KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

THE POTENTIAL OF INDIGENOUS PLANTS FOR USE IN PHYTOREMEDIATION OF TAILINGS DAM AT CHIRANO GOLD MINE, GHANA

A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL SCIENCE IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE

BY

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DECLARATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

With great pleasure I dedicate this work to my supervisor,

Ebenezer J. D. Belford (PhD)

To my caring and loving father,

John K. Nkansah

And

To a friend like no other

Evelyn Owusu-Dentaah

I thank all of you for your guidance and support in endeavour ways for making this dream a reality.

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LIST OF ABFEVIATIONS AND ACRONYMS

As	Arsenic
CN	Cyanide (free)
Cd	Cadmium
Zn	Zinc
BF	Bioaccumulation factor
TF	Translocation factor
TSF1	Tailings Storage Facility 1

BABDA Bibiani-Anhwiaso-Bekwai SWD Sefwi-Wiawso Districts pH Hydrogen potential HCl Hydrogen Chloride

HNO_3	Nitric acid
EDTA	Ethylenediaminetetraacetic acid
AAS	Atomic Absorption Spectrometer

ABSTRACT

The potential of indigenous plants for use in phytoremediation of heavy metal contaminated soil in Chirano Gold Mine Limited was investigated. Plant species growing in and around the Tailings Storage Facility 1 were sampled in five plots, randomly selected. Plants species diversity was determined using the Shannon-Weiner Index. Plants root and shoot of all identified species and soil samples were collected and analysed for Arsenic, Cadmium and Zinc concentrations using Atomic Absorption Spectrophotometer while for Cyanide concentration Cyanide Analyser (Flow-injection analysis) was used. Bioavailable fractions of studied metals were also measured with formation of metal complex with Ethylenediaminetetraacetic acid and ammonium acetate reagents. Data obtained were subjected to Analysis of Variance (ANOVA) using SPSS version 16 with values for $p < 0.05$ considered significantly different. The hyper-accumulation potential and mobility of heavy metals within the plants were determined from the bioaccumulation and translocation factors. A total of 19 plant species belonging to 8 families were identified. The most abundant family was Poaceae (37%). Grasses were the dominant growth form which contributed much to the Shannon-Weiner Index of 2.01. Majority of plants species (90%) are propagated by seeds. The total and bioavailable mean content of heavy metals (Zn, Cd and As) varied in the area with Zinc being most predominant13.20±0.06 mg/kg. However, CN was the most bioavailable with percentage bioavailability of 64. The soil elemental concentrations of Zn (13.20 mg/kg), Cd (0.29 mg/kg), As (3.0 mg/kg) and CN (0.11 mg/kg) were below the WHO recommended standards of 200 mg/kg, 1.4 mg/kg, 12 mg/kg, and 0.9 mg/kg for Zn, Cd, As and CN respectively. The concentrations of all metals were significantly higher in the roots than in the shoots. In all plant species Zinc was the most accumulated heavy metal, recording the highest level of accumulation in the root of *Euphorbia heterophylla*. Bioaccumulation factor as expressed by total and bioavailable metal concentration in soil indicate that all the plant species demonstrate good hyperaccumulation and phytoextraction potential for Zn and Cd whilst 13 and 8 plant species demonstrate good accumulation and phytoextraction potential for CN and As, respectively. The translocation factor indicates that 8 plant species are good phytotranslocators for Zn, 7 plant species for Cd, 10 plant species for As and 8 plants species CN. The accumulative and phytotranslocation potential of these plant species provide useful information about theirs elective exploitation for effective phytoremediation of the tailings dam at Chirano Gold Mine.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Phytoremediation is the use of plant-based technology to degrade, sequester or contain contaminants in soil and water (Abdullah and Sarem, 2010). This technique is gaining grounds in research owing to low cost and its minimal disturbance to earth. In Ghana mining activities in gold sites generate a lot of hazardous wastes, mainly heavy metals from tailings which severely affect the ecosystem, resulting in various degrees of environmental damage, threat to plants, animals as well as human life, and loss of biodiversity (Oppong, 2011; Wong, 2003).

Tailings, a hazardous elemental waste product of ore processing operations can pollute the environment with significant quantities of heavy metals (Oppong, 2011). Currently, modern ore processing techniques avoid the indiscriminate disposal of tailings into the environment. Yet, there are many large, exposed, untreated tailings and derelict sites (Tordoff *et al*., 2000) that desperately need effective re-vegetation to circumvent significant risk to the environment because of the toxic heavy metals and cyanide residues they contain. Thus, slime, otherwise tailings pose health threat to communities living in such areas (Nelushi *et al.*, 2013).

Considerably, large portions of heavy metals are released from tailings to the environment after being oxidized which can lead to the generation of acid drainage especially from sulphide containing tailings (Lapakko, 2002). Oxidation of tailings occurs particularly when

sulphide- containing tailings are exposed to water (moist) and oxygen resulting in the formation of a series of soluble hydrous iron sulphates which hydrolyze to produce highly acidic, ferrous and sulphate-flourished drainage. These conditions results in lowering of the pH and leads to an increased solubility of the heavy metals (Simon *et al*., 2001). Establishment of ecologically successive and self-sustaining mat of vegetation ideally those species native to the region of interest is usually an essential element in a rehabilitation program for contaminated areas. Species of *Chromoleana odorata, Lantana camara*, *Pteris vittata*, *Condylon dactylon* and other wild grasses have been reported for heavy metal bio-indicating and good phytoremedial agents (Aziz, 2011; Gonzaga *et al.*, 2008).

Cleaning tailings using plants, however, is a problem that remains to be addressed on a case-specific basis. The emerging approach to phytoremediation involves the introduction of highly tolerant species such as grass species (Wong, 2003) which have high biomass production, capable of accumulating 0.5 to 1% of metals in their dry weight. The selection of hyperaccumulator species must also be a matter of concern and site-specific and conscious effort of complying with regulations restricting the introduction of foreign species.

1.2 Problem statement

Mine tailings impoundments are sources of heavy metal (Oppong, 2011). The tailings impoundments contains high levels of heavy metals and other chemicals residues like cyanide added during the beneficiation process which can end up in environment through seepage, wind blow or flooding. The mechanical stability of the tailings mass is very poor; others infeasible due to its small grain size and the usually high water contents (U.S.

Environmental Protection Agency, 1994).

Heavy metals in tailings can be traced in soils, water or plants. Plants bio-accumulate heavy metals from contaminated soils through their roots while those that settle on them are absorbed via the leaves (Mendez, 2007). The tailings storage facility (STF 1) in Chirano Gold Mines, Western region, is surrounded by near and far farms where cocoa and other crops are cultivated. The risk herein is potential biological accumulation of heavy metal which can result ill-health in humans like diarrhoea, cancer, stomach cramps, nausea, anaemia, kidney damage and brain damage (Mendez, 2007).

1.3 Justification

Phytomining, a technique for extracting metals from low-grade ore or mine tailings, is a promising technique currently being developed for commercialization in many developed countries; typically US. Field survey of plant species growing in and around Chirano Gold Mines Tailing Storage Facility 1 (TSF1) can provide valuable information for selective exploitation of potential species in phytomining. The need to mitigate environmental contamination is of national concern due to our quest to increase agricultural lands already in use (Aziz, 2011). Moreover, remediation efforts need to be effective and affordable (Abdullah and Sarem, 2010; Rajakaruna *et al*., 2006) as compared to conventional method like excavation which is costly and also likely to introduce secondary contaminants into the environment. Owing to the likely event of acid drainage from mine tailings especially sulphide-containing tailings necessitate the establishments of plant species that have the potential to decontaminate pollutant and also capable of establishing natural succession of

species to prevent erosion of such tailings into neighbouring lands. For successful and effective phytoremediation programmes to be achieved, plants of phytoremediation potential must be sought and used. Thus, studies that screen plants for their potential to phytoremediate contaminated soils are desirable.

1.4 Objectives of the study

1.4.1 Main objective

The goal of this study was to evaluate the potential of indigenous plants for use in phytoremediation of tailings dam at Chirano Gold Mining site, Ghana.

1.4.2 Specific objectives

1. To identify indigenous plant species growing in and around the tailings dam at Chirano Gold Mine
2. To determine the distribution and density of indigenous plant species growing in and around the tailings dam
3. To determine the levels of As, Zn, Cd and Cyanide (CN) in plants species identified growing in and around the tailings dam
4. To determine the bioaccumulation and translocation factors of indigenous plant species for their potential use in phytoremediation of tailings dam at Chirano Gold Mining Site

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Mining in Ghana

The significance of mining industry to the growth of Ghana's gross domestic product over the years cannot be overwritten. In practice, open-pit and underground mining (Remy, 2013; Oppong, 2011) are operationalised in Chirano and other mining companies in Ghana. Open-pit (surface) mining involves stripping the topsoil including flora and fauna to expose the reef, followed by blasting the reef and scooping the ore. However, underground mining entails sinking a vertical shaft deep into the ground which gives access to ore body. Drilled holes are impregnated with dynamite and then blasted into chunks which are conveyed for processing (Remy, 2013; Bempa *et al*., 2013). Gold, bauxite and diamond are examples of minerals mined in Ghana. Chirano achieved its first gold pour in October, 2005 in Ghana and remains one of vibrant mines on the continent of Africa. By-products of the mineral processing which include tailings, sulphuric acid, hydrochloric acid, cyanide residues and other chemicals become hazardous to the environment if standard methods of disposal are not adhered.

2.2 Heavy metal in the environment

In science, heavy metal are generally referred to metals or metalloids (elements that have both metal and non-metal characteristics), with densities above 5 g/cm^3 that can persistent in all parts of the biosphere with limited degradation (Sherene, 2010; Rajeswari and Namburu, 2014). Lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), arsenic (As), silver

(Ag) chromium (Cr), copper (Cu), iron (Fe), and the platinum group elements are wellknown as heavy metals (Duruibe *et al*., 2007; Wong, 2003). Both natural and anthropogenic activities emit heavy metals into the environment. Heavy metals are natural constituents of the Earth's crust. The concentration of several heavy metals has increased several folds in some ecosystems as a result of continual plough of the earth for human benefit. Heavy metal contamination is of global concern, mainly because of the health threat they present to humans and livestock (Nazir *et al*., 2011). Human activities, specifically mining operations are the major causes of emissions of heavy metals (Rajeswari and Namburu, 2014). Tailings dams are places where wastes resulting from gold extraction are stocked. These wastes are mainly composed of grinding ore and water.

Tailings are the major source of heavy metals in mining areas (Oppong, 2011; Remy, 2013).

2.3 Heavy metal contaminated soil remediation technologies

Heavy metals in the environment can be poisonous for macro- and micro-organisms through the direct adverse impact on biochemical and physiological procedures, declining growth, deteriorating cell organelles, and cessation of photosynthesis (Moosavi and Seghatoleslami, 2013). The need for remediation of heavy metals contaminated soils to ensure environment health and safety has become more imperative in Ghana with emergence of small scale mining 'galamsey', industrialization and urbanization and demand for land for agriculture. Decontamination of these sites is recognized as the most difficult problem to be solved. For this reason the development of innovatively economical cost effective solution represent a very interesting technological and scientific issue (Montinaro *et al*., 2007). Remediation technologies, including physical remediation, chemical remediation and biological

remediation are recent techniques used for remediation of heavy metal contaminated soils. Phytoremediation is the biotechnological use of plants and bioavailable energy (solar energy) to detoxify pollutant, and is an ideal and recent technique for environmental clean-up (Gill, 2014).

2.4 Phytoremediation

2.4.1 Phytoremediation– operational strategies

Metallophyte and pseudometallophyte species are the likely pioneers of areas with high heavy metals and metalloids contaminations, such as mine waste and tailings or soils degraded and polluted by mining activities. These plant species have the ability to develop physiological mechanisms of both resistance and tolerance to survive on substrates with high metal pollution (Baker, 1989 as cited in Favas *et al*., 2014).

Plants deploy various phytoremediation techniques depending on the chemical nature and physical properties of the contaminant in question (if it is inert, volatile or subject to degradation in the plant or in the soil) and the plant characteristics (Figure 1). Phytostabilization, phytoextraction, phytofiltration, phytodegradation, phytostimulation constitute principally the five major phytoremediation strategies though more than one may be utilized by a plant simultaneously (Favas *et al*., 2014).

2.4.2 Phytoextraction/ phytoaccumulation

Phytoaccumulation, Phytoabsorption or Phytosequestration involves the absorption of contaminants by roots followed by translocation and accumulation in the aerial or

harvestable parts of plants (Ali *et al*., 2012; Gill, 2014) (Figure 1). It is mainly applied to metals (Cd, Ni, Cu, Zn, Pb) but can also be used for other elements (Se, As) and organic compounds. This technique preferentially uses hyperaccumulator plants that have the ability to store high concentrations of specific metals in their aerial parts (0.01% to 1% dry weight, depending on the metal). *Elsholtzia splendens*, *Alyssum bertolonii*, *Thlaspica erulescens* and *Pteris vittata* are known examples of hyperaccumulator plant species for Cu, Ni, and Zn/Cd and As, respectively (Favas *et al*., 2014).

Phytodesalination is an emerging technique that utilizes halophytes to remove excess salts from saline soils and it is said to be a modality of phytoextraction. Reports of *Suaeda maritime* and *Sesuvium portulacastrum* to remove and accumulate NaCl, from highly saline soils have been accounted in research (Zorrig *et al*., 2012). This technique is a modification of phytoextraction.

2.4.3 Phytodegradation/phytotransformation

Plants with their associate microbes (enzymes) degrade organic pollutants within plants tissues (Figure 1). During phytodegradation (also known as phytotransformation), specific enzymes degrade organic contaminant inside the plant cells that include nitroreductases (degradation of nitroaromatic compounds), dehalogenases (degradation of chlorinated solvents and pesticides) and laccases (degradation of anilines) (Black 1995 as cited in Chaudhry *et al*., 1998). Phytodegradation is limited to the removal of organic pollutants only because heavy metal is non-biodegradable (Ali *et al*., 2013).

2.4.4 Rhizofiltration

Mine tailings are often associated with water layer saturating the impoundment. Plant roots absorb metals from such wastes streams (Moosavi and Seghatoleslami, 2013) concentrate and/or precipitate contaminants, typically, heavy metals or radioactive elements, from anaqueous medium via their root system or other submerged anchoring organs (Favas *et al*., 2014). Aquatic hyperaccumulator are able to tolerate heavy metals due to their high root biomass, or/and high absorption surface hence mostly achieve the best results (Favas *et al*., 2014). Rhizofiltration involves using plants to clean up aquatic environments (Gill, 2014; Moosavi *et al*., 2013).

2.4.5 Phytostabilisation

This uses plants production of compounds to reduce the mobility and bioavailability of pollutants in the environment either by immobilization or prevention of migration at the near-surface of the roots and soil or roots and water (Ghosh and Singh, 2005; Gill, 2014; Moosavi *et al.*,2013) (Figure 1). Phytoimmobilization of contaminants as seen in Figure 1 such as organic or inorganic involves the incorporation of the contaminant into the lignin of the cell wall of roots cells or into humus. Metals are precipitated as insoluble forms by direct action of root exudates and subsequently trapped in the soil matrix. Species of genera *Haumaniastrum*, *Eragrostis*, *Ascolepis, Gladiolus* and *Alyssum* are examples of plants cultivated for this purpose (Favas *et al*.,2014).

2.4.6 Phytovolatilisation

Phytovalatilization involves the conversion of pollutant to volatile forms and subsequent expulsion into the atmosphere via plant leaves (Ali *et al.*, 2013) (Figure 1). Portions of

elemental ions of the groups IIB, VA and VIA of the periodic table (typically Hg, Se and As) are taken up by the roots, and chemically converted into non-toxic forms by this technique. Later the non-toxic compounds are then released into the atmosphere. This technique is applicable for decontaminating organic compounds.

2.4.7 Rhizodegradation/Phytostimulation

Growing roots enhance the proliferation of degrading rhizosphere microorganisms which utilize exudates and metabolites of plants as a source of carbon and energy. On the other hand, plants may exude bio-enzymes themselves to facilitate the degradation. The application of phytostimulation is limited to organic contaminants (Figure 1).

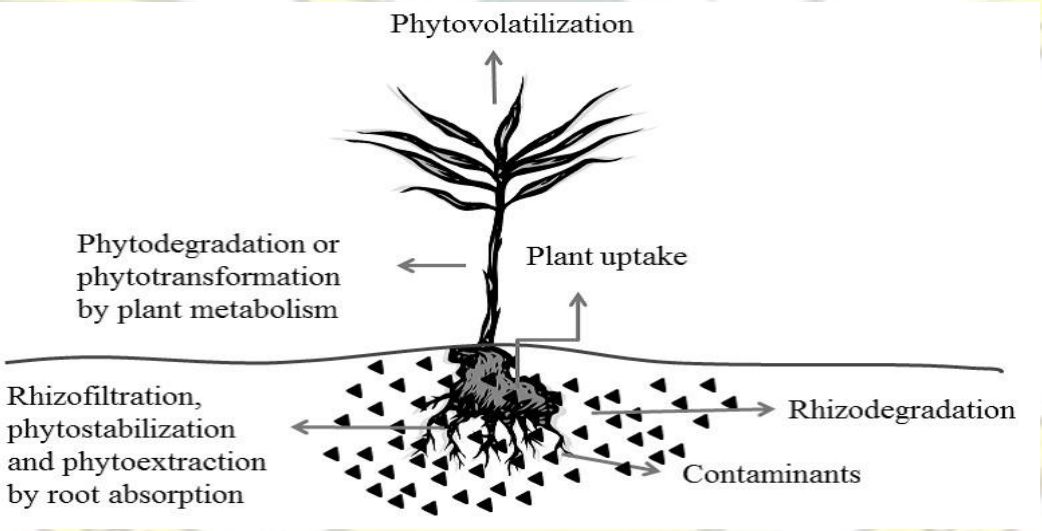


Figure 1: Mechanisms of phytoremediation (Source: Favas *et al*., 2014)

2.5 Plant Characteristics for phytoremediation and phytomining

Using common plants is not viable option in phytoremediation program (Tordoff *et al*., 2000) hence suitable plants should be selected. Subhashini and Swamy (2013) report that plant purported for this clean-up technology is expected to:

- be tolerant to heavy-metals,
- have rapid growth potential with a high biomass yield per hectare,
- have the ability to concentrate high metal in the shoot,
- have a profuse root system, and
- a high bioaccumulation factor.

Phytoremedial agent can act as contaminant accumulators, indicators or excluders; based on the way they take up and translocate constituents to above ground biomass (Kavitha, 2013; Mganga *et al*., 2011).

Excluders

These are plants that are insensitive to the uptake and accumulation of potentially toxic elements. Mainly, monocotyledon grasses such as Sudan grass, fescue belong into this group (Kavitha, 2013; Mganga *et al*., 2011).

Indicators

Heavy metal indicators are plants species that are readily receptors of metals and show linear response to increasing available metal content in soil. They actively accumulate metal in their aerial tissues (Kavitha, 2013; Mganga *et al*., 2011). These plants are capable of storing existing metal concentrate in non-sensitive parts by changing metal compartmentalization

pattern or produces organic chelators that bind metals in the intracellular matrix (Kavitha, 2013).

Accumulators

These are plants that accumulate high contents of elements in their tissues according to their increase in the soil either as non-hyperaccumulator or hyperaccumulator than nonaccumulating species growing nearby (Mganga *et al.*, 2011). Accumulators include many species of *Brassicaceae* (mustard), and Compositae (lettuce, spinach) families. There are extreme accumulators (hyperaccumulators) that can even prosper on contaminated soils and accumulate extremely high contents of trace elements without suffering phytotoxic effect.

2.6 Phytoremediation cap

Phytoremediation cap describes herbs (usually grasses), shrubs or trees that are established on contaminated soils to incorporate contaminant destruction or removal and to halt infiltration of the contaminant into the soil profile. Establishing caps on tailings can minimise the infiltration of rain water and immobilize the spread of pollutants. The fibrous roots of phytoremedial agents increase soil aeration and enhance biological activities of limited macro and micro fauna, and thus, improve the soil (tailings) structure (Mendez, 2007). A posing threat to this technique is that tailings generally are not suitable for the growth of plant roots.

However, various studies have been done with the aim of developing processes of cultivation in tailings. For instance, soil amendment agents like organic soil composed of sawdust, plant

remains, chicken dropping, cow dung and some NPK-fertilizers have been suggested to aid survival and growth of remedial candidates (Aziz, 2011). The vegetated caps thus reduce erosion, and potentially destroy or remove contaminants via principally phytoextraction and phytostablilization. Long-term maintenance of the cap might be required to ensure continual plant succession that will maintain the cap integrity.

2.7 Evaluating phytoremediation as a potential remediation technology

In remediation process, a risk assessment may be performed to evaluate how potential remedial options may address the problem (Gill, 2014). Remedial options such as physical, chemical and biological methods (Khan *et al.*, 2004) are compared to one another, and an innovative remediation technology, such as phytoremediation, must offer advantages in terms of either risk reduction or cost savings over excavation and landfilling of contaminated material or other traditional techniques to be implemented at a site.

2.8 Advantages of phytoremediation

According to Gill (2014), the merits of phytoremediation include the following:

- The technique can be modified to suit a variety of heavy metal compounds.
- *In situ* or *ex situ* application possible with effluent/soil substance respectively. • *In situ* applications decrease the amount of soil disturbance and relatively low cost compared to conventional methods.
- Reduces the amount of waste that has to be sent to landfill (up to 95%), can be further utilized as bio-ore of heavy metals.

- Does not require expensive equipment or highly specialized personnel, and easily implemented and maintained.
- *In situ* applications can immobilize contaminant to avoid spread through air and water.

2.9 Disadvantages of phytoremediation

Phytoremediation has been evaluated to be limited in the following according to (Gill, 2014)

- Restricted to sites with shallow contamination within rooting zone of remediative plants.
- May take up to several years to remediate a contaminated site.
- Often applicable to sites with low contaminant concentrations only.
- Caution must be taken to carefully dispose of harvested plant biomass from phytoextraction as it may be hazardous.
- Climatic conditions are a limiting factor.
- Introduction of non-native species may affect biodiversity. Effects to food web and ultimate contaminant fates might be unknown (Ghosh and Singh, 2005).

2.10 Bioaccumulation and translocation Factors

Studies on phytoremedial agents have mainly based on the interpretation of the analysis of metal concentrations in their above–ground and below-ground parts. Bioaccumulation factor is an indicator of how efficient a plant is in up-taking heavy metals from soil and

concentrating them into its tissues (Zacchini *et al*., 2009). It is described as the concentration of heavy metals in plant shoots divided by the heavy metal concentration in soil (Nazir *et al*., 2011). That is, BF = [Metal] shoot / [Metal] soil. According to Wilson and Pyatt (2007 as citted in Zacchini *et al*., 2009), bioconcentration factor or accumulation factor may be expressed as a percentage. BCF has been categorized into three) as follows: Plant with BCF less than 1 are considered excluders; between 1 and 10 are accumulators and those of magnitude above 10 are termed hyperaccumulators (Iqbal *et al*., 2015).

Translocation factor (TF) also indicates the efficiency of the plant in extracting heavy metals via roots to shoots. It describes the ratio of heavy metal concentration in shoots (stem or leaves) to that in its roots. It is calculated as followsTF = [Metal] shoot / [Metal] root (Zu *et al*.; 2005 cited in Nazir *et al*., 2011). In the same manner, translocation factor can also be expressed in percent according to the following equation (Zacchini *et al.*, 2009).

In screening hyperaccumulators, both BCF and TF play essential role for phytoextraction of heavy metals (Nazir *et al*., 2011). The assessment and selection of phytoremedial candidates entirely depend on BCF and TF values (Wu *et al*., 2011). According to Baker and Brooks (1989),TF>1 indicates that the plant translocates metals effectively from the roots to the shoots. Yoon *et al*.(2006) assumed that plant species with both BCF and TF greater than 1 have the potential to be used for phytoextraction.

2.11 Heavy metals mobility in soil

Most studies of ecosystems describe only the total metals in soils, but bioavailable concentration of metals in soil may be a better predictor for environmental impact of

historical and current emissions of metals (Sherene, 2010). However, plants take up a small amount of heavy metals in the soil that is readily available/bioavailability for transporting to the roots (Gill, 2014; Mehes-Smith *et al*., 2014), and as such risks assessment of environmental pollution and sustainability (Mehes-Smith *et al*., 2014) has to take into account the mobility and the bioavailability of metals (Sherene, 2010).

Mainly, total quantified bioavailable metals (quantity factor), activity and ratio of metals present in soil as in ionic form (intensity factor) and rate of metal transferred from solid to liquid phase to plant roots (reaction kinetics) control the transport of heavy metals from soil to plants (Gill, 2014). The method of binding of heavy metals, and hence their availability, relies on several soil properties; soil organic matter content, pH, temperature, soil texture, soil pore, amendment and additives, residual time and occurrence and forms of cations and anions, oxidation-reduction potential, bioavailability for plants and animals, content of macro and micro nutrients, granulometric composition and resistance of soil (Fijalkowski *et al.*, 2012; Mehes-Smith *et al*., 2014; Sherene, 2010). For instance, Cd and Zn become immobilized in neutral to slightly alkaline soils as compared to highly acidic soils (Fijalkowski *et al*., 2012; Sherene, 2010). Apparently, the bioavailability of heavy metals to plant roots is compromised. According to Mehes-Smith *et al.* (2014) the mobility of heavy metals in contaminated sites may be enhanced over time due to changes in soil environment and degradation of organic matter.

2.12 Sources and toxicity of some elemental contaminants

Arsenic

Arsenic is a metalloid which occurs naturally in the earth's crust behaving more like a nonmetal (Rajeswari and Namburu, 2014). It forms compound with oxygen. This makes As mobile in both oxidizing and reducing environments but controlled by adsorption. It is found alongside the gold ores such arsenopyrites (Fe, As and S) (cited in Bempah *et al*., 2013). The inorganic arsenic easily dissolves and enters underground and surface waters. Tsai *et al*. (1999 as cited in Oppong, 2011), the majority of cases, internal cancer has been ascribed to arsenic exposure; a dermatologic hallmark of arsenic poisoning has also been identified. According to (Tseng, *et al.*, 1968 as cited in Oppong, 2011) chronic dermal exposure to arsenic causes skin cancer. The prevalence of skin cancer is very high in areas where chronic exposure to inorganic arsenic is very high.

Cadmium

Cadmium a soft, ductile toxic metal is often found in associated with Zn (Naja and Volesky, 2009). Coal burning is the main source of environmental cadmium (Rajeswari and Sailaja, 2014). It is a heavy metal of environmental interest due to its high mobility and the health threat it poses at even small concentration to plants and animal metabolism. During weathering Cadmium is unplugged as soluble Cd^{2+} which represent Cd toxicity agent. The substitution of Cd^{2+} for Zn^{2+} in enzyme results in its toxicity (Duruibe *et al.*, 2007).

Cadmium mobility is restricted under both acidic and alkaline conditions by clay minerals. Oral ingestion is the major source of cadmium poisoning because it is capable of bioaccumulation through the food chain, typically in plants and seafood (Morais *et al*, 2012). In plants, a typical symptom of Cd is stunting and chlorosis. Ingestion of elevated levels of

cadmium has resulted in kidney failure and softening of bones (Rajeswari and Sailaja, 2014). Generally, Cd has shown to interfere with the uptake, translocation and the utilization of several essential plant nutrient (Ca, Mg, P and K) and water by plants (Das *et al*., 1997).

Zinc

Zinc as a heavy metal of much concern since it is a profitable plant micronutrient as well as a potential contaminant in soils. Zinc does not occur in the natural environment but rather present only in the divalent state i.e. Zn (II) (Ngu, 2011). Zinc is the least toxic amongst heavy metals; it is an essential element in human diet as it is required to maintain the functioning of the immune system. In soil-water medium, the speciation of Zn, and thus the free Zn activity determines the availability of Zn for plants as a micronutrient and its characteristics as a contaminant. The solubility of Zn in soil solution must be quantified to evaluate bioavailability and transport of Zn in soils. Higher concentrations of Zn can be toxic to flora and fauna, a subject of current environmental concern.

Just like with metal such as Mn or Pb, soil chemistry of zinc is influenced by the pH of the soil. Zinc adsorption is related to cation exchange sites in acidic soils, while in alkaline soils the chemistry is governed by organic ligands. However, in more alkaline soils zinc can form an organozinc complex, which would also eventually increase metals mobility (Sherene, 2010). Metal oxides influence the mobility of zinc in soils and zinc has been found to be highly associated with oxides. Clayey soil is also found capable of absorbing zinc. High concentrations of calcium and phosphorous in soils immobilize them.

Cyanide

The term cyanide refers to a compound that contains the cyanogen (CN) radical. In a case of poison, the CN portion of the compound is of concern and thus any reference to the amount present in these spheres, air, water, land (soil), sediments, or other media only points to this part of the compound (Trapp and Christiansen, 2003). According to Canadian Council of Ministers of the Environment (1999), free cyanide refers to hydrogen cyanide and cyanide ion (CN-) Cyanide is often reported as cyanide, hydrogen cyanide, sodium cyanide, potassium cyanide, or copper (I) cyanide. A major contributor of the much cyanide in the environment is from human activities. In spite of the above, cyanide occurs naturally in fruits, seeds, roots, and leaves of many plants. Bioavailable cyanides can exudate into the environment by natural biogenic processes from higher plants, bacteria, and fungi. Cyanide cannot be accumulated and it is easily metabolized (Trapp and Christiansen, 2003). The major cyanide released into soils or water are from the cyanidation process in mineral extraction (Remy, 2013), disposal of cyanide wastes in landfills and the use of cyanide-containing road salts in industries. In soil, cyanide present at low concentrations is biodegradable under aerobic conditions with the initial formation of ammonia, which would be converted to nitrite in the presence of nitrifying bacteria. In contrast, under anaerobic conditions, the cyanides ion will denitrify to gaseous nitrogen (Trapp and Christiansen, 2003).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site description

Chirano Gold Mines Limited is a Kinross Company located in the Bibiani-AnhwiasoBekwai (BABDA) and Sefwi-Wiawso Districts (SWD) of the Western Region of Ghana (Figure 2). It lies between Latitude 6º00'00'' N and 6º24'75'' N and Longitude 2º21'33'' W and 2º24'33'' W. The project area is about one hundred kilometres (100 km) south-west of the city of Kumasi and fifteen kilometres (15km) south-southwest of the township of Bibiani. The mine has a lease area of about 36 km^2.

The project lies within the wet-semi-equatorial climatic region of Ghana. The project area is characterized by an annual double maxima rainfall pattern occurring in the months of March to July and from September to mid-November. Approximately 55 to 60% of the total rainfall is recorded during the first rainy season. The mean annual rainfall varies widely from year to year with a mean of 1472.7 mm and a range of 1056.2 to 1929.0 mm. The mining company lies partly within the Suraw sub-basin of the Tano River and partly in the main Ankobra basin.

3.2 Sampling site

The plants and soil samples used in this study were collected from the tailings dam of Chirano Gold Mines Tailings Storage Facility 1 (TSF1) in the Western region of Ghana

(Figure 2). Five plots were laid randomly along the facility. Plant samples were collected within a distance of 1.6 m from the embankment towards the centre of the tailings impoundment. The total sampling area was 160 m^2. Each of the plots was 2 x 16 m^2.

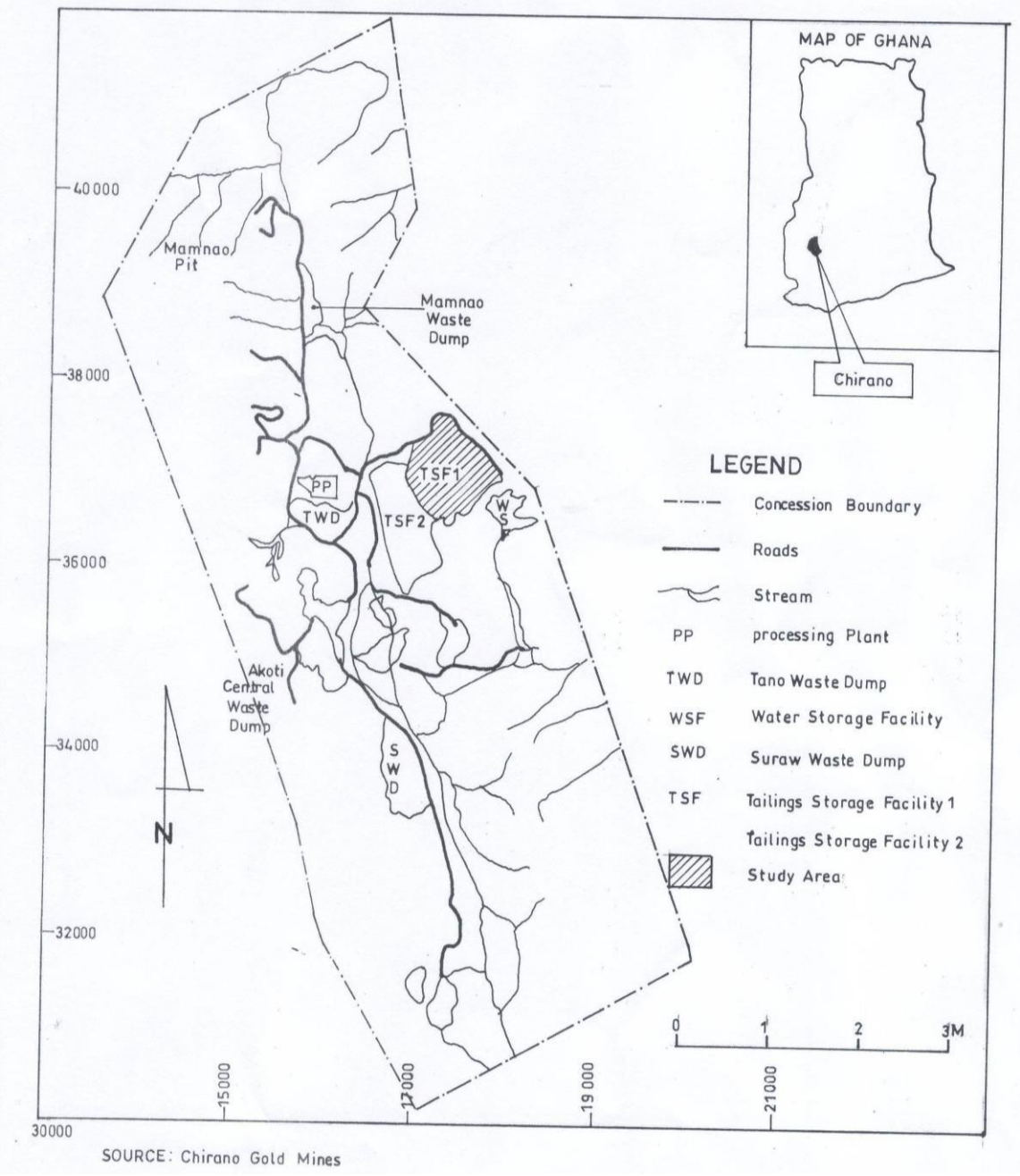


Figure 2: Study area and sampling site

3.3 Identification of plant species

Plants species were identified with the help of a plant taxonomist. Plant species were labelled individually and paper enveloped until ready for digestion.

3.4 Determination of species distribution, abundance and relative abundance The abundance was determined as the total number of individuals of each species whereas the relative abundance was determined as abundance of a particular species to the ratio of overall abundance of all species. Species diversity was determined using Shannon Wiener's index under formulae:

Shannon's index (H) = $- \sum_{i=1}^{S} \rho_i \ln \rho_i$.

Where:

S= total number of species in the community $\rho_i =$ proportion of *S* made up of the *i*th species

3.5 Collection of samples

3.5.1 Plant samples

Plant samples of each plant species within each sampling plot were collected. The roots were separated from the shoots and put into labelled packets and sent to the laboratory for drying and digestion for subsequent heavy metals and cyanide analysis.

3.5.2 Soil samples

Soil samples around the roots (rhizosphere) of the plants removed from each plot were collected when the plants were uprooted. Soil samples were mixed together (homogenize) to get a uniform sample.

3.6 Sample preparation and analysis

3.6.1 Determination of soil pH

The composite soil sample was air dried to steady weight. It was then ground into fine powder using porcelain mortar and pestle and sieved through 2 mm plastic mesh to avoid metal contamination. Soil pH was measured in solution of 1:1 soil: water ratio using pH meter (Hanna instrument 211). In measuring the pH, the meter was calibrated with buffer solutions of pH 4, 7, and 9.

3.6.2 Digestion of soil samples

Unwanted materials were removed from the soil. Soil samples were air dried in a clean room to avoid contamination. It was then ground and sieved through a 2 mm sieve. For analysis, 1 g of the composite soil sample was weighed into a beaker and 3 ml of HCl and 1 ml of concentrated HNO_3 were added and heated on a hot plate at 100^{o}C for 10 minutes to destroy any oxidizable materials and carbonates. The digestion was conducted in microwave digester. The solutions were topped with deionized water to the 50 ml mark and filtered with a Whatman filter paper. These extracts were used for the determination of total concentration of heavy metals, Zn, Cd, As and CN- by using flame Atomic absorption

Spectrophotometer (VGP 210) and flow-in-injection analyzer. Blank samples made from only reagents without sample were analyzed to get rid of any background concentration metals in the system. The extractable fraction of Zn, Cd, As and CN in soil was also done by weighing 1g of the soil sample into extraction container and 25 ml of EDTA and ammonium acetate were added, shaken for 2hrs and passed through a mesh sieve (2.0 mm) (Gavlak *et al*. 1994). The solution was then filtered and the filtrate collected for analysis using AAS and the flow-in-injection analyzer.

3.6.3 Plant tissue analysis

3.6.3.1 Digestion of plant samples

Samples were cut into smaller pieces with a plastic knife. The samples were put in different crucibles and ashed in a furnace at 65ºC for two hours. A quantity of the ash (1 g) from each plant sample was weighed separately into a beaker. To each, 3 ml of concentrated HCl and 1 ml of concentrated HNO_3 were added, and heated on a hot plate at 100ºC for 10 minutes to destroy any oxidizable materials and carbonates. The solutions were topped with deionized water to the 50 ml mark and filtered using a Whatman filter paper. Each plant and homogenized sample filtrates were analysed for the presence of the available heavy metals (Zn, Cd, As) and cyanide using the flame Atomic Absorption Spectrophotometer and the flow-in-injection analyser.

3.6.3.2 Operation of the Atomic Absorption Spectrometer (AAS)

Atomic Absorption Spectrometer (AAS) was used for the analytical determination of the heavy metals (Zn, Cd and As) and the elemental compound (CN). The instrument uses light

to measure the concentration of gas phase atoms. The atoms absorb light and make transitions to higher energy levels. Since each element has a unique electronic structure, the wavelength of light at which the absorption would take place is a unique property of each individual element. The source of light is a hallow cathode lamp made of the same element as the metal of interest. The metal concentration is determined from the amount of light absorbed. To determine the concentration of heavy metals of interest filtrates were aspirated into the excitation region of the AAS where they were desolvated, vaporised and atomised by a flame discharge. The monochromator was used to isolate the specific wavelength of light emitted by the hallow cathode lamp from the non-analytical ones. The hallow cathode lamp used depended on the metal being analyzed. A light sensitive detector measured the absorbed light and a computer measured the response of the detector and translated this into concentration.

3.7 Determination of bioaccumulation and translocation factors

Bioaccumulation factor was defined as the concentration of heavy metals in plant shoots divided by the heavy metal concentration in soil (Nazir *et al*., 2011) and is given in equation1.BF = [Metal] shoot / [Metal] soil. Translocation factor was described as the ratio of heavy metal concentration in plant shoot to that in plant root (Zacchini *et al*., 2009) and is given in equation 2. TF = [Metal] shoot / [Metal] root.

3.8 Data analysis

Data obtained for the mean concentrations of heavy metals in the plants parts (shoot, root and whole) as well as the different levels of metals in the plants were compared using

OneWay Analysis of Variance (ANOVA) at a significance level of 5%. Tukey-B was used to identify significant differences between the means. The ANOVA was run using SPSS version 20.

3.9 Quality Assurance

- Plastic blades were utilized amid homogenisation of the samples in order to dispose of conceivable defilement from the utilization of metal blades.
- The samples were refrigerated to avert change in constituents preceding investigation.
- Blank samples produced using just reagents without test were analysed to dispose of any background concentration metals in the system.
- Keeping in mind the end goal to ensure exact determination of fixation by the AAS, different gauges of the substantial metals of interest were utilized.

CHAPTER FOUR

4.0 RESULTS

4.1 Diversity of plant species at Chirano Gold Mines TSF1

Plant species identified growing in and around the tailings dam at Chirano Gold Mining Site are represented in Table 1. A total of 19 plant species belonging to 8 families were identified. Plants of the Poaceae family were the most abundant forming 37%. This was followed by families of Asteraceae and Euphorbiaceae (16% each). The families, Leguminosae, Crassulaceae, Pteridaceae, Smilacaceae, Solanaceae and Loganiaceae had 1 plant species each and together formed 32% of the species in these families (Table 1).

The growth forms of the species were grasses (37%), herbs (32%), shrubs (26%) and fern (5%) (Table 1). Annuals formed 58% whilst perennials constituted 42% of the life forms. Majority of fifteen plant species representing (78%) were identified as being propagated by seeds. Other five plant species of 26% showed either vegetative/seed or seed/basal or spore or vegetative propagation.

Table 1: Taxonomical description of the plant species at Chirano mine (TSF1)

S.N	Name of species	Family	Common name	Local name	Habit	Growth Form	Propagation
1.	*Chromolaena odorata* Linn.	Asteraceae	Siamweed	Acheampong	Perennial	Shrub	Seeds/Basal
2.	*Mimosa pudica* Linn.	Leguminosae	Sensitive plant	Aberewa kata wo	Perennial	Herb	Stem CuttingSeeds
3.	*Rhynchelytrum repens* (Willd) C.E. Hubbard	Poaceae	Blanketgrass	to	Annual	Grass	Seeds
4.	*Conyza sumatrensis* Linn.	Asteraceae	Fleabane		Annual	Herb	Seeds
5.	*Bryophyllum pinnatum* Lam.	Crassulaceae	Resurrection plant		Perennial	Shrub	Seeds/
6.	*Euphorbia heterophylla* Linn.	Euphorbiaceae	Spurge weed		Annual	Herb	VegetativeSeeds
7.	*Spigella anthelmia* Linn.	Loganiaceae	worm bush		Annual	Herb	Seeds
8.	*Eragrostis tremula* Hochst. Ex Steud.	Poaceae	Lovegrass		Annual	Grass	Seeds
9.	*Tridax procumbens* Linn.	Asteraceae	Tridax		Annual	Herb	Seeds
10.	*Pteris vittata* L.	Pteridaceae	Chinese brake		Perennial	Fern	Spore
11.	*Digitaria horizontalis* Wild	Poaceae	Cebadilla fern		Annual	Grass	Seeds
12.	*Digitaria gayana* (Kunth) Stapf ex. A Chev.	Poaceae	Fall witchgrass	Mpuru	Annual	Grass	Seeds
13.	*Echinochloa colona* Linn.	Poaceae	Junglerice		Annual	Grass	Seeds
14.	*Paspalum scrobiculatum* Linn	Poaceae	Common	Kodo millet	Perennial	Grass	Seeds
15.	*Smilax anceps* Willd. (= smilax Kraussiana Meisn.)	Smilacaceae	West Africa paspalum Sarsaparilla		Perennial	Shrub	Vegetative
16.	*Solanum erianthum* D. Don L	Solanaceae	Potato tree	Pepediawuo	Perennial	Shrub	Seeds
17.	*Digitaria insularis* (L.) Fedde	Poaceae	Sourgrass	Kofuotidwene	Annual	Grass	Seeds

18.	*Alchornea cordifolia* (Schum. & Thonn.)	Euphorbiaceae	Christmas bush		Perennial	Shrub	Seeds/ vegetative
19	*Euphorbia hyssopifolia* Linn	Euphorbiaceae	Fireplant		Annual	Herb	stem cuttingSeeds

Family
: Asteraceae

Botanical name: *Conyza sumatrensis* (Retz) Walker

Common name: fleabane

Description: An erect, softly-hairy, annual herb up to 120 cm high, that reproduces from seeds. The stem is sub-woody at the base, ribbed, hairy and often not branched below the inflorescence. The leaves are variable, with the upper ones alternate on the stem, while the lower ones are in a rosette at the base. The leaves are sessile, hairy, lanceolate to oblanceolate, 4-8 cm long and 1-5cm wide, sub-entire or deeply serrated, acute and gradually becoming winged at the base. The inflorescence is a long, leafy, auxiliary panicle with clusters of numerous small, dull-yellow to brown florets about 6mm long on ascending pedicels.

Habitat: A weed of cultivated fields and roadsides, commonly found in hilly regions, in the forest/Savanna transition zone (Agyakwa and Akobundu, 1987).

Family

Plate 1*: Conyza sumatrensis* Linn

: Leguminosae: Mimosoideae

: *Mimosa pudica* Linn.

Common name: Sensitive plant

Description: A prickly perennial herb that has sensitive leaves and usually prostrate stems that trail on the ground. It reproduces from seeds. The stem is round and straggling; usually covered with hairs but sometimes smooth, and always with some scattered flat, recurved prickles. The leaves are alternate and bipinnate, 1 or 2 paired on a common prickly stalk (rhachis) about 4 cm long. The leaflets are oblong-linear, up to 12mm long, smooth or softly hairy, especially at the margins. They are very sensitive and fold up or close at the slightest touch. Each substalk (pinnae) has about 12-25 pairs of leaflets. The inflorescence consists of flowers in globose heads in leaf axils, and is usually on pedicels that are 2.5 cm long. The flowers are pinkish, round and about 12 mm in diameter. The fruits are 1-3seeded, flat

Family

Botanical name

densely packed in briskly pods up to 2 cm long that are clustered on a peduncle about 3-5 cm long. The seed are round, pale brown and smooth about 2mm in diameter. **Habitat**: A common weed on lawns, roadsides, pastures and waste areas. It was probably introduced as a cover crop but has become a widespread weed(Agyakwa and Akobundu, 1987).

Plate 2: *Mimosa pudica* Linn

: Loganiaceae

Botanical name: *Spigellaanthelmia* Linn.

Common name: worm bush, pinkweed, bomvier.

Description: A hairless, annual herb with an erect stem up to 60 cm high that reproduces form seeds. The stem is hollow, round and smooth. The leaves are opposite, 4 in a whorl, lanceolate or ovate-lanceolate, 15 cm long and 6cm wide acute at the apex, wedge-shaped at the base, and smooth with transparent veins and entire margins. The inflorescence is a long, narrow, terminal spike up to 12cm long and surmounted by leaves. The flowers are small, many, subsessile, funnel-shaped and pinkish –purple, up to 8mm long. The fruits are bi-

Family

lobed, warty capsules about 15 mm in diameter, containing up to 15 black equally warty seeds(Agyakwa and Akobundu, 1987).

Habitat: A common weed of cultivated fields in open regrowths, waste areas and roadsides. It is considered poisonous to animals (Agyakwa and Akobundu, 1987).

Plate 3: *Spigella anthelmia* Linn

: Euphorbiaceae

: *Euphorbia heterophylla* Linn.

Common name: Spurge weed, wild poinsettia

Description: An erect fast growing annual herb that grows up to 9 cm high. It exudes a white latex when cut and reproduces itself from seeds. The stem is hollow, rounded and smooth. The leaves are alternate, variable in shape, oblong-lanceolate to ovate, 6-15 cm long and 4-7 cm wide, acute at the apex, wedge-shaped at the base and subtended on petioles that are 1-2 cm long. The leaf blade is smooth with wavy or toothed margins. The inflorescence consists

Family

Botanical name

of terminal cymes with clusters of greenish subsessile flowers, subtended by leafy bracts. The fruit is a 3-chambered capsule that splits along the midrib when ripe. The seeds are dark brown to black in colour(Agyakwa and Akobundu, 1987).

Habitat: A common weed of cultivated fields in the forest and Savanna zones throughout West Africa. It is a serious problem is cowpea and soybean cultivation because it is more competitive than these crops for growth resources(Agyakwa and Akobundu, 1987).

Plate 4: *Euphorbia heterophylla* Linn

Family: Asteraceae

Botanical name: *Chromolaena odorata*(L.) R.M. King and Robinson (= *Eupatoriumodoratum* L.)

Common name: Siamweed

Description: A diffuse, rapidly growing, slowly scented perennial shrub up to 3 m or more high that reproduces from seeds and vegetatively from cut basal shoots. The stem is cylindrical, robust rather scrambling and dichotomously branched. It is sparingly pubescent. Immature leaves are often purplish but mature leaf blades are greenish, up to 12 cm long and 5cm across with an acute apex. The leaves may have sub-entire to coarsely toothed margins. The leaves may be hairless or sparingly hairy. However, they generally have glandular dots that emit a strong smell. The inflorescence is a many-flowered corymbs, usually at the terminals, but occasionally in the axils of upper leaves. The flowers are pale blue, mauve or whitish with florets borne in pedunculate clusters(Agyakwa and Akobundu, 1987).

Habitat: A troublesome weed of open cultivated fields, roadsides and plantation crops. It is widespread in West Africa from coastal fringes of the rainforest to the Southern edge of the Guinea Savanna(Agyakwa and Akobundu, 1987).

Family

Botanical name

Plate 5: *Chromolaena odorata* (L.) R.M. King and Robinson (= Eupatoriumodoratum L)

: Crassulaceae

: Bryophyllum pinnatum(Lam.)

Common name: Resurrection plant, Canterbury bells, air plant.

Description: An erect, succulent perennial shrub about 60-120 cm high that can reproduce from seeds and also vegetatively from leaf-bulbils. The stem is thick and fleshy. It branches from the base and is often ribbed. The leaves are opposite, fleshy, greenishpurple, simple or trifoliate, obovate, about 10 cm long and 5-6 cm wide, smooth, coarsely crenate at the margins where often there are bulbils. The inflorescence is made up of dropping flowers in loose panicles at the terminal of the stem. The flowers are showy, and have 4-lobed corolla tubes that are reddish-purple at the top, and 4-lobed inflated calyx tubes that are greenish yellow and purplish at the base(Agyakwa and Akobundu, 1987). **Habitat**: Introduced ornamental plants weed of plantation crops and farm settlement in many parts of West Africa(Agyakwa and Akobundu, 1987).

Family: Poaceae

Botanical name:

Plate 6*: Bryophyllum pinnatum (Lam.)*

Rhynchelytrum repens(Willd) C.E. Hubbard.

Common name: Blanketgrass, natalgrass, natalredtop

Description: A straggling annual grass up to about 90c m high that reproduces from seeds. The stem is slender, often rooting at the nodes or sometimes prop-rooted. The leaves are linear, have fine tips, are glabrous or sometimes hairy and have slightly scrabrid margins. The ligule is fringed with short hairs and the sheath is glabrous or sometimes hairy. The inflorescence is a fluffy panicle 5-20 cm long with slender branches bearing silvery white to pink hairy spikelets about 2.5-6 mm long.

Habitat: A weed of field crops and waste areas. It is widespread and abundant in the forest transition and the Savanna zones.

Family

Botanical name

Plate 7*: Rhynchelytrum repens* (Willd) C.E. Hubbard

Family: Poaceae

Botanical name:

Digitariagayana(Kunth) Stapf ex. A Chev.

Description: a tufted annual grass about 100 cm high with weak hairy stems. The leaves are about 10-15 cm long, often densely hairy on the blades and along the sheaths. The inflorescence is variable and consists1-3 or 5 branches of racemes, each of which is about 15cm long. The spikelets are dense and silky and sometimes, about 5 mm long.

Habitat: a widespread weed of Guinea Savanna zone, common in arable fields, roadsides and bush fallows.

Plate 8: *Digitaria gayana* (Kunth) Stapf ex. A Chev.

Family: Poaceae

Botanical name:

*Eragrostistremula*Hochst. Ex Steud.

Common name: Lovegrass

Description: A loosely tufted annual grass up to about 100 cm long that has slender, rounded stems and reproduces from seeds. The leaves are linear, about 5-15 m long and have beautiful, pale, pink to purple, flattened and trembling spikelets on long stalks up to 10 cm long. The spikelets vary in size and may be 1.5-2.5cm long but elongate to about 4cm when fully mature(Agyakwa and Akobundu, 1987).

Habitat: A weed of field crops in the Savanna zones.

Plate 9: *Eragrostis tremula* Hochst. Ex Steud

Family: Poaceae

Botanical name:

Echinochloacolona(Linn.) Link

Common name: Junglerice

Description: An erect or semi-straggling annual grass about 60 cm high, rooting at the nodes,it reproduces from seeds. The stem is rounded, greenish, sometimes purplish and densely tufted at the base. The leaves are linear about 30 cm long and 7 mm wide, without hairs and ligules but rough at the margins and have smooth and slightly compressed sheaths. The inflorescence is a raceme, varies in colour from green to purple and has ascending branches that bear closely crowed ovate spikelets.

Habitat: common weed of field crops, particularly rice. It grows in a wide range of soil moisture conditions, from swampy or hydromorphic soils to dry land.

Plate 10: *Echinochloa colona* Linn

Family: Poaceae

Botanical name:

Family: Asteraceae

Botanical name: *Tridax procumbens* Linn.

Common name: Tridax, coat buttons

Description: A rough hairy annual herb, with weak trailing branches up to 40 cm high, sometimes rooting at a lower node that reproduces from seeds. The stem is soft wooded, semi-prostrate and low-branching from a woody tap root. It is generally hairy. The leaves are simple opposite, ovate or broadly-lanceolate, 5-7 cm long and 2-3 cm wide, coarselytoothed with a pointed apex, wedge-shaped at the base, subsessile and rather rough to the touch. The inflorescence is a solitary, terminal or axillary flower-head on a slender peduncle up to 20cm long. The flowers consist of ray florets that are creamy white and trilobed and disc florets that are yellow.

Habitat: A common weed of cultivated crop, lawns, waste areas and roadside.

Plate 11: *Tridax procumbens* Linn.

Family

Botanical name
: Poaceae

: *Digitaria horizontalis* Wild

Common name:

Description: A creeping annual grass with semi-prostrate stems about 30-60 cm high, rooting at the nodes and reproduces from seeds. The stem is rounded, sprawling or erect and branches. The leaves are linear-lanceolate, 5-10 cm long and 0.7-1.5 cm wide. They have rough margins, are thin and dark-green acute at tips and round or slightly narrowed at the base. The sheath is slightly keeled and compressed and the ligule is inconspicuous and pale. The inflorescence is made up of 10-20 hairy spikes each about 6-12 cm long, about 4 or 5 of the spikes are whorled below and the rest arranged horizontally above the whorl on a common axis that is often hairy. The spikelets are small, about 2-2.5 mm long and they usually overlap by about half their length.

Habitat: A weed of field crops, roadsides and waste areas. It is widespread in West Africa.

Family

Plate 12: *Digitaria horizontalis* Wild

: Pteridaceae

Botanical name: *Pteris vittata*

Common name: Chinese brake fern.

Description: *P. Vittata* is a perennial, evergreen species of fern in the genus *Pteris*, native to china. It is an invasive plant that is terrestrial or lithophytic. It is known to be a hyperaccumulator plant of arsenic used in phytoremediation. It has a linear frond segment and sub-palmate division. The fronds are monomorphic, arching, appearing to radiate from a crow. It has 1-pinnate and oblong-obovate leave shape. It is a rhizome; short-creeping plant that reproduces by spores. It is a fast growing plant that can grow up to about 1m. **Habitat**: A weed found in Eurasia, Africa and America. Mostly grows along roadsides and almost on any calcareous substrate such as old masonry, sidewalks, building crevices.

Family

Botanical name

Plate 13: *Pteris vittata* L

Family: Smilacaceae

Botanical name: *Smilax anceps*Willd. (= smilax KraussianaMeisn.)

Common name: West Africa Sarsaparilla

Description: A prickly, perennial, climber that has a thick underground rhizome and looks very much like the yam plant, but it is distinguished by its long, twinning, interpetiolar tendrils. It reproduces vegetatively. The stem is touch, fibrous to more or less woody, glabrous, darkgreen and covered with stiff, short, curved spines. The leaves alternate, ovate to broadly elliptic, about 12cm long and 7cm wide, abruptly and sharply pointed at the tips, rounded to subacute at the base, smooth or both surfaces and with 3-inconspicuous upcurving veins that radiate from the base. The inflorescence is a many-flowered axillary umbel that has a short, and about 0.5cm wide. The fruit is small round berry that ripens to a pale yellowish green on maturity.

Habitat: Common weed of field crops in both the Savanna and forest zone of West Africa.

Plate 14: *Smilax anceps* Willd. (= smilax KraussianaMeisn

: Solanaceae

Botanical name: *Solanum erianthum*

Common name: Potato tree or Mullein Nightshade

Description: Shrub, stems and leaves are densely stellate pubescent, prickles absent; leaves alternate, simple, ovate to lanceolate, base-obtuse, margin somewhat irregular, apex acute, inflorescence a terminal cymes, petals white, reflexed; anthers prominent; fruit a yellow berry.

Habitat: found in in dry and moist forests. It grows in disturbed areas, such as roadsides, fields, and waste places and may be considered a weed.

Family

Plate 15: *Solanum eriathum* D. DonL

Family: Poaceae

Botanical name:*Digitariainsularis*(L.) Feddie

Common name: sourgrass

Description:Sourgrass is a tufted perennial weed infesting annual and perennial crops. It has very short, swollen rhizomes. The stems reach a height of 80–130 cm and are erect, branched from the lower and middle nodes, swollen bases, with woolly bracts, glabrous internodes and nodes. Sheaths papillose - pilose in their majority, ligule 4–6 mm long, blades linear, 20–50 cm long and 10–20 mm wide. Inflorescence 20–35 cm long, numerous clusters, 10–15 cm long, solitary triquetrous rachis of clusters, 0.4-0.7 mm wide, scabrous; spikelets lanceolate, 4.2-4.6 mm long, paired, caudate, densely covered with trichomes up to 6 mm

long, brown or whitish, ranging up to 5 mm from the apex of the spikelet; lower glume triangular to ovate, to 0.6 mm long, enervate, membranous; upper glume 3.5-4.5 mm long, acute, 3-5 nerved, ciliated; inferior lemma as long as spikelet, acuminate, 7-nerved, covered with silky hairs, upper lemma 3.2-3.6 mm long, acuminate, dark brown; anthers 1-1.2 mm long.[1]

Plate 16: *Digitaria insularis* L

: Euphorbiaceae

Botanical name: *Alchornea cordifolia*(Schum. &Thonn.) Mull Arg.

Common name: Christmas bush

Description: An erect, sometimes scrambling, bush perennial shrub or small Tree up to 4 m high that reproduces from seeds and vegetatively from stem cuttings. The stem is woody, greyish, many branched and bushy when young. The leaves are simple and alternate, broadly-ovate 10-28 cm long and 6.5-16 cm wide. The leaf blade is heart-shaped at the base, acuminate and the apex, entire to sub-entire at the margin with long petioles. The leaf is mostly smooth to the touch but often has a few glands at the base. The inflorescence consists of axillary panicles. The flowers are greenish-white. The male flowers are long spikes 8-36

Family

cm long, while the female flowers are simple and on short stalks. The fruit is a 3-chambered capsule with red seeds.

Habitat: A common plant in secondary forest regrowth and a weed of cultivated fields in the forest zone.

Plate 17: *Alchornea cordifolia* (Schum. &Thonn.) Mull Arg

Family

: Euphorbiaceae

Botanical name: *Euphorbia hyssopifolia* Linn.

Description: An erect, many-branched annual herb up to 40 cm high, that reproduces from seeds. It exudes white latex when cut. The stem is erect or sometimes sprawling, reddish, smooth, rounded and jointed. The internodes are up to 5cm apart. Leaves are simple and opposite, ovate-elliptic, variable in size, 1-3 cm long, and up to 1.0 cm wide, asymmetrical, sessile to subsessile, the margins finely serrated, acute at the apex and smooth on the surface. The inflorescence is a dichotomously branched, terminal or sub-terminal raceme, usually leafy and with small flowers that have no petals. The fruit is a 3-lobed capsule that contains three small, black and wrinkled seeds.

Habitat: A common weed of cultivated fields but also present in laws garden and roadsides. It is probably an introduced plant in West Africa.

Plate 18: *Euphorbia hyssopifolia* Linn

: Poaceae

Family

Botanical name: *Paspalum scrobiculatum* Linn.

Common name: Ditch millet, Indian paspalum, rice grass paspalum

Description: A semi-tuffed, stragglilng perennial, up to 60 cm high that reproduces at the lower nodes and reproduces from seeds. The stem is usually rounded, flattened at the base, slender, smooth and sometimes purplish below. The leaves are linear, about 15-25 cm long and 1-1.5cm wide, rounded and clasping at stem at the base and may or may not be hairy on both surfaces. The ligule is membranous, brownish and about 0.5mm long and the sheath is dark-green and has some hairs at the tips below the blades. The inflorescence is made up of 2-4 or occasionally six flattened ribbon-like racemes each about 8 scm long and 2-3 mm wide, which bear two rows of rounded and flattened spikelets about 2 mm in diameter, that are greenish-yellow and become dull reddish-brown and fall off at maturity. **Habitat**: A weed of field crops and pastures, but also found on shady and damp places. It is widespread in West Africa.

Plate 19: *Paspalum scrobiculatum* Linn

4.2 Distribution and abundance of plant species in Chirano Gold Mines site The distribution and abundance of plant species in the sampled plots in Chirano Gold Mine site are presented in Table 2. *Chromolena odorata* and *Rhynchelytrum repens* were found growing in all the five sampling plots. *Pteris vittata* which was found growing in plots A, B and C had the highest relative abundance of 26.72 % followed by *Rhynchelytrum repens* with a relative abundance of 23.65 % and occurring in all plots. *Smilax anceps* had the least abundance with a relative abundance of 0.11 %. *Mimosa pudica, Spigella anthelmia, Eragrostis tremula, Digitaria horizontalis, Paspalum scrobiculatum and Solanum erianthum* were found in three of the sampling plots Table 2.

Table 2: Distribution, abundance and relative abundance of plant species in the plots

			PLOTS						Relative abundance
S.N	**Name of species**	**Family**	**A**	**B**	**C**	**D**	**E**	**Abundance**	
1	*Chromolena odorata*Linn	Asteraceae	1	4	20	54	105	184	19.43
2	*Mimosa pudica*Linn	Leguminosae		2	1	1	9	13	1.37
3	*Rhynchelytrum repens*	Poaceae	1	4	20	94	105	224	**23.65**
4	*Conyzasumatrensis*	Asteraceae					6	6	0.63
5	*Bryophyllum* pinnatum Lam	Crassuleceae					7	7	0.74
6	*Euphorbia heterophylla* Linn.	Euphorbiaceae				17		17	1.80
7	*Spigella anthelmia*Linn.	Loganiaceae	11		4		5	20	2.11
8	*Eragrostis tremula*	Poaceae	28	23	3			54	5.70
9	*Tridax procumbens*	Asteraceae		2	5			7	0.74
10	*Pteris vittata*	Pteridaceae	102	111	40			253	**26.72**
11	*Digitaria horizontalis*	Poaceae		3	7	5		15	1.58
12	*Digitaria gayana*	Poaceae		11	5			16	1.69
13	*Echinochloa colona*	Poaceae			3			3	0.32
14	*Paspalum scrobiculatum* Linn	Poaceae	48	1	41	13		103	10.88
15	*Smilax anceps*	Smilacaceae					1	1	**0.11**
16	*Solanum erianthum*	Solanaceae	1		1	1		3	0.32
17	*Digitaria insularis* (L.) Fedde	Poaceae		3	4		9	16	1.69
18	*Alchornea cordifolia* (Schum.	Euphorbiaceae		2				2	0.21
19	*Euphorbia hyssopifolia*Linn.	Euphorbiaceae			3			3	0.32

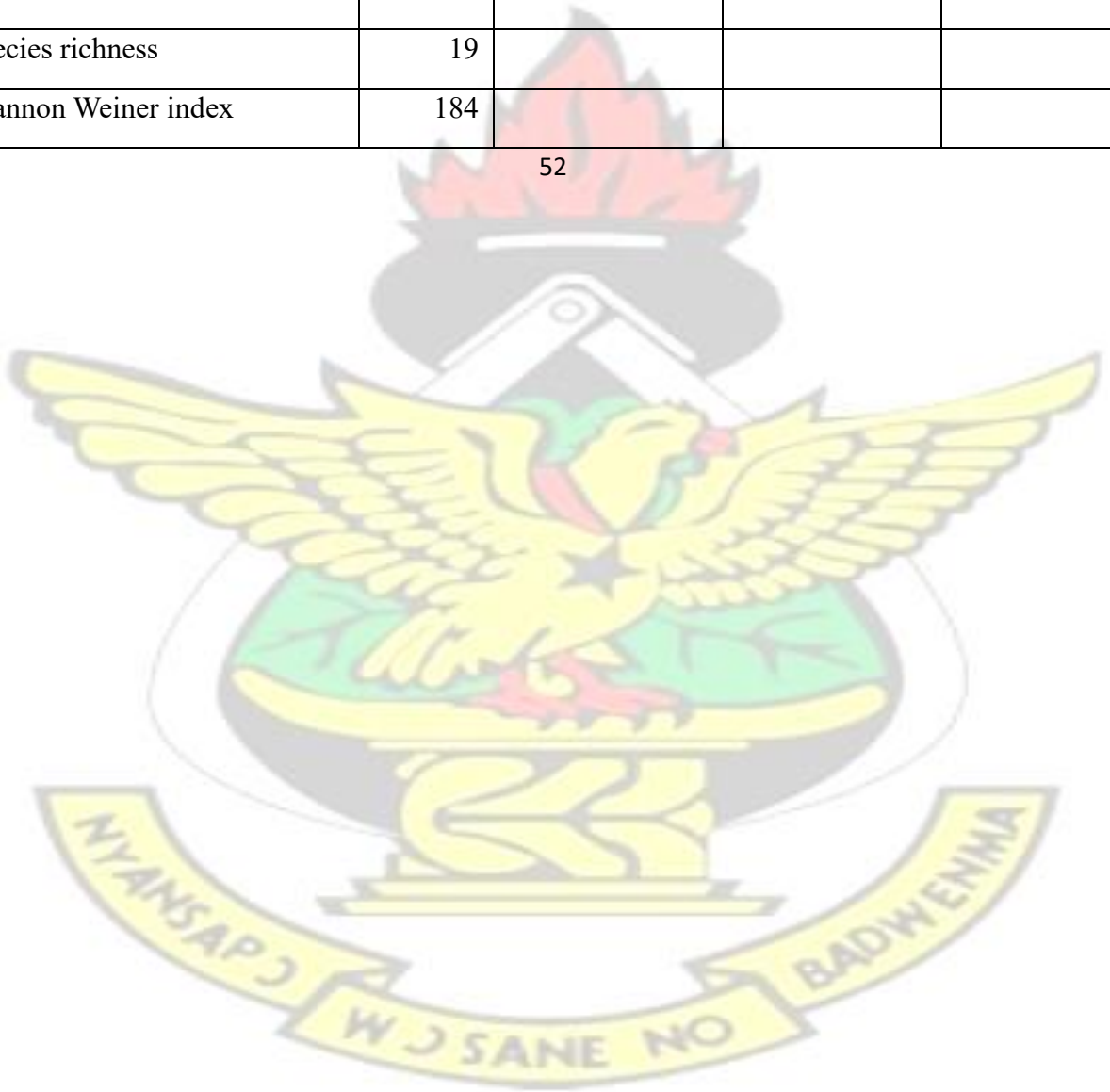
4.3 Diversity of the species used in the study

The Shannon-Weinner diversity Index of the plant species is presented in Table 3. Total number of individuals of the species was 947 with species richness of 19. *Pteris vittata*, *Rhynchelytrum repens* and *Chromolena odorata* contributed greatly to Shannon diversity index. *Smilax anceps* and *Alchornea cordifolia* contributed least to the diversity index (Table 3). The Shannon diversity index in the area was 2.01.

Table 3: Shannon-Weiner index diversity of the species

S.N	Name of species	Number found	Species proportion (pi)	In pi	pi * In (pi)	-1(pi * In (pi))
1	*Chromolena odorata*	184	0.19	-1.64	-0.32	**0.32**
2	*Mimosa pudica*	13	0.01	-4.29	-0.06	0.06
3	*Rhynchelytrum repens*	224	0.24	-1.44	-0.34	**0.34**
4	*Conyza sumatrensis*	6	0.01	-5.06	-0.03	0.03
5	*Bryophyllum pinnatum*	7	0.01	-4.91	-0.04	0.04
6	*Euphorbia heterophylla*	17	0.02	-4.02	-0.07	0.07
7	*Spigella anthelmia*	20	0.02	-3.86	-0.08	0.08
8	*Eragrostis tremula*	54	0.06	-2.86	-0.16	0.16
9	*Tridax procumbens*	7	0.01	-4.91	-0.04	0.04
10	*Pteris vittata*	253	0.27	-1.32	-0.35	**0.35**
11	*Digitaria horizontalis*	15	0.02	-4.15	-0.07	0.07
12	*Digitaria gayana*	16	0.02	-4.08	-0.07	0.07
13	*Echinochloa colona*	3	0.00	-5.75	-0.02	0.02
14	*Paspalum scrobiculatum*	103	0.11	-2.22	-0.24	0.24
15	*Smilax anceps*	1	0.00	-6.85	-0.01	**0.01**
16	*Solanum erianthum*	3	0.00	-5.75	-0.02	0.02
17	*Digitaria insularis*	16	0.02	-4.08	-0.07	0.07

18	*Alchornea cordifolia*	2	0.00	-6.16	-0.01	**0.01**
19	*Euphorbia hyssopifolia*	3	0.00	-5.75	-0.02	0.02
	Total number of individuals	947				
	Species richness	19				
	Shannon Weiner index	184				**2.01**



4.4 Concentration of heavy metals and pH in the tailings at Chirano

The mean concentrations of heavy metals (Zn, Cd, Zn and CN-) and pH in the soil (tailings) sampled in five plots at Chirano Mine Tailings Site are represented in Table 4. The concentrations of metals in the soil were below the WHO recommended standard for agricultural soils. Zinc recorded the highest total metal concentration of 13.20 mg/kg. This was five times more than what was the available metal concentration. The total Cadmium concentration of 0.29 mg/kg was six times more than its available concentration in the soil. The available Arsenic concentration of 1.21 mg/kg was 39% of its total concentration in the soil. Although CN recorded the least concentration in the soil, its available concentration of 0.07 mg/kg was 64% of its total (0.11 mg/kg).

Table 4: Mean pH and metals concentration (mg/kg) in the soil

Parameter	Zn	Cd	As	CN-	pH
Total	**13.20±0.06**	0.29±0.02	3.08±0.04	**0.11±0.03**	7.08±0.01
Available	2.76±0.08	0.05±0.00	1.21±0.04	0.07±0.02	-
%Available	20.90	17.24	39.29	**63.63**	-
Standard	200	1.4	12	0.9	6-8

4.5 Mean concentration of Zinc in plant species

The mean concentration of Zn in the plant species are presented in Table 5. Concentration of Zn in the root of *Euphorbia heterophylla* (135.76 mg/kg) was the highest whilst lowest roots Zn concentration was found in *Rhynchelytrum repens* (12.24 mg/kg).The highest shoot Zn concentration was recorded in *Smilax anceps* of 91.97 mg/kg whilst the lowest was found in

Alchornea cordifolia shoot (7.58 mg/kg). *Euphorbia heterophylla* recorded the highest whole plant Zn metal concentration of 186.49 mg/kg whilst the least whole plant Zn metal concentration was found in *Pteris vittata* (23.02 mg/kg). In all the plants, the accumulation of Zn levels in the roots exceeded the accumulation in the shoots. For all the plant parts, Zn concentration differed significantly among the different species. *Euphorbia heterophylla* and *Alchornea cordifolia* accumulated significantly higher levels of Zn than all the other species in the roots. *Smilax anceps* and *Digitaria horizontalis* accumulated significantly more elevated amounts of Zn than the various species in the shoots.

Table : Mean c
5 oncentration (mg/kg) of Zinc in plant species

Name of species	Family	Common name	Roots	Shoots	Whole plant
Chromolaena odorata Linn.	Asteraceae	Siamweed	16.16±0.17^{c}	25.16±0.32^{g}	41.32±0.0.48^{c}
Mimosa pudica Linn.	Leguminosae	Sensitive plant	26.66±0.21^{f}	21.24±0.01^{f}	47.90±0.22^{d}
Rhynchelytrum repens (Willd) C.E.	Poaceae	Blanketgrass	**12.24±0.18^{a}**	57.53±0.09^{n}	69.77±0.26^{j}
Conyza sumatrensis Linn.	Asteraceae	Fleabane	23.76±0.27^{e}	40.04±0.07^{j}	63.80±0.32^{h}
Bryophyllum pinnatum Lam.	Crassulaceae	Resurrection plant	20.37±0.34^{d}	30.84±0.0.52^{i}	51.21±0.86^{e}
Euphorbia heterophylla Linn.	Euphorbiaceae	Spurge weed	**135.76±1.02^{p}**	50.73±0.10^{m}	**186.49±1.11^{q}**
Spigella anthelmia Linn.	Loganiaceae	worm bush	40.64±0.37^{i}	81.24±0.06^{o}	121.88±0.40^{l}
Eragrostis tremula Hochst. Ex Steud.	Poaceae	Lovegrass	42.19±0.37^{j}	83.37±0.35^{p}	125.56±0.35^{m}
Tridax procumbens Linn.	Asteraceae	Tridax	31.57±0.05^{g}	21.14±0.13^{f}	52.71±0.14^{f}
Pteris vittata L.	Pteridaceae	Chinese brake fern	13.68±0.09^{b}	9.34±0.16^{b}	**23.02±0.07^{a}**
Digitaria horizontalis Wild	Poaceae	Cebadilla	45.41±0.49^{k}	**88.78±0.12^{q}**	134.19±0.58^{n}
Digitaria gayana (Kunth) Stapf ex. A	Poaceae	Fall witchgrass	53.98±0.26^{m}	44.12±0.14^{k}	98.05±0.30^{k}
Echinochloa colona Linn.	Poaceae	Junglerice	37.07±0.12^{h}	19.14±0.02^{e}	56.21±0.13^{g}
Paspalum scrobiculatum Linn	Poaceae	Common paspalum	46.65±0.12^{l}	18.31±0.10^{d}	64.96±0.17^{h}
Smilax anceps L.	Smilacaceae	West Africa Sarsaparilla	54.02±0.07^{m}	**91.97±0.07^{r}**	**145.99±0.12^{p}**
Solanum erianthum L.	Solanaceae	Potato tree	19.38±0.54^{d}	14.57±0.24^{c}	33.95±0.37^{b}
Digitaria insularis (L.) Fedde	Poaceae	Sourgrass	40.84±0.02^{i}	24.59±0.26^{h}	65.43±0.31^{i}
Alchornea cordifolia (Schum. &Thonn.	Euphorbiaceae	Christmas bush	**114.20±1.42^{o}**	**7.58±0.23^{a}**	121.78±1.19^{l}
Euphorbia hyssopifolia Linn	Euphorbiaceae	Fireplant	90.64±0.6^{n}	49.11±0.10^{c}	139.75±0.13^{o}

Mean ± SD in same column with different letters in superscripts differ significantly ($p<0.05$)

4.6 Mean concentration of Cadmium in plant species

The mean concentration of Cd in the plant species are exhibited in Table 6. Concentration of Cd in the root of *Pteris vittata* (3. 21 mg/kg) was the most noteworthy while least roots Cd focus was found in *Spigella anthelmia* (0.30 mg/kg). The most noteworthy shoot Cd focus was recorded in *Solanum erianthum* (3.04 mg/kg) while the most minimal was found in *Bryophyllum pinnatum* (0.33 mg/kg). *Smilax anceps* recorded the most noteworthy entire plant Cd metal concentration tion of 5.29 mg/kg while the slightest entire plant Cd metal fixation was found in *Digitaria gayana* (1.76 mg/kg). In every one of the plants, the accumulation of Cd levels in the roots surpassed the gathering in the shoots. For all the plant parts, Cd concentration did not vary significantly among some species. *Pteris vittata* and *Smilax anceps* accumulated altogether more elevated amounts of Cd than the various species in the roots. *Solanum erianthum* and *Euphorbia hyssopifolia* accumulated essentially more hoisted measures of Cd than the different species in the shoots.

Table : Mean c
6 oncentration (mg/kg) of Cadmiumin plant species

Name of species	Family	Common name	Roots	Shoots	Whole plant
Chromolaena odorata Linn.	Asteraceae	Siamweed	1.53±0.03^{c}	0.90±0.01^{b}	2.43±0.03^{b}
Mimosa pudica Linn.	Leguminosae	Sensitive plant	1.36±0.01^{c}	1.54±0.18^{d}	2.90±0.18^{c}
Rhynchelytrum repens (Willd) C.E. Hubbard	Poaceae	Blanketgrass	1.56±0.02^{c}	1.66±0.04^{de}	3.22±0.05^{d}
Conyza sumatrensis Linn.	Asteraceae	Fleabane	1.44±0.01^{c}	1.07±0.03^{c}	2.51±0.03^{b}
Bryophyllum pinnatum Lam.	Crassulaceae	Resurrection plant	2.21±0.01^{efg}	**0.33±0.02^{a}**	2.54±0.01^{b}
Euphorbia heterophylla Linn.	Euphorbiaceae	Spurge weed	1.90±0.01^{de}	2.71±0.03^{h}	4.61±0.03^{f}
Spigella anthelmia Linn.	Loganiaceae	worm bush	**0.30±0.01^{a}**	2.29±0.07^{g}	2.59±0.07^{b}
Eragrostis tremula Hochst. Ex Steud.	Poaceae	Lovegrass	2.62±0.02^{hi}	1.10±0.00^{c}	3.72±0.02^{e}
Tridax procumbens Linn.	Asteraceae	Tridax	2.02±0.03^{ef}	2.94±0.05^{j}	4.96±0.05^{h}
Pteris vittata L.	Pteridaceae	Chinese brake fern	**3.21±0.02^{j}**	1.57±0.04^{d}	4.78±0.04^{h}
Digitaria horizontalis Wild	Poaceae	Cebadilla	1.95±0.01^{de}	2.86±0.01^{j}	4.81±0.05^{h}
Digitaria gayana (Kunth) Stapf ex. A Chev.	Poaceae	Fall witchgrass	1.35±0.00^{c}	0.41±0.01^{a}	**1.76±0.01^{a}**
Echinochloacolona Linn.	Poaceae	Junglerice	2.29±0.02^{fg}	0.79±0.01^{b}	3.08±0.02^{d}
Paspalumscrobiculatum Linn	Poaceae	Common paspalum	2.73±0.03^{i}	1.77±0.03^{e}	4.50±0.05^{f}
Smilax anceps L.	Smilacaceae	West Africa Sarsaparilla	**3.17±0.03^{j}**	2.12±0.03^{f}	**5.29±0.03^{i}**
Solanum erianthum L.	Solanaceae	Potato tree	0.85±0.02^{b}	**3.04±0.06^{k}**	3.89±0.05^{e}
Digitariainsularis (L.) Fedde	Poaceae	Sourgrass	2.51±0.04^{ghi}	2.26±0.03^{g}	4.77±0.07^{g}
Alchorneacordifolia (Schum. &Thonn.	Euphorbiaceae	Christmas bush	1.57±0.56^{c}	1.54±0.01^{d}	3.11±0.55^{d}
Euphorbia hyssopifolia Linn	Euphorbiaceae	Fireplant	1.63±0.02^{cd}	**2.75±0.01^{h}**	4.38±0.02^{f}

Mean ± SD in same column with different letters in superscripts differ significantly ($p<0.05$)

4.7 Mean concentration of Arsenic (mg/kg) in plant species

Arsenic mean concentration in the plant species are presented in Table 7. The highest root As concentration was recorded in *Alchornea cordifolia* of 1.55 mg/kg whereas the lowest root As concentrations were found in three plant (*Chromolaena odorata*, *Tridax procumbens* and *Euphorbia hyssopifolia*) in concentrations of 0.10 mg/kg each. Concentration of As in the shoot of *Digitaria gayana* (2.09 mg/kg) was the highest. The lowest however, was found in 3 plant species (*Conyza sumatrensis*, *Digitaria horizontalis* and *Spigella anthelmia*) (0.10 each). In all *Digitaria gayana* (i.e. the whole plant) recorded the highest As metal concentration of 2.20 mg/kg whereas the lowest concentration was recorded in *Echinochloa colona* (0.27 mg/kg). In all the plant species, the accumulation of As levels in the shoot exceeded the accumulation in the roots. For all the plant parts, As concentration did not fluctuate essentially among a few plant species. *Alchornea cordifolia* and *Rhynchelytrum repens* amassed by and large more raised measures of Cd than the different species in the roots. *Digitaria gayana* and *Mimosa pudica* aggregated basically more raised measures of As than the distinctive species in the shoots.

Table : Mean c
7 oncentration of Arsenic (mg/kg) in plant species

Name of species	Family	Common name	Roots	Shoots	Whole plant
Chromolaena odorata Linn.	Asteraceae	Siamweed	**0.10±0.01^{a}**	1.53±0.02^{h}	1.63±0.01^{j}
Mimosa pudica Linn.	Leguminosae	Sensitive plant	0.12±0.02^{a}	**1.64±0.02^{i}**	1.76±0.03^{k}
Rhynchelytrum repens (Willd) C.E.	Poaceae	Blanketgrass	**1.31±0.01^{j}**	0.12±0.02^{a}	1.43±0.03^{h}
Hubbard *Conyza suma trensis* Linn.	Asteraceae	Fleabane	0.77±0.02^{h}	**0.10±0.00^{a}**	0.87±0.02^{f}
Bryophyllum pinnatum Lam.	Crassulaceae	Resurrection plant	0.44±0.02^{d}	0.11±0.01^{a}	0.54±0.02^{c}
Euphorbia heterophylla Linn.	Euphorbiaceae	Spurge weed	0.72±0.03^{g}	0.76±0.02^{e}	1.48±0.03^{h}
Spigella anthelmia Linn.	Loganiaceae	worm bush	0.64±0.02^{f}	**0.10±0.01^{a}**	1.74±0.03^{k}
Eragrostis tremula Hochst. Ex Steud.	Poaceae	Lovegrass	0.12±0.02^{a}	0.34±0.02^{b}	0.46±0.03^{b}
Tridax procumbens Linn.	Asteraceae	Tridax	**0.10±0.01^{a}**	0.52±0.02^{c}	0.63±0.02^{d}
Pteris vittata L.	Pteridaceae	Chinese brake fern	0.33±0.02^{b}	1.22±0.03^{g}	1.55±0.05^{i}
Digitaria horizontalis W ild	Poaceae	Cebadilla	1.10±0.01^{a}	**0.10±0.02^{a}**	1.20±0.02^{g}
Digitaria gayana (Kunth) Stapf ex.	Poaceae	Fall witchgrass	0.11±0.01^{a}	**2.09±0.02^{j}**	**2.20±0.03^{l}**
A Chev. *Echinochloa colona* Linn.	Poaceae	Junglerice	0.16±0.01^{b}	0.11±0.01^{a}	**0.27±0.02^{a}**
Paspalum scrobiculatum Linn	Poaceae	Common paspalum	0.13±0.04^{b}	0.60±0.02^{d}	0.73±0.03^{e}
Smilax anceps L.	Smilacaceae	West Africa Sarsaparilla	0.73±0.04^{g}	0.11±0.02^{a}	0.84±0.06^{f}
Solanum erianthum L.	Solanaceae	Potato tree	0.52±0.03^{e}	0.92±0.02^{f}	1.44±0.03^{h}
Digitaria insularis (L.) Fedde	Poaceae	Sourgrass	0.66±0.01^{f}	0.15±0.02^{a}	0.81±0.01^{e}
Alchornea cordifolia (Schum. &Thonn.	Euphorbiaceae	Christmas bush	**1.55±0.01^{k}**	0.12±0.02^{a}	1.67±0.03^{j}

Table : Mean c

Euphorbia hyssopifolia Linn	Euphorbiaceae	Fireplant	**0.10±0.02[a]**	0.32±0.02[b]	0.42±0.02[b]

Mean ± SD in same column with different letters in superscripts differ significantly ($p<0.05$)

4.8 Mean concentration of Cyanide (mg/kg) in plant species

Cyanide mean concentration in the plant species are shown in Table 8. *Eragrostis tremula* had concentration of 0.16 mg/kg which was higher than the concentrations in the various species. Be that as it may, the lowest concentration of CN was found in 2 plant species (*Smilax anceps* and *Euphorbia hyssopifolia*) (0.08 mg/kg each). Convergence of CN in the shoot of 5 plant species (*Chromoleana odorata*, *Bryophyllum pinnatum*, *Digitaria gayana*, *Echinochloa colona* and *Alchornea cordifolia*) 0.14 mg/kg each were the most elevated while the least was found in 1 plant species, *Solanum erianthum* (0.08 mg/kg). *Digitaria gayana* recorded the most astounding entire plant CN concentration (0.29 mg/kg) whereas the minimum entire plant CN concentration was discovered 2 plant species, *Solanum erianthum* and *Smilax anceps* (0.19 mg/kg each). In all the plant species, the collection of CN levels in the roots surpassed the aggregation in the shoots. The various plant parts showed basically among a couple of plant species no significant difference in CN concentration. *Eragrostis tremula* amassed all things considered more raised measures of CN than the distinctive species in the roots. *Chromolaena odorata, Bryophyllum pinnatum, Euphorbia heterophylla, Digitaria gayana, Echinochloa colona* and *Alchornea cordifolia* amassed essentially more raised measures of As than the unmistakable species in the shoots.

Table : Mean c

8 oncentrationof Cyanide (mg/kg)in plant species

Name of species	Family	Common name	Roots	Shoots	Whole plant
Chromolaena odorata Linn.	Asteraceae	Siamweed	0.12±0.02^{abcd}	**0.14±0.02^{abc}**	0.26±0.03^{abcd}
Mimosa pudica Linn.	Leguminosae	Sensitive plant	0.11±0.02^{abcd}	0.10±0.02^{abc}	0.21±0.04^{abc}
Rhynchelytrum repens(Willd) C.E. Hubbard	Poaceae	Blanketgrass	0.13±0.01^{abcd}	0.09±0.02^{ab}	0.22±0.02^{abc}
Conyza sumatrensis Linn.	Asteraceae	Fleabane	0.12±0.02^{abcd}	0.10±0.01^{abc}	0.22±0.02^{abc}
Bryophyllum pinnatum Lam.	Crassulaceae	Resurrection plant	0.09±0.02^{abc}	**0.14±0.03^{abc}**	0.23±0.02^{abcd}
Euphorbia heterophylla Linn.	Euphorbiaceae	Spurge weed	0.10±0.02^{abcd}	**0.14±0.03^{abcc}**	0.24±0.01^{abcd}
Spigella anthelmia Linn.	Loganiaceae	worm bush	0.14±0.03^{bcd}	0.13±0.02^{abc}	0.27±0.01^{bcd}
Eragrostis tremula Hochst. Ex Steud.	Poaceae	Lovegrass	**0.16±0.03^{d}**	0.11±0.02^{abc}	0.27±0.02^{bcd}
Tridax procumbens Linn.	Asteraceae	Tridax	0.15±0.03^{cd}	0.11±0.01^{abc}	0.26±0.03^{abcd}
*Pteris vittata*L.	Pteridaceae	Chinese brake fern	0.13±0.03^{abcd}	0.09±0.02^{ab}	0.22±0.03^{abc}
*Digitaria horizontalis*Wild	Poaceae	Cebadilla	0.12±0.03^{abcd}	0.10±0.02^{abc}	0.22±0.01^{abc}
Digitaria gayana (Kunth) Stapf ex. A Chev.	Poaceae	Fall witchgrass	0.15±0.02^{cd}	**0.14±0.01^{abc}**	**0.29±0.02^{d}**
Echinochloa colona Linn.	Poaceae	Junglerice	0.14±0.02^{bcd}	**0.14±0.02^{abc}**	0.28±0.02^{cd}
Paspalum scrobiculatum Linn	Poaceae	Common paspalum	0.10±0.01^{abcd}	0.10±0.02^{abc}	0.20±0.03^{ab}
Smilax anceps L.	Smilacaceae	West Africa	**0.08±0.01^{a}**	0.11±0.02^{abc}	**0.19±0.02^{a}**
Solanum erianthum	Solanaceae	Potato tree	0.11±0.01^{abcd}	**0.08±0.03^{a}**	**0.19±0.02^{a}**
Digitaria insularis (L.) Fedde	Poaceae	Sourgrass	0.11±0.01^{abcd}	0.10±0.02^{abc}	0.21±0.01^{ab}
Alchornea cordifolia (Schum. &Thonn.)	Euphorbiaceae	Christmas bush	0.09±0.01^{abc}	**0.14±0.03^{abc}**	0.23±0.03^{ab}
Euphorbia hyssopifolia Linn	Euphorbiaceae	Fireplant	**0.08±0.02^{a}**	0.13±0.02^{abc}	0.21±0.04^{abc}

Mean ± SD in same column with different letters in superscripts differ significantly ($p<0.05$)

4.9 Concentration of metals in the plant species

The mean concentration of the heavy metals and the cyanide in the plant species are presented in Table 9. Results obtained were subjected to SPSS analysis at a significant value of 0.05. The concentrations of the heavy metals and the cyanide were higher and significantly different in the roots, shoots and the whole plants based on Tukey's B multiple comparison test ($p < 0.05$). The concentrations of the heavy metals concentrations in the roots, shoots and whole plant were significantly different except for As and CN in the roots of *C. odorata*, *M. pudica*, *E. heterophylla*, *T. procumbens*, *D. gayana*, *P. scrobiculatum* and *E. hyssopifolia*. Metal concentrations in the root, shoot and whole plant differently except for As, and CN in the shoot of *R. repens*, *C. sumatrensis*, *D. horizontalis*, *S. anceps* and *D. insularis*. The Zn, Cd, As and CN concentrations in the plants parts differ significantly except for Cd and CN in the root of *S. anthelmia* as well as in the shoot for As and CN.

Metal concentrations in the root, shoot and whole plant differ significantly except for As and CN in the root, shoot and whole plant of *E. tremula*. All the metal concentrations differ significantly in the root, shoot and whole plant of *P. vittata*. There is significant difference between the metal in root, shoot and whole pant except for As and CN in the root and whole plant of *E. colona*. There is significant difference between metals except for As and CN in the roots and whole plant; Cd, As and CN in the shoots of *B. pinnatum*. The metal concentration in the plants differ significantly except for As and CN in the shoot as well as in the whole plant of *A. cordifolia*. The Zn, Cd, As and CN concentrations in the plant were significantly different except for Cd, As and CN in the root of *S. erianthum*. In all the Zn concentrations in the whole plant species differ significantly.

(a-g)

Table 9 : Level of Zn, Cd, As and CN- in roots and shoots of plants species

(a)

Metal	*Chromoleana odorata*			*Mimosa pudica*			*Rhynchelytrum repens*		
	Root	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**
Zn	16.16±0.17^{c}	25.16±o.32^{d}	41.33±0.48^{d}	26.66±0.21^{c}	21.24±0.01^{c}	47.90±0.22^{d}	12.24±0.18^{d}	57.52±0.09^{d}	69.77±0.26^{d}
Cd	1.53±0.03^{b}	0.89±0.01^{b}	2.43±0.03^{c}	1.36±0.01^{b}	1.54±0.18^{b}	2.90±0.04^{c}	1.56±0.02^{c}	1.66±0.04^{c}	3.22±0.05^{c}
As	0.10±0.01^{a}	1.53±0.02^{c}	1.63±0.01^{b}	0.12±0.02^{a}	1.64±0.02^{b}	1.76±0.03^{b}	1.31±0.01^{b}	0.12±0.02^{a}	1.43±0.03^{b}
CN	0.12±0.02^{a}	0.14±0.02^{a}	0.26±0.03^{a}	0.11±0.02^{a}	0.10±0.02^{a}	0.21±0.03^{a}	0.13±0.01^{a}	0.93±0.02^{a}	0.22±0.22^{a}

Mean ± SD in same column with different superscript letters differ significantly ($p<0.05$)

(b)

Metal	*Conyza sumatrensis*			*Bryophyllum pinnatum*			*Euphorbia heterophylla*		
	Root	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**
Zn	23.76±0.27^{d}	40.04±0.07^{c}	63.80±0.32^{d}	20.37±0.34^{c}	30.84±0.52^{b}	51.21±0.86^{c}	135.76±0.03^{c}	50.73±0.10^{d}	186.49±0.01^{d}
Cd	1.44±0.01^{c}	1.07±0.03^{b}	2.51±0.03^{c}	2.21±0.01^{b}	0.33±0.02^{a}	2.54±0.01^{b}	1.90±0.01^{b}	2.71±0.03^{c}	4.62.0.03^{c}
As	0.77±0.02^{b}	0.10±0.00^{a}	0.87±0.02^{b}	0.43±0.02^{a}	0.11±0.01^{a}	0.54±0.02^{a}	0.72±0.03^{a}	0.76±0.02^{b}	1.48±0.03^{b}
CN	0.12±0.02^{a}	0.10±0.01^{a}	0.22±0.02^{a}	0.87±0.02^{a}	0.14±0.03^{a}	0.23±0.02^{a}	0.97±0.02^{a}	0.11±0.01^{a}	0.21±0.01^{a}

Mean ± SD in same column with different superscript letters differ significantly ($p<0.05$)

(c)

Metal	*Spigella anthelmia*			*Eragrostis tremula*			*Tridax procumbens*		
	Root	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**
Zn	40.64±0.37^{c}	81.24±0.06^{c}	121.88±0.40^{d}	42.19±0.07^{c}	83.37±0.35^{c}	125.56±0.35^{c}	31.57±0.05^{c}	21.14±0.13^{d}	52.71±0.14^{d}
Cd	0.29±0.01^{ab}	2.29±0.07^{b}	2.58±0.07^{c}	2.62±0.02^{b}	1.10±0.00^{b}	3.72±0.02^{b}	2.02±0.03^{b}	2.94±0.05^{c}	4.96±0.05^{c}
As	0.64±0.02^{b}	0.10±0.01^{a}	0.74±0.03^{b}	0.12±0.02^{a}	0.34±0.02^{a}	0.46±0.03^{a}	0.09±0.01^{a}	0.53±0.02^{b}	0.62±0.02^{b}
CN	0.14±0.03^{a}	0.13±0.02^{a}	0.27±0.01^{a}	0.16±0.03^{a}	0.11±0.02^{a}	0.27±0.02^{a}	0.15±0.03^{a}	0.11±0.01^{a}	0.26±0.03^{a}

(a-g)

Mean ± SD in same column with different superscript letters differ significantly ($p<0.05$)

Table 9 : Contd

(d)

Metal	*Pteris vittata*			*Digitaria horizontalis*			*Digitaria gayana*		
	Root	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**
Zn	13.68 ± 0.09^{d}	9.34 ± 0.16^{d}	23.02 ± 0.02^{d}	45.41 ± 0.49^{d}	88.78 ± 0.12^{c}	134.19 ± 0.5^{d}	53.08 ± 0.26^{c}	44.12 ± 0.14^{d}	98.09 ± 0.30^{c}
Cd	3.21 ± 0.02^{c}	1.57 ± 0.04^{c}	4.78 ± 0.04^{c}	1.95 ± 0.01^{c}	2.86 ± 0.05^{b}	4.81 ± 0.05^{c}	1.35 ± 0.00^{b}	0.41 ± 0.01^{b}	1.76 ± 0.01^{b}
As	0.33 ± 0.02^{b}	1.22 ± 0.03^{b}	1.54 ± 0.05^{b}	1.09 ± 0.01^{b}	0.10 ± 0.02^{a}	1.19 ± 0.02^{b}	0.11 ± 0.01^{a}	2.09 ± 0.02^{c}	2.19 ± 0.03^{c}
CN	0.13 ± 0.03^{a}	0.09 ± 0.02^{a}	0.22 ± 0.03^{a}	0.12 ± 0.03^{a}	0.10 ± 0.02^{a}	0.23 ± 0.01^{a}	0.15 ± 0.02^{a}	0.14 ± 0.01^{a}	0.29 ± 0.02^{a}

Mean ± SD in same column with different superscript letters differ significantly ($p<0.05$)

(e)

Metal	*Echinochloa colona*			*Paspalum scrobiculatum*			*Smilax anceps*		
	Root	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**
Zn	37.07 ± 0.12^{c}	19.14 ± 0.02^{d}	56.20 ± 0.13^{c}	46.65 ± 012^{c}	18.31 ± 0.10^{d}	64.96 ± 0.17^{d}	54.02 ± 0.07^{b}	91.97 ± 0.07^{c}	145.99 ± 0.12^{d}
Cd	2.29 ± 0.02^{b}	0.79 ± 0.01^{c}	3.08 ± 0.02^{b}	2.73 ± 0.03^{b}	1.77 ± 0.03^{c}	4.50 ± 0.05^{c}	3.17 ± 0.03^{c}	2.12 ± 0.03^{b}	5.29 ± 0.03^{c}
As	0.16 ± 0.01^{a}	0.10 ± 0.01^{a}	0.26 ± 0.02^{a}	0.13 ± 0.04^{a}	0.60 ± 0.02^{b}	0.73 ± 0.03^{b}	0.73 ± 0.04^{b}	0.11 ± 0.02^{a}	0.84 ± 0.06^{b}
CN	0.14 ± 0.02^{a}	0.14 ± 0.02^{b}	0.28 ± 0.02^{a}	0.10 ± 0.01^{a}	0.10 ± 0.02^{a}	0.20 ± 0.03^{a}	0.80 ± 0.01^{a}	0.11 ± 0.02^{a}	0.19 ± 0.02^{a}

Mean ± SD in same column with different superscript letters differ significantly ($p<0.05$)

(a-g)

Table 9 : Contd

(f)

Metal	*Solanum erianthum*			*Digitarita insularis*		
	Root	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**
Zn	19.38±0.54^{c}	14.57±0.24^{d}	33.96±0.31^{d}	40.84±0.02^{d}	24.59±0.26^{c}	65.43±0,28^{d}
Cd	0.85±0.02^{b}	3.04±0.06^{c}	3.89±0.05^{c}	2.51±0.04^{c}	2.26±0.03^{b}	4.77±0.07^{c}
As	0.52±0.03^{ab}	0.92±0.02^{b}	1.43±0.03^{b}	0.65±0.01^{b}	0.15±0.02^{a}	0.80±0.01^{b}
CN	0.11±0.01^{a}	0.08±0.03^{a}	0.19±0.02^{a}	0.11±0.01^{a}	0.10±0.02^{a}	0.21±0,01^{a}

Mean ± SD in same column with different superscript letters differ significantly ($p<0.05$)

(g)

Metal	*Alchornea cordifolia*			*Euphorbia hyssopifolia*		
	Root	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**
Zn	114.19±1.42^{c}	7.58±0.23^{c}	121.77±1.31^{c}	90.64±0.06^{c}	49.11±0.10^{d}	139.75±0.13^{d}
Cd	1.57±0.56^{b}	1.54±0.01^{b}	3.11±0.55^{b}	1.63±0.02^{b}	2.75±0.01^{c}	4.38±0.02^{c}
As	1.55±0.01^{b}	0.12±0.02^{a}	1.67±0.03^{ab}	0.09±0.02^{a}	0.32±0.02^{b}	0.41±0.02^{b}
CN	0.09±0.01^{a}	0.14±0.03^{a}	0.23±0.03^{a}	0.08±0.03^{a}	0.13±0.02^{a}	0.21±0.04^{a}

Mean ± SD in same column with different superscript letters differ significantly ($p<0.05$)

4.10 Total Zn, Cd, As and CN bioaccumulation factors

The total heavy metal bioaccumulation factors for the plant species are presented in Table 10.Bioaccumulation factor greater than 1 for the total Zn was found in 18 plant species, 17 plant species and 19 plant species in their roots, shoots and whole plants respectively. Bioaccumulation factor greater than 1 was recorded in all the plant species for total Cd in their roots, shoots and whole plant.

In all no plant species had bioaccumulation factor greater than 1 for As in either of roots or shoots or whole plant whilst 10 plant species, 7 plant species and 19 plant species recorded bioaccumulation factor greater than 1 for total CN in their roots, shoots and whole plants respectively.

Table 10: Total Zn, Cd, As and CN Bioaccumulation factors

Species	Zn			Cd			As			CN-		
	Root	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**	**Root**	**Shoot**	**Whole**
Chromoleana odorata	**1.22**	**1.91**	**3.13**	**5.16**	**3.02**	**8.18**	0.03	0.50	0.53	**1.08**	**1.21**	**2.29**
Mimosa pudica	**2.02**	**1.61**	**2.63**	**4.58**	**5.20**	**9.79**	0.04	0.53	0.57	0.97	0.85	**1.82**
Rhycheltrumrepens	0.93	**4.36**	**5.29**	**5.25**	**5.60**	**10.84**	0.43	0.04	0.47	**1.15**	0.82	**1.97**
Conyza sumatrensis	**1.80**	**3.03**	**4.83**	**4.87**	**3.61**	**8.47**	0.25	0.03	0.28	**1.03**	0.88	**1.91**
Bryophyllumpinnatum	**1.54**	**2.34**	**3.88**	**7.45**	**1.12**	**8.57**	0.14	0.04	0.18	0.76	**1.24**	**2.00**
Euphorbia heterophylla	**10.29**	**3.84**	**14.13**	**6.42**	**9.15**	**15.56**	0.23	0.25	0.48	0.85	1.00	**1.85**
Spigellaanthelmia	**3.08**	**6.16**	**9.24**	**1.00**	**7.72**	**8.72**	0.21	0.03	0.24	**1.21**	**1.12**	**2.32**
Eragrostis tremula	**3.20**	**6.32**	**9.52**	**8.83**	**3.71**	**12.54**	0.04	0.11	0.15	**1.38**	0.97	**2.76**
Tridaxprocumbens	**2.39**	**1.60**	**3.99**	**6.81**	**9.91**	**16.72**	0.03	0.17	0.20	**1.29**	0.97	**2.26**
Pterisvittata	**1.04**	0.71	**1.74**	**10.83**	**5.28**	**16.11**	0.11	0.40	0.50	**1.18**	0.79	**1.97**
Digitariahorizontalis	**3.44**	**6.73**	**10.17**	**6.56**	**9.65**	**16.21**	0.36	0.03	0.39	**1.09**	0.91	**2.00**
Digitariagayana	**4.09**	**3.34**	**7.43**	**4.55**	**1.37**	**5.92**	0.03	0.68	0.71	**1.35**	**1.26**	**2.62**
Echinochloacolona	**2.81**	**1.45**	**4.26**	**7.73**	**2.67**	**10.40**	0.05	0.03	0.08	**1.21**	**1.26**	**2.47**
Paspalumscrobiculatum	**3.53**	**1.39**	**4.92**	**9.20**	**5.97**	**15.17**	0.04	0.20	0.24	0.91	0.91	**1.82**
Smilax anceps	**4.09**	**6.97**	**11.06**	**10.70**	**7.15**	**17.84**	0.24	0.04	0.27	0.71	1.00	**1.71**
Solanumerianthum	**1.47**	**1.10**	**2.57**	**2.88**	**10.26**	**13.13**	0.17	0.30	0.47	0.97	0.74	**1.71**
Digitariainsularis	**1.86**	**3.09**	**4.96**	**8.47**	**7.63**	**16.10**	0.21	0.05	0.26	0.97	0.91	**1.88**
Alchorneacordifolia	**8.65**	0.57	**9.23**	**5.28**	**5.20**	**10.48**	0.50	0.04	0.54	0.79	**1.24**	**2.03**
Euphorbia hyssopifolia	**6.87**	**3.72**	**10.59**	**5.51**	**9.28**	**14.79**	0.03	0.10	0.13	0.71	**1.15**	**1.85**

BF=metal concentration of plant root to soil, shoot to soil or whole plant to soil. Value >1 are in bold font

4.11 Bioavailable Zn, Cd, As and CN Bioaccumulation factors

The available heavy metal bioaccumulation factors for the plant species are presented in Table 11. All the plant species recorded bioaccumulation factor greater than 1 for the available Zn and Cd. Two (2) plant species (*R. repens* and *A. cordifolia*), 4 plant species (*C. odorata*, *M. pudica*, *P. vittata* and *D. gayana*) and 8 plant species (*C. odorata*, *M. pudica*, *R. repens*, *E. heterophylla*, *P. vittata*, *D. gayana*, *S. erianthum* and *A. cordifolia*) recorded bioaccumulation factor greater than 1 for the available As in their roots, shoots and whole plants respectively. Nevertheless, 13 plant species, 14 plant species and 13 plant species had bioaccumulation factor greater than 1 for the available CN in their roots, shoots and whole plants respectively.

Table 11: Bioavailable Zn, Cd, As and CN bioaccumulation factors

Species	Zn			Cd			As			CN-		
	Root	Shoot	Whole	Root	Shoot	Whole	Root	Shoot	Whole	Root	Shoot	Whole
Chromoleanaodorata	**5.86**	**9.13**	**14.99**	**33.02**	**19.35**	**52.37**	0.08	**1.27**	**1.35**	**1.68**	**1.86**	**3.54**
Mimosa pudica	**9.67**	**7.71**	**17.38**	**29.35**	**33.31**	**62.66**	0.10	**1.35**	**1.46**	**1.50**	**1.32**	**2.82**
Rhycheltrumrepens	**4.44**	**20.87**	**25.31**	**33.60**	**35.83**	**69.42**	**1.08**	0.10	**1.18**	0.13	0.09	0.22
Conyza sumatrensis	**8.62**	**14.52**	**23.14**	**31.15**	**23.09**	**54.24**	0.64	0.08	0.72	**1.59**	**1.36**	**2.95**
Bryophyllum pinnatum	**7.39**	**11.19**	**18.58**	**7.45**	**1.12**	**8.57**	0.36	0.09	0.45	**1.18**	**1.91**	**3.09**
Euphorbia heterophylla	**49.25**	**18.40**	**67.65**	**41.08**	**58.56**	**99.64**	0.59	0.63	**1.22**	0.10	0.11	0.21
Spigella anthelmia	**14.74**	**29.47**	**44.21**	**6.40**	**49.42**	**55.83**	0.53	0.08	0.61	0.14	0.13	0.27
Eragrostis tremula	**15.30**	**30.24**	**45.55**	**2.62**	**1.10**	**3.72**	0.10	0.28	0.38	**2.14**	**1.50**	**3.64**
Tridax procumbens	**11.45**	**7.67**	**19.12**	**43.60**	**63.45**	**107.05**	0.08	0.43	0.51	0.11	**0.15**	0.26
Pteris vittata	**4.96**	**3.39**	**8.35**	**69.35**	**33.81**	**103.16**	0.27	**1.01**	**1.28**	0.13	0.09	0.22
Digitaria horizontalis	**16.47**	**32.21**	**48.68**	**42.01**	**61.80**	**103.81**	0.08	0.91	0.99	0.12	0.10	0.23
Digitaria gayana	**4.09**	**3.34**	**7.43**	**29.14**	**8.78**	**37.91**	0.09	**1.73**	**1.82**	**2.09**	**1.95**	**4.04**
Echinochloa colona	**13.45**	**6.94**	**20.39**	**49.50**	**17.12**	**66.62**	0.13	0.09	0.22	**1.86**	**1.95**	**3.81**
Paspalum scrobiculatum	**16.92**	**6.64**	**23.56**	**58.92**	**38.20**	**97.12**	0.10	0.50	0.60	**1.41**	**1.41**	**2.82**
Smilax anceps	**19.60**	**33.36**	**52.96**	**68.49**	**45.76**	**114.24**	0.60	0.09	0.69	**1.09**	**1.55**	**2.64**
Solanum erianthum	**7.03**	**5.29**	**12.32**	**18.42**	**65.68**	**84.10**	0.43	0.76	**1.19**	**1.50**	**1.14**	**2.64**
Digitaria insularis	**14.81**	**8.92**	**23.74**	**54.24**	**48.85**	**103.09**	0.54	0.12	0.66	**1.50**	**1.41**	**2.91**
Alchornea cordifolia	**41.43**	**2.75**	**44.17**	**33.81**	**33.31**	**67.12**	**1.28**	0.10	**1.38**	**1.23**	**1.91**	**3.14**
Euphorbia hyssopifolia	**32.88**	**17.82**	**50.70**	**35.25**	**59.42**	**94.68**	0.08	0.26	0.34	**1.09**	**1.77**	**2.86**

BF=metal concentration ration of plant root to soil, shoot to soil or whole plant to soil. Value >1 are in bold font

4.12 Translocation factors of Zn, Cd, As and CN in the plant species

The translocation factors of the heavy metals in the plant species are presented in Table 12. Most of the plant species showed selective translocation for the metals. The translocation factor indicates that 8 plant species (*C. odorata*, *R. repens*, *C. sumatrensis, B. pinnatum*, *S. anthelmia*, *E. tremula*, *D. horizontalis and S. anceps*) are good phytotranslocators for Zn, 7 plant species (*M. pudica*, *R. repens*, *E. heterophylla*, *S. anthelmia*, *T. procumbens*, *D. horizontalis* and *S. erianthum*) for Cd, 8 plant species (*C. odorata*, *M. pudica*, *E. heterophylla*, *E. tremula*, *T. procumbens*, *P. vittata*, *D. gayana* and *P. scrobiculatum*) for As and 5 plants species (*C. odorata*, *B. pinnatum*, *E. heterophylla*, *E. colona* and *P. scrobiculatum*) for CN. Amongst the 19 plant species, *Digitaria gayana* had the highest TF of 19.77 for As. *Chromoleana odorata* demonstrated a translocation factor of 14.97 also for As. Metal transport for As in *Mimosa pudica* was 13.40.

12: Translocation factors of Zn, Cd, As and CN in the plant species

Species	Translocation factors			
	Zn	**Cd**	**As**	**CN-**
Chromoleanaodorata	**1.56**	0.59	**14.97**	**1.11**
Mimosa pudica	0.80	**1.13**	**13.40**	0.88
Rhylcheltrumrepens	**4.70**	**1.07**	0.09	0.72
Conyza sumatrensis	**1.68**	0.74	0.13	0.86
Bryophyllumpinnatum	**1.51**	0.15	0.25	**1.62**
Euphorbia heterophylla	0.37	**1.43**	**1.07**	**1.17**
Spigellaanthelmia	**2.00**	**7.72**	0.16	0.93
Eragrostis tremula	**1.98**	0.42	**2.88**	0.70
Tridax procumbens	0.67	**1.46**	**5.49**	0.75
Pteris vittata	0.68	0.49	**3.74**	0.68
Digitariahorizontalis	**1.96**	**1.47**	0.09	0.84
Digitaria gayana	0.82	0.30	**19.77**	0.93
Echinochloa colona	0.52	0.35	0.67	**1.05**
Paspalum scrobiculatum	0.39	0.65	**4.79**	**1.00**
Smilax anceps	**1.70**	0.67	0.15	**1.42**
Solanum erianthum	0.75	**3.57**	**1.76**	0.76
Digitariainsularis	0.60	0.90	0.22	0.94
Alchorneacordifolia	0.07	0.99	0.08	**1.56**
Euphorbia hyssopifolia	0.54	**1.69**	**3.30**	**1.63**

TF= metal concentration ratio of plant shoots to roots. Values >1 are in bold font **CHAPTER FIVE**

5.0 DISCUSSION

For the phytoremediation of contaminated soils with heavy metals, it is relevant to consider plants that represent high metal accumulation, high biomass production, and as well capable of transporting high level of metals from the root to shoot in order to ensure the highest chance of removing the metal from the soil. This study assessed the status of metal contamination in Chirano Gold Mine site (Tailings Storage Facility 1) and further evaluated the potential of 19 native plants for future clean-up exercise.

Table

5.1 Taxonomy, distribution, abundance and diversity of plant species

This study inventoried 19 plant species belonging to eight (8) families, 16 genera and 4 growth forms. The families: Poaceae, Euphorbiaceae and Asteraceae were the most abundant (69%). According to Malik *et al*. (2010) grasses (family: Poaceae) have been given more preference to shrubs or trees in use for phytoaccumulation because of their high growth rate, easy adaptability to stressful environment and high biomass production.

The findings concur with the study conducted by Messou *et al*. (2013) identified a total of 130 taxa belonging to 39 families of which the most frequent families (36.9% of the total taxa) were Poaceae, Euphorbiaceae and Cyperaceae although Cyperaceae species were not recorded in this study. The plant species in this study were classified into different habit forms (life cycle) which included those that were phanerophytes (perennial plants) and therophytes (annual plants) consistent with a report by Assédé *et al*. (2012).

Pteris vittata found in plots A, B and C had the highest relative abundance of 26.72 % confirming its easy adaptability and as a good colonizer (Ma *et al*., 2001). It establishes easily in a variety of soil environments (Ma *et al.*, 2001). This plant has the potential to be used to clean up arsenic-contaminated sites. In a phytoextraction process, the perennial nature of *Pteris vittata* makes the process more cost-effective as no replanting is needed after harvest (Gonzaga *et al*., 2008). Plant species that occur naturally in dense populations should be given preference in the selection process of plants for phytoremediation (Merkl *et al.*, 2004). They ensure rapid vegetation cover which enhances their easy root penetration of the soil and as such directly influences the success of phytoremediation.

Worldwide, over 400 species covering 45 families have been identified as hypercaccumulators in various capacities to extract metals (Prasad and Freitas, 2003). Among these families, some were collected on the Chirano mine site (TSF1) that included Poaceae, Asteraceae, Euphorbiaceae and Solanaceae. The presence of these plant families on this site could be possibly attributed to the suitable climatic conditions (Malik *et al*., 2010).

5.2 pH and heavy metal concentrations in the soil

Previous research has shown that the soil at Chirano is neutral (Remy, 2013).This was expected since the tailing materials are classified as Non-Acid-Forming (NAF) and they have a high neutralizing capacity (Remy, 2013) due to the lime that is added during the ore extraction to reduce the pH. More so, the soil sample contained some amount of topsoil which may have masked the actual pH and the available heavy metals in the tailings. In this

study, the area of research was predominantly contaminated with Zn which is consistent with the finding of Nazir *et al*. (2011) in which an industrial area was mostly polluted with Zn.

Most mobile elements which include Cd and Zn become immobile in neutral and alkaline soils as compared to highly acidic soils (Fijalkowski *et al*., 2012; Sherene, 2010). Therefore; extreme availability of these elements to plants in the site is unlikely due to the non-acidic forming nature Chirano tailings (Rajeswari and Namburu, 2014) which makes the tailings virtually neutral. Hence, the heavy metals levels determined in the soil samples were within the pollutant concentration limits in soils set by WHO (Agyarko *et al.*, 2010; Canadian Council of Ministers of the Environment, 1999).

5.3 Heavy metals in the roots and shoots of plant species

Generally plants metal concentrations vary from species to species (Lăcătuşu *et al*., 2009) owing to plant response under different environmental conditions (Mganga *et al*., 2011). This was evident in this study as heavy metal concentrations in plants varied from species to species. Though it has been suggested that species of the family Euphorbiceae are good for phytoremediation (Messou *et al.*, 2013), *A. cordifolia* (Euphorbiceae) recorded the lowest Zn concentration. The maximum Cd concentration was found in the root of *P. vittata*. This present study buttresses the great potential of *P. vittata* to survive in Cd contaminated soils (Xiyuan *et al*., 2007).

5.4 Bioaccumulation factor

From analyzed data, it was revealed in this study that a lot of the plant species showed metal concentrations >10 mg/kg in the shoots and as such may be considered as hyperaccumulators

(Baker and Brooks, 1989). The BF and TF can be used to estimate a potential for phytoremediation purposes.

Zn plays pivotal role in the growth of plants (Nazir *et al*., 2011) but at high concentrations it inhibit root cell division. Plants mostly utilize Zn as a divalent cation, which effect itself as a metal component or enzymes or as a functional, structural or regulatory co-factor of many enzymes (Nazir *et al*., 2011). Like Cd, the maximum level of Zn was again found in the shoots of *Smilax anceps.* The shoot of *D. horizontalis* also contained higher amount of Zn. Most of the plant species accumulated Zn above the recommended guideline 10 mg/kg recommended by Baker and Brooks (1989). This indicates the high mobility of Zn from roots to shoots and thus, easy accessibility by the plants. From this study, 5 plant species (*E. heterophyll*a- 135.76 mg/kg, *A. cordifolia*- 114.20 mg/kg, *E. hyssopifolia*-90. 64 mg/kg, *S. anceps*-54.02 mg/kg and *D. gayana*- 53.98 mg/kg) accumulated high amount of Zn in their roots, among them were 3 herbs with only 1 shrub and a grass which is consist with study by Nazir *et al*. (2011) who out 5 plant species identified 3 grass species to have accumulated high amount of Zn in their roots.

Cd is often found in association of Zn ores and thus derives its toxicological properties from it. Cadmium soil contamination occurs by the addition of phosphatic fertilizers (Containing 2-200 mg Cd/kg) domestic and sewage sludge, wear of automobile tyres, lubricants and mining and metallurgical activities (Sherene, 2010). The maximum root (rhizoid) Cd concentration (3.21 mg/kg) was found in *Pteris vittata* whilst in study by (Abidemi *et al*., 2014) the roots of *Cleome viscosa* recorded the highest Cd concentration of

30 mg/kg. This portrays the high affinity of *Cloeme viscosa* for Cd as compared to *P. vittata* in this study.

Soils with different properties are expected to have different Arsenic availability, and different levels in plant species. These factors influence the ability of a plant to access arsenic from soils, especially over a long time period (Gonzaga *et al*., 2008). In a survey of the potential of 36 plants (17 species) growing on a contaminated site, it was reported in (Yoon *et al*., 2006) that none of the plants were suitable for phytoextraction of Pb, Cu and Zn whilst peculiar to this study, none the plant species showed BF value >1 for total As accumulation (Table 10) and therefore no individual species has the potential for phytoextraction of the total As as compared to available As where there was selective accumulation potential. In Table 11, the roots of 2 plants species (*Rhycheltrum repens* and *Alchornea cordifolia*) and the shoots of 4 plant species (*C. odorota*, *M. pudica*, *P. vittata*, *D. gayana*) showed available As accumulation to be greater than 1. The above demonstrates that not all total heavy metal in the soil would be available for plant metabolism and in other cases toxicity. *Pteris vittata* is a known species for effectively removing Arsenic from As contaminated soils (Gonzaga *et al*., 2008). This was not in the case of this study where it showed low Arsenic accumulation <1 (Table 10). The various plant parts of P. *vittata* as reported in (Tu *et al*., 2002) revealed that most (circa 90%) of the arsenic was transported to the fronds, with the least arsenic concentrations in roots.

However, this did not reflect in this study for the total As. Many factors may have contributed this revelation. Factors that include soil arsenic concentration, soil properties, the presence

of other ions, exposure time, and the age of the plants may have influenced the As absorption and accumulation from the soils by these plant species as reported (Tu *et al*., 2002).

Cyanide measurement within plant tissue is important for evaluation of phytoremediation of cyanide in soil and groundwater (Ebbs *et al*., 2003) and also for assessing routes of cyanide toxicity to both plant and animals. Cyanide is used for the gold extraction and only a fraction (less than 5 ppm) to be found in Chirano tailings (Remy, 2013). The maximum value (0.16 mg/kg) for CN- concentration was found in the roots of *Eragrostis tremula,* also the shoots of *Chromoleana odorata*, *bryophyllum pinnatum*, *Euphorbia heterophylla, Echinochloa colona* and *Alchornea cordifolia* contained higher amount (0.14 mg/kg) of CN- (Table 8). No plant species accumulated CN- above 0.9 mg/kg recommended standard for agriculture lands (Canadian Council of Ministers of the Environment, 1999).

In acidic soils, volatilization becomes a significant removal process of free cyanide; and may be the dominant mechanism for cyanide loss from soil surfaces (USEPA 1984)(as cited in Canadian Council of Ministers of the Environment, 1999). However, this mechanism is unlikely to happen due to the Non-Acid-Forming (NAF) nature of Chirano tailings. Remy (2013), explains the loss of cyanide residues in Chirano tailings as due to the parallel reactions between reagent bunds (NaOH, HCl and NaCN-) and the lime added at the leach tank as pH modifier. Three plant species (*D. gayana*-0.29 mg/kg, *A. E. colona*-0.28 mg/kg, and *S. anthelmia*-0.27 mg/kg) on the whole accumulated high amount of CN-; among them 2 were grasses with only herb.

5.5 Total and available fraction of heavy metals and cyanide in soil

The bioavailable heavy metals (Mehes-Smith e*t al*., 2014) content in soil samples are less than total metal content.Factors including temperature, soil pH and aeration, fertilization, competition between plant species, the size of the plant and the structure of its root system, may impedemetal availability in the environment (Fijalkowski *et al*, 2012; Sherene, 2010).This study showed elevated Zn, Cd, As and CN- accumulation ratios when EDTA and ammonia acetate were added to the soil sample and the BFs calculated. This was in accordance with Kos *et al*.(2003), who also demonstrated that EDTA application promoted the accumulation of Pb, Cd and Zn in several plant species from different families, including *Cannabis sativa*, *Medicago sativa*, *Zea mays* and *Sorghum vulgare.*

EDTA can help liberate the proportion of phytoavailable Zn, Cd, As and CN dissolved in soil solution and activating the soil colloids. Soil colloids are the most active portion of the soil which often determines the physical, chemical and biological properties of the soil. EDTA and ammonia acetate application was evident in the bioavailable BFs values for As which had no species accumulation greater than 1 when the di-acids were used in the soil sample analysis. These values were indication that chunk of the heavy metal were available for the plant use but needed some amelioration.

5.6 Translocation factor

According to Sherene (2010) available concentration of metals in soil may be a better predictor for environmental impact of historical and current emissions of metals in a contaminated site. The process of phytoextraction typically requires the translocation of

heavy metals to the easily harvestable above-ground parts i.e., shoots (Khan *et al*., 2004). By comparing BF (i.e. metal concentration of plant shoot to soil) and TF, Plants exhibiting TF and essentially BF values less than one are unsuitable for phytoextraction (Fitz and Wenzel, 2002).

Heavy metal-tolerant species with high BF (i.e.metal concentration ratio of plant root to soil) and low TF can be used for phytostabilisation of contaminated sites, together with a vegetative cover (Yoon *et al.*, 2006). Plants deploy this technique, phytostabilisation, in order to immobilize toxic metals in contaminated soils (Susarla *et al*., 2002). Plants ability to change environmental conditions via root exudates is harnessed by this technique. Plants have the potential to immobilize heavy metals through absorption and accumulation by roots, adsorption onto roots, or precipitation within rhizosphere. Phytostablilization help contain the metal and prevent leaching into groundwater and also impede the metal bioavailability for entry into the food chain. The absorption of Zn, Cd and CN by plant roots and further translocation to the shoot is very low in most plants analyzed. This is an indication that most of the species are tolerable to high levels of trace elements and can be better players for soil remediation but at otherwise are toxic to the food chain when consumed as forage.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study was conducted to screen plants growing in and around contaminated area in Chirano concession (TSF1) to determine their potential for phyteremediation. The tailings Storage Facility 1 area presented high floristic diversity. In total, 19 plant specieswere

distributed into 8 families have been listed. The most frequent families were Poaceae, Euphorbiaceae and Asteraceae. The results obtained from the study suggest that there is a high potential for the use of plant species from these families: Poaceae, Euphorbiceae and Asteraceae in phytoremediation.

Bioaccumulation factor as expressed by total and bioavailable metal concentration in soil indicate that all of the plant species demonstrate good hyperaccumulation and phytoextraction potential for Zn and Cd whilst 13 and 8 plant species demonstrate good accumulation and phytoextraction potential for CN and As respectively. Additionally, several plant species had BF and TF greater than 1. *Digitaria gayana*, *C. odorata* and *M. pudica* were most effective in taking up Arsenic. Undoubtedly, the accumulative and phytotranslocation potential of these plant species provide useful information about their selective exploitation for effective phytoremediation of the tailings dam at Chirano Gold Mine.

6.2 Recommendations

Phytoremediation needs to be embraced because of the cost-effective solution it presents in site restoration and decontamination. It is suggested that future studies should consider:

- pot experiment using some selected plants in the family Poaceae particularly, *E. heterophyll*a, *D. horizontalis* and *D. gayana*.
- soil amelioration program to enhance the bioavailability of heavy metals to plants.
- bridging the gap in this study, by taking soil samples from each of the plots to determine the parameters for the cause for the spacial distribution of the plants species at the site.

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APPENDICES

APPENDIX A

Guidelines for acceptable levels of heavy metals in soil

Parameter	Zn	Cd	As	CN-	pH
Total	**13.20±0.06**	0.29±0.02	3.08±0.04	**0.11±0.03**	7.08±0.01
Available	2.76±0.08	0.05±0.00	1.21±0.04	0.07±0.02	
%Available	20.90	17.24	39.29	**63.63**	
Standard	200	1.4	12	0.9	6-8

(Agyarko *et al*., 2010)

(Canadian Council of Ministers of the Environment, 1999) **APPENDIX B**

SPSS output on the analysis of variance on ranks to compare the heavy metal concentration in plants parts (shoot, root and whole)

Shoot- *Chromoleana odorata*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1367			
Cd	3		.8967		
As	3			1.5333	
Zn	3				25.1633

Means for groups in homogeneous subsets are displayed. a.

Uses Harmonic Mean Sample Size = 3.000.

Root- *Chromoleana odorata*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
As	3	.1033		
CN	3	.1233		
Cd	3		1.5300	
Zn	3			16.1633

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Whole-Chromoleana odorata

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2600			
As	3		1.6333		
Cd	3			2.4267	
Zn	3				41.3267

Means for groups in homogeneous subsets are displayed. a.
Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Mimosa pudica*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.0967		
Cd	3		1.5433	
As	3		1.6400	
Zn	3			21.2433

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Root- *Mimosa pudica*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.1100		
As	3	.1233		
Cd	3		1.3600	
Zn	3			26.6600

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Whole-*Mimosa pudica*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2067			
As	3		1.7600		
Cd	3			2.9033	
Zn	3				47.9033

Means for groups in homogeneous subsets are displayed. a.
Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Rhyncheltrum repens*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.0933		
As	3	.1233		
Cd	3		1.6600	

Zn	3			57.5267

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Root-*Rhyncheltrum repens*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1300			
As	3		1.3100		
Cd	3			1.5567	
Zn	3				12.2433

Means for groups in homogeneous subsets are displayed. a.
Uses Harmonic Mean Sample Size = 3.000.

Whole-*Rhyncheltrum repens*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2233			
As	3		1.4300		
Cd	3			3.2167	
Zn	3				69.7700

Means for groups in homogeneous subsets are displayed. a.
Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Conyza sumatrensis*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
As	3	.1000		
CN	3	.1000		
Cd	3		1.0700	

Zn	3			40.0367

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Root-*Conyza sumatrensis*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1167			
As	3		.7733		
Cd	3			1.4433	
Zn	3				23.7633

Means for groups in homogeneous subsets are displayed. a.

Uses Harmonic Mean Sample Size = 3.000.

Whole-*Conyza sumatrensis*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2167			
As	3		.8700		
Cd	3			2.5133	
Zn	3				63.8000

Means for groups in homogeneous subsets are displayed. a.

Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Bryophyllum pinnatum*

Tukey B

metal	N	Subset for alpha = 0.05	
		1	2
As	3	.1100	
CN	3	.1400	
Cd	3	.3333	
Zn	3		30.8400

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Root-*Bryophyllum pinnatum*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.0867		
As	3	.4367		
Cd	3		2.2100	
Zn	3			20.3733

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Whole-*Bryophyllum pinnatum*

Tukey B

metal	N	Subset for alpha = 0.05

		1	2	3
CN	3	.2267		
As	3	.5433		
Cd	3		2.5433	
Zn	3			51.2133

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Euphorbia heterophylla*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1133			
As	3		.7633		
Cd	3			2.7133	
Zn	3				50.7333

Means for groups in homogeneous subsets are displayed. a.

Uses Harmonic Mean Sample Size = 3.000.

Root-*Euphorbia heterophylla*

Tukey B

metal	N	Subset for alpha = 0.05

		1	2	3
CN	3	.0967		
As	3	.7167		
Cd	3		1.9033	
Zn	3			135.7600

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Whole-*Euphorbia heterophylla*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2100			
As	3		1.4767		
Cd	3			4.6167	
Zn	3				186.4933

Means for groups in homogeneous subsets are displayed. a.

Uses Harmonic Mean Sample Size = 3.000.

Shoot- *Echinochloa colona*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
As	3	.1067			
CN	3		.1433		

Cd	3			.7933	
Zn	3				19.1367

Means for groups in homogeneous subsets are displayed. a.
Uses Harmonic Mean Sample Size = 3.000.

Root- ***Echinochloa colona***

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.1367		
As	3	.1600		
Cd	3		2.2933	
Zn	3			37.0667

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Whole-

Tukey B

Echinochloa colona

metal	N	Subset for alpha = 0.05		
		1	2	3
As	3	.2633		
CN	3	.2800		
Cd	3		3.0867	
Zn	3			56.2033

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Shoot -*Digitaria horizontalis*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
As	3	.1000		
CN	3	.1033		
Cd	3		2.8633	
Zn	3			88.7833

Means for groups in homogeneous subsets are a. Uses Harmonic Mean Sample Size = 3.000.

Root-*Digitaria horizontalis*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1233			
As	3		1.0967		
Cd	3			1.9467	
Zn	3				45.4067

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Whole-*Digitaria horizontalis*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2267			
As	3		1.1933		
Cd	3			4.8100	
Zn	3				134.1900

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Digitaria gayana*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1433			
Cd	3		.4067		
As	3			2.0900	
Zn	3				44.1167

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Root-*Digitaria gayana*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
As	3	.1067		
CN	3	.1533		
Cd	3		1.3500	
Zn	3			53.9800

Whole-

Tukey B

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Digitaria gayana

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2967			
Cd	3		1.7567		
As	3			2.1933	
Zn	3				98.0967

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Eragrostis tremula*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.1100		
As	3	.3433		
Cd	3		1.1000	
Zn	3			83.3733

Means for groups in homogeneous subsets are
a. Uses Harmonic Mean Sample Size = 3.000.

Root- *Eragrostis tremula*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
As	3	.1200		
CN	3	.1567		
Cd	3		2.6200	
Zn	3			42.1900

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Whole-

Tukey B

Ergrostis tremula

metal	N	Subset for alpha = 0.05	
		1	2
CN	3	.2667	
As	3	.4600	
Cd	3	3.7200	
Zn	3		111.7067

Means for groups in homogeneous subsets a.
Uses Harmonic Mean Sample Size =

Shoot- ***Pteris vittata***

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.0900			
As	3		1.2200		
Cd	3			1.5667	
Zn	3				9.3433

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Root- ***Pteris vittata***

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1333			
As	3		.3267		
Cd	3			3.2133	

Whole-

Tukey B

Zn	3				13.6800

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Pteris vittata

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2233			
As	3		1.5433		
Cd	3			4.7800	
Zn	3				23.0233

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Smilax anceps*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
As	3	.1100		
CN	3	.1133		
Cd	3		2.1200	
Zn	3			91.9700

Means for groups in homogeneous subsets are a. Uses Harmonic Mean Sample Size = 3.000.

Root-*Smilax anceps*

Tukey B

metal	N	Subset for alpha = 0.05

Whole-

Tukey B

		1	2	3	4
CN	3	.0800			
As	3		.7300		
Cd	3			3.1733	
Zn	3				54.0200

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Smilax anceps

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1933			
As	3		.8367		
Cd	3			5.2933	
Zn	3				145.9900

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Shoot- ***Spigella anthelmia***

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
As	3	.1000		
CN	3	.1267		
Cd	3		2.2900	
Zn	3			81.2433

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Whole-

Tukey B

Root *Spigella anthelmia*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.1367		
Cd	3	.2967	.2967	
As	3		.6367	
Zn	3			40.6400

Means for groups in homogeneous subsets are a. Uses Harmonic Mean Sample Size = 3.000.

Whole *Spigella anthelmia*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2633			
As	3		.7333		
Cd	3			2.5867	
Zn	3				121.8833

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Tridax procumbens*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1100			
As	3		.5267		
Cd	3			2.9400	
Zn	3				21.1400

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Root -*Tridax procumbens*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
As	3	.0967		
CN	3	.1467		
Cd	3		2.0200	
Zn	3			31.5667

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Whole-*Tridax procumbens*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2567			
As	3		.6200		
Cd	3			4.9600	
Zn	3				52.7067

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Shoot- *Solanum erianthum*

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.0833			
As	3		.9167		
Cd	3			3.0433	
Zn	3				14.5733

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Root- *Solanum erianthum*

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.1100		
As	3	.5200	.5200	

Whole-

Tukey B

Cd	3		.8533	
Zn	3			19.3833

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Solanum erianthum

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1933			
As	3		1.4333		
Cd	3			3.8967	
Zn	3				33.9567

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Shoot- ***Digitaria insularis***

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.1033		
As	3	.1467		
Cd	3		2.2633	
Zn	3			24.5900

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Root- ***Digitaria insularis***

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4

CN	3	.1100			
As	3		.6567		
Cd	3			2.5133	
Zn	3				40.8400

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Whole-

Tukey B

Digitaria insularis

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2133			
As	3		.8000		
Cd	3			4.7767	
Zn	3				65.4300

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Shoot- ***Paspalum scrobiculatum***

Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1033			
As	3		.6033		
Cd	3			1.7700	
Zn	3				18.3100

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Root- ***Paspalum scrobiculatum***

Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.1033		
As	3	.1267		
Cd	3		2.7300	
Zn	3			46.6467

Means for groups in homogeneous subsets are a. Uses Harmonic Mean Sample Size = 3.000.

Whole-
Tukey B

Paspalum scrobiculatum

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2067			
As	3		.7267		
Cd	3			4.5000	
Zn	3				64.9567

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Shoot-*Euphorbia hyssopifolia*
Tukey B

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.1300			
As	3		.3167		
Cd	3			2.7533	
Zn	3				49.1133

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Root-*Euphorbia hyssopifolia*
Tukey B

metal	N	Subset for alpha = 0.05		
		1	2	3
CN	3	.0800		
As	3	.0967		

Whole-

Tukey B

Cd	3		1.6333	
Zn	3			90.6367

Means for groups in homogeneous subsets are a.
Uses Harmonic Mean Sample Size = 3.000.

Euphorbia hyssopifolia

metal	N	Subset for alpha = 0.05			
		1	2	3	4
CN	3	.2100			
As	3		.4100		
Cd	3			4.3867	
Zn	3				139.7500

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Appendix C

Comparing mean concentration of heavy metal in plants shoots

Zn

Tukey B

Species	N	Subset for alpha = 0.05															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
R.repens	3	12.2433															
P.vittata	3		13.6800														
C.odorata	3			16.1633													
S.erianthum	3				19.3833												
B.pinnatum	3				20.3733	23.7633											
C.sumatrensis	3																
M.pudica	3						26.6600										
T.procumbens	3							31.5667									
E.colona	3								37.0667								
S.anthelmia	3									40.6400							
D.insularis	3									40.8400							
E.tremula	3										42.1900						
D.horizontalis	3											45.4067					

P.scrobiculatum	3												46.6467				
D.gayana	3													53.9800			
S.anceps	3													54.0200			
E.hyssopifolia	3														90.6367		
A.cordifolia	3															114.1967	
E.heterophylla	3																135.7600

Means for groups in homogeneous subsets are displayed. a.
Uses Harmonic Mean Sample Size = 3.000.

Cd Tukey

B

Species	N	Subset for alpha = 0.05									
		1	2	3	4	5	6	7	8	9	10
S.anthelmia	3	.2967									
S.erianthum	3		.8533								
D.gayana	3			1.3500							
M.pudica	3			1.3600							
C.sumatrensis	3			1.4433							
C.odorata	3			1.5300							
R.repens	3			1.5567							
A.cordifolia	3			1.5667							

E.hyssopifoli	3			1.6333	1.6333						
E.heterophyll	3				1.9033	1.9033					
D.horizontalis	3				1.9467	1.9467					
T.procumben	3					2.0200	2.0200				
B.pinnatum	3					2.2100	2.2100	2.2100			
E.colona	3						2.2933	2.2933	2.2933		
D. insularis	3							2.5133	2.5133	2.5133	
E.tremula	3								2.6200	2.6200	
P.scrobiculatu	3									2.7300	
S.anceps	3										3.1733
P.vittata	3										3.2133

Means for groups in homogeneous subsets are displayed. a.
Uses Harmonic Mean Sample Size = 3.000.

As

Tukey B

Species	N	Subset for alpha = 0.05										
		1	2	3	4	5	6	7	8	9	10	11
E.hyssopifolia	3	.0967										
T.procumbens	3	.0967										
C.odorata	3	.1033	.1033									
D.gayana	3	.1067	.1067									
E.tremula	3	.1200	.1200									
M.pudica	3	.1233	.1233									
P.scrobiculatum	3	.1267	.1267									
E.colona	3		.1600									
P.vittata	3			.3267								
B.pinnatum	3				.4367							
S.erianthum	3					.5200						
S.anthelmia	3						.6367					
D. insularis	3						.6567					
E.heterophylla	3							.7167				
S.anceps	3							.7300	.7300			
C.sumatrensis	3								.7733			

D.horizontalis	3									1.0967		
R.repens	3										1.3100	
A.cordifolia	3											1.5533

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

CN Tukey

B

Species	N	Subset for alpha = 0.05			
		1	2	3	4
S.anceps	3	.0800			
E.hyssopifolia	3	.0800			
B.pinnatum	3	.0867			
A.cordifolia	3	.0900	.0900		
E.heterophylla	3	.0967	.0967	.0967	
P.scrobiculatum	3	.1033	.1033	.1033	.1033
M.pudica	3	.1100	.1100	.1100	.1100
S.erianthum	3	.1100	.1100	.1100	.1100
D. insularis	3	.1100	.1100	.1100	.1100
C.sumatrensis	3	.1167	.1167	.1167	.1167
C.odorata	3	.1233	.1233	.1233	.1233
D.horizontalis	3	.1233	.1233	.1233	.1233
R.repens	3	.1300	.1300	.1300	.1300
P.vittata	3	.1333	.1333	.1333	.1333

S.anthelmia	3	.1367	.1367	.1367	.1367
E.colona	3	.1367	.1367	.1367	.1367
T.procumbens	3		.1467	.1467	.1467
D.gayana	3			.1533	.1533
E.tremula	3				.1567

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Comparing mean concentration of heavy metal in plants Roots

Zn

Tukey B

Species	N	Subset for alpha = 0.05															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
R.repens	3	12.24															
P.vittata	3		13.68														
C.odorata	3			16.16													
S.erianthum	3				19.38												
B.pinnatum	3				20.37												
C.sumatrensis	3					23.76											
M.pudica	3						26.66										
T.procumbens	3							31.56									
E.colona	3								37.06								
S.anthelmia	3									40.64							
D. insularis	3									40.84							
E.tremula	3										42.19						
D.horizontalis	3											45.40					
P.scrobiculatu	3												46.64				
D.gayana	3													53.98			
S.anceps	3													54.02			
E.hyssopifolia	3														90.63		
A.cordifolia	3															114.1	
E.heterophylla	3																135.7

Means for groups in homogeneous subsets are displayed.

a. Uses Hamonic Mean Sample size=3.00

Cd

Tukey B

Species	N	Subset for alpha = 0.05									
		1	2	3	4	5	6	7	8	9	10
S.anthelmia	3	.2967									
S.erianthum	3		.8533								
D.gayana	3			1.3500							
M.pudica	3			1.3600							
C.sumatrensis	3			1.4433							
C.odorata	3			1.5300							
R.repens	3			1.5567							
A.cordifolia	3			1.5667							
E.hyssopifolia	3			1.6333	1.6333						
E.heterophylla	3				1.9033	1.9033					
D.horizontalis	3				1.9467	1.9467					
T.procumbens	3					2.0200	2.0200				
B.pinnatum	3					2.2100	2.2100	2.2100			
E.colona	3						2.2933	2.2933	2.2933		
D. insularis	3							2.5133	2.5133	2.5133	
E.tremula	3								2.6200	2.6200	
P.scrobiculatum	3									2.7300	
S.anceps	3										3.1733
P.vittata	3										3.2133

Means for groups in homogeneous subsets are displayed. a.

Uses Harmonic Mean Sample Size = 3.000.

As Tukey

B

Species	N	Subset for alpha = 0.05										
		1	2	3	4	5	6	7	8	9	10	11
E.hyssopifoli	3	.096										
T.procumben	3	.096										
C.odorata	3	.103	.103									
D.gayana	3	.106	.106									
E.tremula	3	.120	.120									
M.pudica	3	.123	.123									
P.scrobiculat	3	.126	.126									
E.colona	3		.160									
P.vittata	3			.326								
B.pinnatum	3				.436							
S.erianthum	3					.520						
S.anthelmia	3						.636					
D. insularis	3						.656					
E.heterophyll	3							.716				
S.anceps	3							.730	.730			
C.sumatrensis	3								.773			
D.horizontali	3									1.096		
R.repens	3										1.310	
A.cordifolia	3											1.553

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Tukey B

CN

Species	N	Subset for alpha = 0.05			
		1	2	3	4
S.anceps	3	.0800			
E.hyssopifolia	3	.0800			
B.pinnatum	3	.0867			
A.cordifolia	3	.0900	.0900		
E.heterophylla	3	.0967	.0967	.0967	
P.scrobiculatum	3	.1033	.1033	.1033	.1033
M.pudica	3	.1100	.1100	.1100	.1100
S.erianthum	3	.1100	.1100	.1100	.1100
D. insularis	3	.1100	.1100	.1100	.1100
C.sumatrensis	3	.1167	.1167	.1167	.1167
C.odorata	3	.1233	.1233	.1233	.1233
D.horizontalis	3	.1233	.1233	.1233	.1233
R.repens	3	.1300	.1300	.1300	.1300
P.vittata	3	.1333	.1333	.1333	.1333
S.anthelmia	3	.1367	.1367	.1367	.1367
E.colona	3	.1367	.1367	.1367	.1367
T.procumbens	3		.1467	.1467	.1467
D.gayana	3			.1533	.1533
E.tremula	3				.1567

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Comparing mean concentration of heavy metal in whole plants

Zn

Tukey B

Whole	N	Subset for alpha = 0.05																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
P.vittata	3	23.0233																
S.erianthum	3		33.9567															
C.odorata	3			41.3267														
	3																	
M.pudica	3				47.9033													
	3																	
	3																	
B.pinnatum	3					51.2133												
	3																	
T.procumbens	3						52.7067											
	3																	
	3																	
E.colona	3							56.2033										
C.sumatresis	3								63.8000									
	3																	
	3											98.0967						
P.scrobilatum									64.9567	64.9567								
D. insulari										65.4300								
R.repens											69.7700							
D.gayana																		
A.cordifolia													121.7733					
S.anthelmia													121.8833					
E.tremula	3													125.5633				
D.horizontalis	3														134.1900			
E.hyssopifolia	3															139.7500		
S.anceps	3																145.9900	
	3																	186.49

E.heterophylla																		

33

Means for groups in homogeneous subsets are displayed. a. Uses Harmonic Mean Sample Size = 3.000.

Tukey B

Cd

Whole	N	Subset for alpha = 0.05								
		1	2	3	4	5	6	7	8	9
D.gayana	3	1.756								
C.odorata	3		2.426							
C.sumatrensi	3		2.513							
B.pinnatum	3		2.543							
S.anthelmia	3		2.586	2.586						
M.pudica	3			2.903	2.903					
E.colona	3				3.086					
A.cordifolia	3				3.110					
R.repens	3				3.216					
E.tremula	3					3.720				
S.erianthum	3					3.896				
E.hyssopifoli	3						4.386			
P.scrobilatum	3						4.500	4.500		
E.heterophyll	3						4.616	4.616	4.616	
D. insularis	3							4.776	4.776	
P.vittata	3							4.780	4.780	
D.horizontali	3							4.810	4.810	
T.procumben	3								4.960	
S.anceps	3									5.293

Means for groups in homogeneous subsets are displayed. a.
Uses Harmonic Mean Sample Size = 3.000.

Tukey B

As

Whole	N	Subset for alpha = 0.05											
		1	2	3	4	5	6	7	8	9	10	11	12
E.colona	3	.2633											
E.hyssopifolia	3		.4100										
E.tremula	3		.4600										
B.pinnatum	3			.5433									
T.procumbens	3				.6200								
P.scrobilatum	3					.7267							
S.anthelmia	3					.7333							
D. insularis	3					.8000	.8000						
S.anceps	3						.8367						
C.sumatrensis	3						.8700						
D.horizontalis	3							1.1933					
R.repens	3								1.4300				
S.erianthum	3								1.4333				
E.heterophylla	3								1.4767	1.4767			
P.vittata	3									1.5433			
C.odorata	3										1.6333		
A.cordifolia	3										1.6733		
M.pudica	3											1.7600	
D.gayana	3												2.1933

Means for groups in homogeneous subsets are displayed. a.
Uses Harmonic Mean Sample Size = 3.000.

Tukey B

Tukey B

CN

Whole	N	Subset for alpha = 0.05			
		1	2	3	4
S.anceps	3	.1933			
S.erianthum	3	.1933			
P.scrobilatum	3	.2067	.2067		
M.pudica	3	.2067	.2067		
E.heterophylla	3	.2100	.2100	.2100	
E.hyssopifolia	3	.2100	.2100	.2100	
D. insularis	3	.2133	.2133	.2133	
C.sumatrensis	3	.2167	.2167	.2167	
P.vittata	3	.2233	.2233	.2233	
R.repens	3	.2233	.2233	.2233	
B.pinnatum	3	.2267	.2267	.2267	
D.horizontalis	3	.2267	.2267	.2267	
A.cordifolia	3	.2300	.2300	.2300	.2300
T.procumbens	3	.2567	.2567	.2567	.2567
C.odorata	3	.2600	.2600	.2600	.2600
S.anthelmia	3	.2633	.2633	.2633	.2633
E.tremula	3		.2667	.2667	.2667
E.colona	3			.2800	.2800
D.gayana	3				.2967

Means for groups in homogeneous subsets are displayed. a.

Uses Harmonic Mean Sample Size = 3.000.

Tukey B