Centella asiatica	3	32.5	60	9.13	5.66	14.79	7.39
Rhynchosia luteola	1	15	20	4.21	1.89	6.10	3.05
Erythrina abyssinica	2	5	40	1.40	3.77	5.18	2.59
Impatiens bequartii	1	2.5	20	0.70	1.89	2.59	1.29
Leersia hexandra	1	0.2	20	0.06	1.89	1.94	0.97
Gynura scandes	2	2.7	40	0.76	3.77	4.53	2.27
Tithonia diversiflora	1	2.5	20	0.70	1.89	2.59	1.29
Acanthus repens	1	0.2	20	0.06	1.89	1.94	0.97
Melenis minutiflora	3	20	60	5.62	5.66	11.28	5.64

Crassocephalum vitellinum	2	2.7	40	0.76	3.77	4.53	2.27
Triumfetta codifolia	1	0.2	20	0.06	1.89	1.94	0.97
Hoslundia oposita	2	5	40	1.40	3.77	5.18	2.59
Commelina benghalensis	1	0.2	20	0.06	1.89	1.94	0.97
Oxalis lafifolia	2	2.7	40	0.76	3.77	4.53	2.27
Clerodendron rotundifolium	1	2.5	20	0.70	1.89	2.59	1.29
Cyperus distans	1	0.2	20	0.06	1.89	1.94	0.97
Biumphytum petersianum	1	0.2	20	0.06	1.89	1.94	0.97
Brideria mincranta	1	2.5	20	0.70	1.89	2.59	1.29
Hyparrhenia collina	1	2.5	20	0.70	1.89	2.59	1.29

P3 T14	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Ipomoea batatas	1	15	20	6.67	1.96	8.63	4.31
Ipomoea cairica	1	0.2	20	0.09	1.96	2.05	1.02
Digitaria abyssinica	4	80.2	80	35.64	7.84	43.49	21.72
Acanthus pubescens	4	3.1	80	1.38	7.84	9.22	4.61
Rhynchosia minima convol	1	0.2	20	0.09	1.96	2.05	1.02
Triumfetta cordifolia	1	0.2	20	0.09	1.96	2.05	1.02
Centela asiatica	2	17.5	40	7.78	3.92	11.70	5.84
Pteridium aqualinum	3	5.2	60	2.31	5.88	8.19	4.09
Cassia singueanna	4	35	80	15.56	7.84	23.40	11.69
Tephrosia pumila	1	2.5	20	1.11	1.96	3.07	1.53
Acanthus repens	2	0.4	40	0.18	3.92	4.10	2.05
Bidens grantii	1	2.5	20	1.11	1.96	3.07	1.53
Hoslondia oposita	1	2.5	20	1.11	1.96	3.07	1.53
Spermacoce princae	3	0.6	60	0.27	5.88	6.15	3.07
Rubus rigidus	1	0.2	20	0.09	1.96	2.05	1.02
Melinis minutiflora	3	20	60	8.89	5.88	14.77	7.38
Hyparrhenia collina	1	0.2	20	0.09	1.96	2.05	1.02
Aspilla kotschyi	1	2.5	20	1.11	1.96	3.07	1.53
Hibiscus ludwigii	1	15	20	6.67	1.96	8.63	4.31
Commelina benghalensis	2	0.4	40	0.18	3.92	4.10	2.05
Ageratum conyzoides	2	0.4	40	0.18	3.92	4.10	2.05
Cynodon nlemfuensis	2	5	40	2.22	3.92	6.14	3.07
Crotalaria dewildemaniana	1	15	20	6.67	1.96	8.63	4.31
Sesbania sesban	1	0.2	20	0.09	1.96	2.05	1.02
Crossocephalum vitellinum	1	0.2	20	0.09	1.96	2.05	1.02
Gynura scandens igifuraninda	3	0.6	60	0.27	5.88	6.15	3.07
Biophytum petersianum.	1	0.2	20	0.09	1.96	2.05	1.02
Selaginella sp.	1	0.2	20	0.09	1.96	2.05	1.02
Cyperus distans	1	0.2	20	0.09	1.96	2.05	1.02

P4 T15	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Crotalaria dewildemaniana	3	92.5	60	44.26	9.09	53.35	26.69

Sesbania sesban	2	17.5	40	8.37	6.06	14.43	7.22
Polygonum pulchrum	4	3.1	80	1.48	12.12	13.60	6.81
Digitaria abyssinica	5	85	100	40.67	15.15	55.82	27.92
Ageratum conyzoides	3	0.6	60	0.29	9.09	9.38	4.69
Crassocephalum vitellinum	1	0.2	20	0.10	3.03	3.13	1.56
Cassia singueanna	2	0.4	40	0.19	6.06	6.25	3.13
Gynora scandes	4	3.1	80	1.48	12.12	13.60	6.81
Centella asiatica	3	2.9	60	1.39	9.09	10.48	5.24
Rhynchosia luteola	1	0.2	20	0.10	3.03	3.13	1.56
Tithonia diversiflora	1	0.2	20	0.10	3.03	3.13	1.56
Hyparrhenia collina	1	2.5	20	1.20	3.03	4.23	2.11
Triumfetta cordifolia	1	0.2	20	0.10	3.03	3.13	1.56
Bidens grantii	1	0.2	20	0.10	3.03	3.13	1.56
Melinis minutiflora	1	0.2	20	0.10	3.03	3.13	1.56

P5 T16	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Digitaria velutina	5	192.5	100	50.39	8.40	58.79	50.34
Ageratum conyzoides	4	90.2	80	23.61	3.94	27.55	23.59
Manihot esculenta	5	40.6	100	10.63	1.77	12.40	10.62
Gynura scandes	3	2.9	60	0.76	0.13	0.89	0.76
Oxalis latifolia	2	17.5	40	4.58	0.76	5.34	4.58
Cassia singueans	1	0.2	20	0.05	0.01	0.06	0.05
Cyperus distans	3	2.9	60	0.76	0.13	0.89	0.76
Pennisetum purpureum	1	15	20	3.93	0.65	4.58	3.92
Crassocephalum vitellinum	1	0.2	20	0.05	0.01	0.06	0.05
Cyperus pseudoleptocladus	1	15	20	3.93	0.65	4.58	3.92
Brachiaria semiundulata	1	2.5	20	0.65	0.11	0.76	0.65
Bothriocline longipes	3	2.9	60	0.76	0.13	0.89	0.76

MPARE August 2010

P9 T6 MPARE SITE 2	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Rubus rigidus	1	2.5	20	1.16	2.56	3.73	1.86
Pteridium aqualinum	1	0.2	20	0.09	2.56	2.66	1.33
Vernonia amygdalina	3	7.5	60	3.49	7.69	11.18	5.59
Bidens pilosa	3	5.2	60	2.42	7.69	10.11	5.06
Digitaria abyssinica	3	5.2	60	2.42	7.69	10.11	5.06
Manihot esculenta	2	5	40	2.33	5.13	7.45	3.73
Musa sapientum	2	30	40	13.96	5.13	19.09	9.54
Ipomoea batatas	5	92.7	100	43.14	12.82	55.96	27.98
Oxalis latifolia	1	0.2	20	0.09	2.56	2.66	1.33
Leonotus nepetifolia	3	2.9	60	1.35	7.69	9.04	4.52
Dracoena afromontana	3	2.9	60	1.35	7.69	9.04	4.52

Ageratum conyzoides	3	17.7	60	8.24	7.69	15.93	7.96
Euphorbia tirucalli	2	5	40	2.33	5.13	7.45	3.73
Mangifera indica	2	5	40	2.33	5.13	7.45	3.73
Hyparrhenia filipendula	1	0.2	20	0.09	2.56	2.66	1.33
Conyza welwitschii	2	2.7	40	1.26	5.13	6.38	3.19
Psidium guajava	2	30	40	13.96	5.13	19.09	9.54

P12 T7	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Eragrostis exasperata.	1	37.5	20	8.44	3.70	12.15	6.07
Digitaria abyssinica	4	252.5	80	56.86	14.81	71.67	35.84
Lantana camara	1	2.5	20	0.56	3.70	4.27	2.13
Psidium guajava	1	15	20	3.38	3.70	7.08	3.54
Eucalyptus ficifolia	2	40	40	9.01	7.41	16.41	8.21
Hoslundia opposita	3	17.5	60	3.94	11.11	15.05	7.53
Spermacoce princae	3	2.9	60	0.65	11.11	11.76	5.88
Cupressus sp.	2	2.7	40	0.61	7.41	8.02	4.01
Psidium guajava	1	2.5	20	0.56	3.70	4.27	2.13
Helichrysum globosum	1	15	20	3.38	3.70	7.08	3.54
Ageratum conyzoides	2	15.2	40	3.42	7.41	10.83	5.42
Crassocephalum vitellinum	1	0.2	20	0.05	3.70	3.75	1.87
Pteridium aqualinum	1	2.5	20	0.56	3.70	4.27	2.13
Rubus rigidus	1	0.2	20	0.05	3.70	3.75	1.87
Commelina benghalensis	1	0.2	20	0.05	3.70	3.75	1.87
Manihot esculenta	1	37.5	20	8.44	3.70	12.15	6.07
Passiflora ligularis	1	0.2	20	0.05	3.70	3.75	1.87

Mar-11

Mpara site2

P12 T17	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Vernonia amygdalina	1	0.2	20	0.07	2.38	2.45	1.22
Crossocephalum vitellinum	2	2.7	40	0.93	4.76	5.69	2.85
Hyparrhenia filipendula	1	0.2	20	0.07	2.38	2.45	1.22
Triumfetta cordifolia	4	7.7	80	2.65	9.52	12.18	6.09
Manihot esculenta	5	130	100	44.81	11.90	56.72	28.36
Agretatum conyzoides	5	35.2	100	12.13	11.90	24.04	12.02
Digitaria velutrina	4	67.7	80	23.34	9.52	32.86	16.43
Ipomoea cairica	4	22.5	80	7.76	9.52	17.28	8.64
Ipomoea batatas	4	10	80	3.45	9.52	12.97	6.49
Brachiaria semiundulata	1	0.2	20	0.07	2.38	2.45	1.22
Spermacoce princae	1	0.2	20	0.07	2.38	2.45	1.22
Erytrina abyssinica	1	2.5	20	0.86	2.38	3.24	1.62
Galisonga parviflora	1	0.2	20	0.07	2.38	2.45	1.22
Gynura scandes	1	2.5	20	0.86	2.38	3.24	1.62
Sesbania sesban	1	0.2	20	0.07	2.38	2.45	1.22

Eucyptus ficifolia.	1	2.5	20	0.86	2.38	3.24	1.62
Bidens grantii	2	2.7	40	0.93	4.76	5.69	2.85
Melenis minutiflora	1	0.2	20	0.07	2.38	2.45	1.22
Centella asiatica	1	2.5	20	0.86	2.38	3.24	1.62
Bidens pilosa	1	0.2	20	0.07	2.38	2.45	1.22

RWASARE August 2010
RWASARE SITE3

P13 T11	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Cynodon nlemfuensis	1	2.5	16.67	0.52	2.08	2.60	1.30
Digitaria abyssinica	5	35.2	83.33	7.32	10.42	17.73	8.87
Ageratum conyzoides	5	100	83.33	20.79	10.42	31.21	15.61
Pennesetum purpureum	4	60	66.67	12.47	8.33	20.81	10.41
Ipomoea batatas	4	60	66.67	12.47	8.33	20.81	10.41
Eleusine indica	1	2.5	16.67	0.52	2.08	2.60	1.30
Melinis minuflora	2	5	33.33	1.04	4.17	5.21	2.60
Colocasia esculenta	3	30.2	50.00	6.28	6.25	12.53	6.27
Commelina benghalensis	1	2.5	16.67	0.52	2.08	2.60	1.30
Bidens pilosa	2	5	33.33	1.04	4.17	5.21	2.60
Gynura scandens	1	2.5	16.67	0.52	2.08	2.60	1.30
Hibiscus ludwigii	2	15.2	33.33	3.16	4.17	7.33	3.66
Hoslundia opposita	1	2.5	16.67	0.52	2.08	2.60	1.30
Bambusa vulgaris	2	52.5	33.33	10.91	4.17	15.08	7.54
Pteridium aqualinum	1	2.5	16.67	0.52	2.08	2.60	1.30
Polygonum pulchrum	1	0.2	16.67	0.04	2.08	2.12	1.06
Leonotus nepetifolia	1	15	16.67	3.12	2.08	5.20	2.60
Ipomoea cairica	2	52.5	33.33	10.91	4.17	15.08	7.54
Passiflora edilus	2	17.5	33.33	3.64	4.17	7.80	3.90
Erythrina abyssinica	4	10	66.67	2.08	8.33	10.41	5.21
Triumfetta cordifolia	1	2.5	16.67	0.52	2.08	2.60	1.30
Dasylepis racemosa	1	2.5	16.67	0.52	2.08	2.60	1.30
Dyschoriste trichocalyx	1	2.5	16.67	0.52	2.08	2.60	1.30

Rwasare Site: 3 Mar-11

P13 T18	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Passiflora edulis	1	2.5	20	1.32	2.38	3.70	1.85
Bambusa vulgaris	1	15	20	7.94	2.38	10.32	5.16
Triumfetta cordifolia	2	2.7	40	1.43	4.76	6.19	3.10
Commelina benghalensis	1	0.2	20	0.11	2.38	2.49	1.24
Ageratum conyzoides	4	5.4	80	2.86	9.52	12.38	6.19
Pennisetum purpureum	3	7.5	60	3.97	7.14	11.11	5.56
Impetiens buntonii	1	0.2	20	0.11	2.38	2.49	1.24
Melenis minutifolia	2	0.4	40	0.21	4.76	4.97	2.49
Colcasia esculentra	2	5	40	2.65	4.76	7.41	3.70

Erytrina abyssinica	3	42.5	60	22.49	7.14	29.63	14.81
Bridelia bridellifolia	2	2.7	40	1.43	4.76	6.19	3.10
Crassocephalum vitellinum	3	0.6	60	0.32	7.14	7.46	3.73
Nephrolepis cordifolia	1	0.2	20	0.11	2.38	2.49	1.24
Achyranthus aspera	1	0.2	20	0.11	2.38	2.49	1.24
Leonotus nepetifolia	1	0.2	20	0.11	2.38	2.49	1.24
Dissotis ruandensis	1	0.2	20	0.11	2.38	2.49	1.24
Zea mays	2	75	40	39.68	4.76	44.44	22.22
Digitaria abyssinica	3	17.7	60	9.37	7.14	16.51	8.25
Galisonga parviflora	2	2.7	40	1.43	4.76	6.19	3.10
Acanthus pubescens	1	0.2	20	0.11	2.38	2.49	1.24
Cyperus distans	1	0.2	20	0.11	2.38	2.49	1.24
Ipomoea batatas	1	2.5	20	1.32	2.38	3.70	1.85
Gynora scandes	1	0.2	20	0.11	2.38	2.49	1.24
Brachiaria semiundulata	1	2.5	20	1.32	2.38	3.70	1.85
Ipomoea cairica	1	2.5	20	1.32	2.38	3.70	1.85

BIRAMBO Site 4:Aug.10

P10 T8	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Nephrolepis cordifolia	2	175	20	55.14	7.41	62.54	31.27
Melinis minutiflora	3	5.2	30	1.64	11.11	12.75	6.37
Imperata cylindrical	3	17.7	30	5.58	11.11	16.69	8.34
Digitaria abyssinica	4	52.9	40	16.67	14.81	31.48	15.74
Bridelia micrantha	4	55.2	40	17.39	14.81	32.21	16.10
Lantana camara	2	2.7	20	0.85	7.41	8.26	4.13
Helichrysum mechoianum	1	0.2	10	0.06	3.70	3.77	1.88
Polysias fulva	4	7.7	40	2.43	14.81	17.24	8.62
Desmodium intortum	1	0.2	10	0.06	3.70	3.77	1.88
Pennisetum purpureum1	1	0.2	10	0.06	3.70	3.77	1.88
Rhyncholyntum repens	1	0.2	10	0.06	3.70	3.77	1.88
Paspalum sciobiculatum	1	0.2	10	0.06	3.70	3.77	1.88

P10 T9	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Digitaria abyssinica	6	525	60	58.26	12.50	70.76	35.38
Dyschoriste trichocalyx	1	2.5	10	0.28	2.08	2.36	1.18
Acalypha racemosa	4	5.4	40	0.60	8.33	8.93	4.47
Ludwigia abyssinica	7	8.3	70	0.92	14.58	15.50	7.75
Centella asiatica	1	2.5	10	0.28	2.08	2.36	1.18
Pennesetum purpureum	1	0.2	10	0.02	2.08	2.11	1.05
Polygonum pulchrum	8	160.4	80	17.80	16.67	34.47	17.23
Triumfetta cordifolia	2	2.7	20	0.30	4.17	4.47	2.23
Leersia hexandra	7	178.1	70	19.76	14.58	34.35	17.17
Commelina benghalensis	3	2.9	30	0.32	6.25	6.57	3.29
Ageratum coyzoides	1	0.2	10	0.02	2.08	2.11	1.05

Cyperus latifolia	6	10.4	60	1.15	12.50	13.65	6.83
Cyperus papyrus	1	2.5	10	0.28	2.08	2.36	1.18

P11 T10	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Cyperus papyrus	5	437.5	50	64.74	20.83	85.57	42.79
Polygonum pulchrum	5	150	50	22.20	20.83	43.03	21.51
Leersia hexandra	4	47.5	40	7.03	16.67	23.70	11.85
Dyschoriste trichocalyx	2	2.7	20	0.40	8.33	8.73	4.37
Ludwigia abyssinica	4	17.9	40	2.65	16.67	19.32	9.66
Commelina benghalensis	1	0.2	10	0.03	4.17	4.20	2.10
Bridelia micrantha	1	15	10	2.22	4.17	6.39	3.19
Triumfetta cordifolia	1	2.5	10	0.37	4.17	4.54	2.27
Bridelia bridellifolia	1	2.5	10	0.37	4.17	4.54	2.27

Birambo Site 4: May.11

P10 T19	**P**	**D**	**F**	**DR**	**FR**	**DF**	**Φ**
Leersia heandra	5	145	100	58.59	12.5	71.09	35.54
Cyperus latifolia	1	0.2	20	0.08	2.5	2.58	1.29
Ageratum conyzoides	4	20.2	80	8.16	10	18.16	9.08
Dissotis ruandensis	2	2.7	40	1.09	5	6.09	3.05
Commelina benghalensis	1	0.2	20	0.08	2.5	2.58	1.29
Ludwigia abyssinica	2	0.4	40	0.16	5	5.16	2.58
Gynura scandes	2	0.4	40	0.16	5	5.16	2.58
Triumfetta cordifolia	2	0.4	40	0.16	5	5.16	2.58
Indigofera arrecta	1	0.2	20	0.08	2.5	2.58	1.29
Bidens grantii	3	0.6	60	0.24	7.5	7.74	3.87
Pennisetum purpureum	1	62.5	20	25.25	2.5	27.75	13.88
Crotalaria dewildemaniana	1	0.2	20	0.08	2.5	2.58	1.29
Biumphetum petersianum	1	0.2	20	0.08	2.5	2.58	1.29
Nephrolepis cordifolia	1	0.2	20	0.08	2.5	2.58	1.29
Brachiaria semiundulata	2	2.7	40	1.09	5	6.09	3.05
Crassocephalum vitellinum	3	0.6	60	0.24	7.5	7.74	3.87
Cassia singueans	2	5	40	2.02	5	7.02	3.51
Helichrysum globosum	1	2.5	20	1.01	2.5	3.51	1.76
Galisonga parviflora	2	2.7	40	1.09	5	6.09	3.05
Panicum chionachyne	1	0.2	20	0.08	2.5	2.58	1.29
Polygonum pulchrum	1	0.2	20	0.08	2.5	2.58	1.29
Leonotus nepetifolia	1	0.2	20	0.08	2.5	2.58	1.29

P11 T20	P	D	F	DR	FR	DF	Φ
Polygonum pulchrum	5	215	100	41.54	15.15	56.69	28.34
Leersia hexandra	4	60	80	11.59	12.12	23.71	11.86
Ageratum conyzoides	4	0.8	80	0.15	12.12	12.28	6.14
Hyparrenia nifa	5	3.3	100	0.64	15.15	15.79	7.89

Ludwigia abyssinica	3	20	60	3.86	9.09	12.95	6.48
Commelina benghalensis	2	0.4	40	0.08	6.06	6.14	3.07
Cyperus latifolia	3	5.2	60	1.00	9.09	10.10	5.05
Cyperus papyrus	5	212.5	100	41.05	15.15	56.21	28.10
Galisonga parviflora	2	0.4	40	0.08	6.06	6.14	3.07

Appendix 4: Presence ans absence of plant species in Gatumba mining area

1. **Ruhanga site**

	T1	T2	T3	T4	T5	T12	T13	T14	T15	T16
Bidens pilosa	0	1	0	0	0	1	1	0	0	0
Biumphytum petersianum.	1	0	0	0	0	1	1	1	0	0
Bridelia bridellifolia	0	0	0	0	1	**0**	0	0	0	0
Bridelia micrantha	0	0	0	0	1	**0**	1	0	0	0
Cassia singueans	0	0	0	1	0	**0**	0	1	1	1
Clerodendron myricoides	0	0	0	0	1	**0**	0	0	0	0
Hibiscus noldeae	0	0	1	1	0	0	0	0	0	0
Hyparrhenia collina	0	1	0	0	0	0	0	1	1	0
Hyparrhenia filipendula	0	1	0	0	0	0	0	0	0	0
Ipomea batatas	0	1	0	0	0	0	0	1	0	0
Manihot esculenta	0	0	0	0	1	**0**	1	0	1	1
Moesa lanceolata	0	0	0	0	1	**0**	0	0	0	0
Myrica salicifolia	0	1	0	0	1	0	1	0	0	0
Panicum chionachne	0	1	0	0	1	0	0	0	0	0
Passiflora ligularis	0	0	0	1	0	0	0	0	0	0
Phytolacca dodecandra	0	0	0	1	1	0	0	0	0	0
Psidium guajava	0	0	0	0	1	**0**	0	0	0	0
Rubus rigidus	0	0	0	1	0	**1**	0	0	0	0
Sesbania sesban	0	0	1	0	0	0	0	1	1	0
Sporobolus pyramidalis	0	1	0	0	0	0	0	0	1	0
Acanthus pubescens	1	0	1	1	0	1	1	1	0	0
Acanthus repens	0	0	0	0	0	1	1	1	0	0
Ageratum conyzoides	1	0	0	1	1	1	1	1	1	1

Antherotomma naudinii	1	0	0	0	0	0	0	0	0	0
Aspilla kotschyi	0	0	0	0	0	0	0	1	0	0
Bidens grantii	0	0	0	0	0	1	0	1	0	0
Bothriocline longipes	0	0	0	0	0	0	0	0	0	1
Brachiaria semiundulata	0	0	0	0	0	0	0	0	0	1
Caesalpina decapetala	0	0	0	1	0	0	0	0	0	0
Centella asiatica	1	1	1	0	0	1	1	1	1	0
Clerodendron rotundifolium	0	0	0	1	1	0	1	0	0	0
Commelina benghalensis	0	0	0	0	0	1	1	1	0	0
Conyza wewitschii.	1	1	0	0	0	0	0	0	0	0
Crassocephalum vitellinum	1	1	0	1	0	1	1	1	1	1
Crotalaria dewildemaniana	0	0	1	0	0	1	0	1	1	0
Crotalaria recta	0	0	1	1	0	0	0	0	0	0
Cupressus sp	0	0	0	1	0	1	0	0	0	0
Cynodon nlemfuensis	0	0	0	0	0	1	0	1	0	0
Cyperus distans	0	0	0	0	0	0	1	1	0	1
Cyperus pseudoleptocladus	0	0	0	0	0	0	0	0	0	1
Digitaria abyssinica	1	1	1	1	0	1	1	1	1	0
Digitaria velutina	0	0	0	0	1	**0**	0	0	0	1
Eriosema montanum	0	0	1	0	0	0	0	0	0	0
Erythrina abyssinica	0	0	0	0	0	0	1	0	0	0
Eucyptus ficifolia.	0	0	0	0	0	1	0	0	0	0
Gynura scandes	0	0	0	0	0	1	1	1	1	1
Helichrysum muchoianum	1	0	0	0	0	0	0	0	0	0
Helichrysum newll	0	0	0	0	0	1	0	0	0	0
Hibiscus ludwigii	0	0	0	0	0	0	0	1	0	0
Hoslundia opposita	1	0	0	1	0	1	1	1	0	0
Hyparrhenia collina	0	0	0	0	0	0	1	0	0	0

Hyparrhenia rufa	0	1	0	0	0	0	0	0	0	0
Impatiens bequartii	0	0	0	0	0	0	1	0	0	0
Indigofera arrecta	0	1	1	0	0	1	0	0	0	0
Ipomea batatas	0	0	0	0	0	1	1	0	0	0
Ipomea cairica	0	0	0	0	0	0	1	1	0	0
Lantana camara	0	0	0	1	1	0	0	0	0	0
Leersia hexandra	0	0	0	0	0	0	1	0	0	0
Ludwigia abyssinica	0	0	0	0	1	**0**	0	0	0	0
Melinis minutiflora	1	1	0	0	0	1	1	1	1	0
Microglossa pyrifolia	0	0	0	0	0	1	0	0	0	0
Oxalis lafifolia	0	0	0	0	0	0	1	0	0	1
Paspalum conjugatum	0	1	1	0	0	0	0	0	0	0
Pennesetum purpureum	0	0	0	1	0	0	0	0	0	1
Polygonum pulchrum	0	0	0	0	0	0	0	0	1	0
Pteridium aqualinum	0	0	0	0	0	1	1	1	0	0
Rhynchosia luteola	0	0	0	0	0	1	1	0	1	0
Rhynchosia minima convol	0	0	0	0	0	0	1	0	0	0
Selaginella sp	0	0	0	0	0	1	0	1	0	0
Sensiviera dawei	0	0	0	1	0	0	0	0	0	0
Spermacoce princae	0	0	0	0	0	1	1	1	0	0
Tephrosia pumila	0	0	0	0	0	0	0	1	0	0
Tithonia diversiflora	0	0	0	0	0	0	0	0	1	0
Triumfetta cordifolia	0	0	0	1	0	**0**	1	1	1	0
Vernonia amygdalina	0	0	1	1	0	0	0	0	0	0

2. Mpare site

P9 T6 MPARE SITE 2	T6	T7	T17
Commelina benghalensis	0	1	0
Crassocephalum vitellinum	0	1	1
Cupressus sp.	0	1	0
Dracoena afromontana	1	0	0
Eragrostis exasperata.	0	1	0
Euphorbia tirucalli	1	0	0
Hoslundia opposita	0	1	0
Ipomea batatas	1	0	0
Lantana camara	0	1	0
Leonotus nepetifolia	1	0	0
Pteridium aqualinum	0	1	0
Rubus rigidus	0	1	0
Ageratum conyzoides	1	1	1
Bidens grantii	0	0	1
Bidens pilosa	1	0	1
Brachiaria semiundulata	0	0	1
Centella asiatica	0	0	1
Conyza welwitschii	1	0	0
Digitaria abyssinica	1	1	0
Digitaria velutrina	0	0	1
Erytrina abyssinica	0	0	1
Eucalyptus ficifolia	0	1	1
Galisonga parviflora kimari	0	0	1
Gynura scandes	0	0	1
Helichrysum globosum	0	1	0
Hyparrhenia filipendula	1	0	0
Hyparrhenia filipendula	0	0	1
Ipomea batatas	0	0	1
Ipomea cairica	0	0	1
Mangifera indica	1	0	0
Manihot esculenta	1	1	1
Melenis minutiflora	0	0	1
Musa banana	1	0	0
Oxalis latifolia	1	0	0
Passiflora ligularis	0	1	0
Psidium guajava	1	1	0
Pteridium aqualinum	1	0	0
Rubus rigidus	1	0	0
Sesbania sesban	0	0	1
Spermacoce princae	0	1	1

Triumfetta cordifolia	0	0	1
Vernonia amygdalana	1	0	1

3. Rwasare site

Plant species	T11	T18
Acanthus pubescens	0	1
Achyranthus aspera	0	1
Ageratum conyzoides	1	1
Bambusa vulgaris	1	1
Bidens pilosa	1	0
Brachiaria semiundulata	0	1
Bridelia bridellifolia	0	1
Colocasia esculenta	1	1
Commelina benghalensis	1	1
Crassocephalum vitellinum	0	1
Cynodon nlemfuensis	1	0
Cyperus distans	0	1
Dasylepis racemosa	1	0
Digitaria abyssinica	1	1
Dissotis ruandensis	0	1
Dyschoriste trichocalyx	1	0
Eleusine indica	1	0
Erythrina abyssinica	1	1
Galisonga parviflora	0	1
Gynura scandens	1	1
Hibiscus ludwigii	1	0
Hoslundia opposita	1	0
Impetiens buntonii	0	1
Ipomea batatas	1	1
Ipomea cairica	1	1
Leonotus nepetifolia	1	1
Melinis minuflora	1	1
Nephrolepis cordifolia	0	1
Passiflora edilus	1	1
Pennesetum purpureum	1	1
Polygonum pulchrum	1	0
Pteridium aqualinum	1	0
Triumfetta cordifolia	1	1
Zea mays	0	1

4. Birambo site

	T8	T9	T10	T19	T20
Acalypha racemosa	0	1	0	0	0
Bridelia micrantha	1	0	1	0	0
Centella asiatica	0	1	0	0	0
Cyperus latifolia	0	1	0	1	1
Desmodium intortum	1	0	0	0	0
Digitaria abyssinica	1	1	0	0	0
Leersia hexandra	0	1	1	1	1
Melinis minutiflora	1	0	0	0	0
Pennisetum purpureum1	1	1	0	1	0
Ageratum coyzoides	0	1	0	1	1
Bidens grantii	0	0	0	1	0
Biumphetum petersianum	0	0	0	1	0
Brachiaria semiundulata	0	0	0	1	0
Bridelia bridellifolia	0	0	1	0	0
Cassia singueans	0	0	0	1	0
Commelina benghalensis	0	1	1	1	1
Crassocephalum vitellinum	0	0	0	1	0
Crotalaria dewildemaniana	0	0	0	1	0
Cyperus papyrus	0	1	1	0	1
Dissotis ruandensis	0	0	0	1	0
Dyschoriste trichocalyx	0	1	1	0	0
Galisonga parviflora	0	0	0	1	1
Gynura scandes	0	0	0	1	0
Helichrysum globosum	0	0	0	1	0
Helichrysum mechoianum	1	0	0	0	0
Hyparrenia nifa	0	0	0	0	1
Imperata cylindrica	1	0	0	0	0
Indigofera arrecta	0	0	0	1	0
Lantana camara	1	0	0	0	0
Leonotus nepetifolia	0	0	0	0	0
Ludwigia abyssinica	0	1	1	1	1
Nephrolepis cordifolia	1	0	0	1	0
Panicum chionachyne	0	0	0	1	0
Paspalum sciobiculatum	1	0	0	0	0
Polygonum pulchrum	0	1	1	1	1
Polysias fulva	1	0	0	0	0
Rhyncholyntum repens	1	0	0	0	0
Triumfetta cordifolia	0	1	1	1	0

Appendix 5: General transect of the four sites in Gatumba

Plant species	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
Acalypha racemosa	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Acanthus pubescens	0	0	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0
Acanthus repens	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
Achyranthes aspera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Ageratum conyzoides	1	0	0	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1
Antherotomma naudinii	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aspilla kotschyi	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Bambusa vulgaris	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0
Bidens grantii	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	0
Bidens pilosa	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0
Biophytum petersianum	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
Bothriocline longipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Brachiaria semiundula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
Bridelia micrantha	0	0	0	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0
Bridelia brideliifolia	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0
Caesalpina decapetala	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cassia singueans	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0
Centella asiatica	1	1	1	0	1	0	0	0	1	0	0	1	1	1	0	0	1	0	0	0
Clerodendrum myricoides	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Clerodendrum rotundifolium	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0
Colocasia esculenta	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
Commelina benghalensis	0	0	0	0	1	1	0	0	1	1	1	1	1	1	0	0	0	1	1	1

Conyza wewitschii	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crassocephalum vitellinum	1	1	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0
Crotalaria arrecta	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
Crotalaria dewildemaniana	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0
Cupressus sp	0	0	0	1	0	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0
Cynodon nlemfuensis	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0
Cyperus distans	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0
Cyperus latifolia	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
Cyperus papyrus	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	1
Cyperus pseudoleptocladus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Cyperus rigidifolius	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1
Dasylepsis racemosa	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Desmodium intortum	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Digitaria abyssinica	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	0	0
Digitaria velutina	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
Dissotis ruandensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Dracoena afromontana	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Dyschoriste trichocalyx	0	0	0	0	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Eleusine indica	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Eragrostis exasperata	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriosema montanum	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erythrina abyssinica	0	0	0	1	0	0	1	1	0	0	1	0	1	0	0	0	1	1	0	0
Eucalyptus filifolia	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0
Euphorbia tirucalli	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galinsoga parviflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
Gynura scandens	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0
Helichrysum globosum	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0

Helichrysum mechoianum	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Helichrysum newll	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Hibiscus ludwigii	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0
Hibiscus noldeae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hoslundia opposita	1	0	0	1	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
Hyparrhenia collina	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
Hyparrhenia filipendula	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Hyparrhenia rufa	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Impatiens bequartii	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Impatiens burtonii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Imperata cylindrica	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Indigofera arrecta	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
Ipomoea batatas	1	0	0	0	0	1	0	0	0	0	1	1	1	1	0	0	1	1	0	0
Ipomoea cairica	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0	1	1	1	0	0
Lantana camara	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Leersia hexandra	0	0	0	0	1	1	0	0	1	1	0	0	1	0	0	0	0	0	1	1
Leonotis nepetaefolia	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	1	1	0
Lipocarpha chinensis	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
Ludwigia abyssinica	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1
Maesa lanceolata	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Mangifera indica	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Manihot esculenta	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0
Melinis minutiflora	1	1	0	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	0	0
Microglossa pyrifolia	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Musa sapientum	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Myrica salicifolia	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Nephrolepis cordifolia	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0

Oxalis latifolia	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0
Panicum chionachne	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Paspalum conjugatum	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paspalum scrobiculatum	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Passiflora edulis	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0
Passiflora ligularis	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Pennisetum purpureum	0	0	0	1	1	0	0	1	1	0	1	0	0	0	0	1	0	1	1	0
Phytolacca dodecandra	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Polygonum pulchrum	0	0	0	0	1	1	1	0	1	0	1	0	0	0	1	0	0	0	1	1
Polyscias fulva	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Psidium guajava	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Pteridium aquilinum	0	0	0	0	0	0	1	0	1	1	1	1	1	1	0	0	0	0	0	0
Rhynchelytrum repens	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Rhynchosia luteola	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Rhynchosia minima	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Rubus rigidus	0	0	0	1	0	1	0	1	1	1	0	1	0	1	0	0	0	0	0	0
Selaginella sp.	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
Senseviera dawei	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Sesbania sesban	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0
Spermacoce princae	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	0	0	0
Sporobolus pyramidalis	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tephrosia pumila	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Tithonia diversiflora	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Triumfetta codifolia	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	0
Vernonia amygdalina	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Zea mays	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Appendix 6: Shannon indices

Table 1: Shannon index results, Ruhanga

Sample	Index	Evenness	Num.Spec.
T1	1.04	1.00	11.00
T2	1.18	1.00	15.00
T3	1.04	1.00	11.00
T4	1.30	1.00	20.00
T5	1.18	1.00	15.00
T12	1.41	1.00	26.00
T13	1.46	1.00	29.00
T14	1.43	1.00	27.00
T15	1.20	1.00	16.00
T16	1.08	1.00	12.00

Table 2: Shannon index results, Mpare

Sample	Index	Evenness	Num.Spec.
T6	1.26	1.00	18.00
T7	1.23	1.00	17.00
T17	1.30	1.00	20.00

Table 3: Shannon indices results, Rwasare

Sample	Index	Evenness	Num.Spec.
T11	1.36	1.00	23.00
T18	1.41	1.00	26.00

Table 4: Shannon indices results, Birambo

Sample	Index	Evenness	Num.Spec.
T8	1.11	1.00	13.00
T9	1.11	1.00	13.00
T10	0.95	1.00	9.00
T19	1.36	1.00	23.00
T20	1.04	1.00	11.00

Table 5 Shannon indices results, Gatumba

Sample	Index	Evenness	Num.Spec.
T1	1.08	1.00	12.00

T2	**1.00**	**1.00**	**10.00**
T3	**1.04**	**1.00**	**11.00**
T4	**1.34**	**1.00**	**22.00**
T5	**1.11**	**1.00**	**13.00**
T6	**1.34**	**1.00**	**22.00**
T7	**1.41**	**1.00**	**26.00**
T8	**1.30**	**1.00**	**20.00**
T9	**1.26**	**1.00**	**18.00**
T10	**1.23**	**1.00**	**17.00**
T11	**1.32**	**1.00**	**21.00**
T12	**1.41**	**1.00**	**26.00**
T13	**1.41**	**1.00**	**26.00**
T14	**1.49**	**1.00**	**31.00**
T15	**1.15**	**1.00**	**14.00**
T16	**1.11**	**1.00**	**13.00**
T17	**1.30**	**1.00**	**20.00**
T18	**1.40**	**1.00**	**25.00**
T19	**1.30**	**1.00**	**20.00**
T20	**0.95**	**1.00**	**9.00**

Appendix 7: Bioaccumulation and Translocation

BCFs znd TFs in different parts of plants	**BCF**				**TF**	
Cs(µg/g)	**Dry season**	**Rainy season**			**Rainy season**	
Plants	Shoots	Roots	Stems	Leaves	Stems	Leaves
Centella asiatica	0.34		0.18	0.24		
Digitaria abyssinica	0.09	0.05	0.05	0.10	0.87	1.78
Melinis minutiflora	0.15	0.06	0.05	0.20	0.83	3.49
Ipomoea batatas	0.49	0.28	0.51	0.52	1.84	1.88
Crotalaria dewildemaniana	0.11		0.13	0.22		
Sesbania sesban	0.22		0.16	0.22		
Manihot esculenta	0.06		0.17	0.13		
Ageratum conyzoides	0.22	0.24	0.10	0.23	0.40	0.96
Pennisetum purpureum	0.07		0.05	0.09		
Polygonum pulchrum	0.07		0.06	0.07		
Cyperus papyrus	0.06		0.12			
Ludwigia abyssinica	0.05		0.11	0.10		
Ipomoea Cairica	0.08		0.05	0.07		

Tithonia diversifolia			0.01	0.04		
Colocasia esculenta	0.03	0.04		0.02		0.52
Erythrina abyssinica	0.13		0.07	0.08		
Phytolacca dodecandra	0.38		0.17	0.38		
Pb(µg/g)						
Centella asiatica	0.08		0.11	0.14		
Digitaria abyssinica	0.10	0.07	0.07	0.24	0.94	3.39
Melinis minutiflora	0.12	0.15		0.09		0.64
Ipomoea batatas	0.07			0.44		
Crotalaria dewildemaniana	0.03			0.04		
Sesbania sesban	0.07		0.13			
Manihot esculenta	0.10		0.03			
Ageratum conyzoides	0.05	0.60	0.12	0.47	0.21	0.78
Pennisetum purpureum	0.09		0.18			
Polygonum pulchrum	0.11			0.01		
Cyperus papyrus	0.04					
Ludwigia abyssinica	0.06		0.91			
Ipomoea Cairica	0.15					
Tithonia diversifolia			0.77	0.20		
Colocasia esculenta	0.18			0.22		
Erythrina abyssinica	0.14					
Phytolacca dodecandra	0.02					
Bi(µg/g)						
Centella asiatica						
Digitaria abyssinica				0.02		
Melinis minutiflora		0.03		0.08		2.57
Ipomoea batatas				0.10		
Crotalaria dewildemaniana				0.00		
Sesbania sesban						
Manihot esculenta						
Ageratum conyzoides		0.18		0.14		0.75
Pennisetum purpureum			0.07	0.02		
Polygonum pulchrum			0.00	0.00		
Cyperus papyrus	0.02					
Ludwigia abyssinica						
Ipomoea Cairica			0.00	0.01		
Tithonia diversifolia				0.01		
Colocasia esculenta		0.01				
Erythrina abyssinica						
Phytolacca dodecandra						
U(µg/g)						
Centella asiatica	0.03		0.03	0.04		
Digitaria abyssinica	0.03	0.07	0.02	0.11	0.28	1.62

Melinis minutiflora	0.05	0.11	0.02	0.14	0.15	1.26
Ipomoea batatas	0.01	0.00	0.03	0.06	7.49	16.97
Crotalaria dewildemaniana	0.01		0.01	0.01		
Sesbania sesban	0.01		0.00	0.01		
Manohot esculenta	0.01		0.00	0.00		
Ageratum conyzoides	0.02	0.15	0.01	0.06	0.08	0.42
Pennisetum purpureum			0.00	0.00		
Polygonum pulchrum			0.00	0.01		
Cyperus papyrus				0.00		
Ludwigia abyssinica	0.00		0.00	0.00		
Ipomoea Cairica	0.01		0.03	0.02		
Tithonia diversifolia			0.00	0.02		
Colocasia esculenta	0.01	0.03		0.01		0.44
Erythrina abyssinica	0.02		0.00	0.00		
Phytolacca dodecandra	0.01		0.00	0.01		
Zn(µg/g)						
Centella asiatica	4.87		21.06	22.39		
Digitaria abyssinica	1.26	6.94	21.69	9.90	3.13	1.43
Melinis minutiflora	1.95	3.68	23.85	18.33	6.49	4.98
Ipomoea batatas	30.21	5.57	7.77	5.57	1.39	1.00
Crotalaria dewildemaniana	4.52		1.01	1.74		
Sesbania sesban	3.16		2.43	3.32		
Manohot esculenta	12.30		6.14	4.39		
Ageratum conyzoides	6.77	2.01	1.47	4.19	0.73	2.08
Pennisetum purpureum	0.87		6.92	0.74		
Polygonum pulchrum	1.20		0.76	0.68		
Cyperus papyrus	0.29		0.30			
Ludwigia abyssinica	1.83		1.64	1.90		
Ipomoea Cairica	3.50		3.97	2.53		
Tithonia diversifolia			10.08	5.97		
Colocasia esculenta	1.65	2.55		1.59		0.63
Erythrina abyssinica	8.27		2.36	1.51		
Phytolacca dodecandra	4.54		3.44	3.83		
As(µg/g)						
Centella asiatica	0.08		0.07	0.09		
Digitaria abyssinica	0.04	0.10	0.03	0.16	0.28	1.53
Melinis minutiflora	0.05	0.11	0.02	0.16	0.18	1.52
Ipomoea batatas	0.01	0.01	0.03	0.16	3.90	18.54
Crotalaria dewildemaniana			0.02	0.03		
Sesbania sesban	0.04		0.05	0.19		
Manihot esculenta	0.01		0.00	0.01		
Ageratum conyzoides	0.02	0.15	0.02	0.11	0.13	0.71
Pennisetum purpureum			0.00	0.01		

Polygonum pulchrum	0.02		0.01	0.03		
Cyperus papyrus	0.00		0.01			
Ludwigia abyssinica	0.01		0.00	0.01		
Ipomoea Cairica	0.01		0.01	0.01		
Tithonia diversifolia			0.00	0.02		
Colocasia esculenta	0.00	0.01		0.01		0.48
Erythrina abyssinica	0.01		0.00	0.01		
Phytolacca dodecandra	0.01		0.01	0.02		
Rb(µg/g)						
Centella asiatica	2.92		2.90	3.64		
Digitaria abyssinica	4.11	0.72	1.10	1.01	1.53	1.40
Melinis minutiflora	0.86	0.58	0.72	1.17	1.25	2.04
Ipomoea batatas	2.48	2.94	3.61	3.81	1.23	1.30
Crotalaria dewildemaniana			2.08	1.80		
Sesbania sesban	0.91		1.22	0.71		
Manihot esculenta	0.74		2.32	2.11		
Ageratum conyzoides	3.22	1.83	1.73	1.76	0.94	0.96
Pennisetum purpureum	2.29		4.98	1.61		
Polygonum pulchrum	1.38		1.96	1.04		
Cyperus papyrus	0.45		0.90			
Ludwigia abyssinica	0.91		1.73	0.83		
Ipomoea Cairica	1.79		0.84	1.26		
Tithonia diversifolia			0.73	1.31		
Colocasia esculenta	0.93	1.02		0.37		0.36
Erythrina abyssinica	0.54		1.82	2.77		
Phytolacca dodecandra	3.68		0.00	0.00		
Cd(µg/g)						
Centella asiatica	0.80		0.57	0.37		
Digitaria abyssinica	0.14	0.15	0.06	0.22	0.39	1.51
Melinis minutiflora	0.28	0.42				
Ipomoea batatas				3.26		
Crotalaria dewildemaniana	1.56					
Sesbania sesban	0.03		0.00			
Manihot esculenta	0.02		0.30			
Ageratum conyzoides	9.39	2.01	2.49	5.51	1.24	2.74
Pennisetum purpureum	0.39					
Polygonum pulchrum	0.89					
Cyperus papyrus	0.21		3.57			
Ludwigia abyssinica	0.26		9.51	0.45		
Ipomoea Cairica	0.67		1.46	1.56		
Tithonia diversifolia			3.49	2.68		
Colocasia esculenta	2.90	0.93		5.85		6.27
Erythrina abyssinica						

Phytolacca dodecandra	0.75		0.44	0.38		
Li(µg/g)						
Centella asiatica	0.13		0.12	0.20		
Digitaria abyssinica	0.11	0.17	0.05	0.25	0.28	1.46
Melinis minutiflora	0.51	0.19	0.13	1.02	0.68	5.43
Ipomoea batatas	0.21	0.14	0.13	0.15	0.94	1.08
Crotalaria dewildemaniana	0.47		0.16	0.26		
Sesbania sesban	0.23		0.03	0.30		
Manihot esculenta	0.06		0.00	0.01		
Ageratum conyzoides	0.67	0.24	0.03	0.21	0.14	0.87
Pennisetum purpureum2	0.00		0.01	0.03		
Polygonum pulchrum	0.05		0.01	0.04		
Cyperus papyrus	0.02		0.01			
Ludwigia abyssinica	0.06		0.01	0.05		
Ipomoea Cairica	0.26		0.06	0.07		
Tithonia diversifolia			0.03	0.17		
Colocasia esculenta	0.04			0.03		
Erythrina abyssinica	0.13		0.01	0.01		
Phytolacca dodecandra	0.15		0.02	0.05		
Cu(µg/g)						
Centella asiatica	3.26		3.39	3.76		
Digitaria abyssinica	3.20	6.88	7.23	2.42	1.05	0.35
Melinis minutiflora	2.72	3.09	1.44	2.53	0.47	0.82
Ipomoea batatas	1.58	0.49	0.46	0.53	0.94	1.08
Crotalaria dewildemaniana	2.78		1.64	3.67		
Sesbania sesban	1.78		12.36	18.85		
Manohot esculenta	1.36		1.53	0.62		
Ageratum conyzoides	3.70	4.15	0.49	0.84	0.12	0.20
Pennisetum purpureum	0.27		0.70	0.33		
Polygonum pulchrum	0.28		0.26	0.17		
Cyperus papyrus	0.08		0.06			
Ludwigia abyssinica	0.56		0.54	0.60		
Ipomoea Cairica	0.50		0.58	0.50		
Tithonia diversifolia			0.60	0.35		
Colocasia esculenta	0.38			0.53		
Erythrina abyssinica	2.47		0.95	1.62		
Phytolacca dodecandra	0.32		0.27	0.36		