The Potential of Arrowroots (*Colocasia esculanta*) in Phytoremediation of Heavy Metals in the Meru Region

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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DEDICATION

This Thesis is dedicated to my late father, Ex Sr. Chief M'Tuerandu M'Kirera (Machuguma), my Mums Charity and Late Sarah and the entire Machuguma family, who encouraged me to strive relentlessly in search of knowledge.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
APHA	America Public Health Association
BAL	British Anti-Lewisite
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
GoK	Government of Kenya
KEBS	Kenya Bureau of Standards
KeMU	Kenya Methodist University
Kg	Kilogram
JKUAT	Jomo Kenyatta University of Agriculture and Technology
MEWASS	Meru Water and Sewerage Services
MOA	Ministry of Agriculture
MPH&S	Ministry of Public Health and Sanitation
Mg	Milligram
ml	Milliliter
MUCST	Meru University College of Science and Technology
NEMA	National Environmental Management Authority
N.P.K	Nitrogen, Phosphorus, Potassium (Compound Fertilizer)
UoN	University of Nairobi
µg	Microgram
pH	Hydrogen Ion Concentration

Ppm   Parts Per Million

RDA   Recommended Dietary Allowance

TFR   Tea Research Foundation

WHO   World Health Organization

ABSTRACT

Potential health hazard implications of heavy metals in taro/arrowroot (*Colocasia esculenta*) are imminent especially if taro is cultivated in heavily polluted water bodies due to the fact that taro plant bio-accumulate heavy metals. Determination of heavy metals in food crops is important in order to establish their concentration levels. This study sought to investigate the presence and concentration of heavy metals: Cadmium, Chromium, Copper, Mercury, Manganese, Lead and Zinc in the leaves and corms of the taro/arrowroot plant and the corresponding water and sediments from Gachioma and Karumanthi rivers in Meru Town of Meru County.

The concentration levels of these heavy metals in the plant were determined to assess whether taro can accumulate them to toxic levels. Taro corms and leaves together with water and sediment samples were collected along the two rivers. The solid samples were first dried in the sun then in an oven and ashed in the muffle furnace. The residue was leached from the vessel using hot concentrated hydrochloric acid then digested using a mixture of nitric, perchloric and sulphuric acids in a volume ratio of 3:1:1. The samples were analyzed at JKUAT Chemistry laboratories using the Buck Scientific Atomic Absorption Spectrophotometer (AAS) model 210 VGP. Microsoft Excel Computer Software was used to analyze the data. Analysis showed that concentration of mercury was below detection limits in all the analytes from the two rivers. Cadmium concentration levels in water from the two rivers were below detection limits. The study showed that concentration of chromium was highest in Gachioma River with a mean of 0.162 ± 0.003 ppm while the concentration for all

other metals in the two rivers was below 0.12 ppm. In the sediments, the metal with the highest concentration was manganese in Gachioma River sediments which ranged between 4.755 and 11.000 ppm with a mean of 7.824 ± 0.172 ppm. The metal with lowest concentration in the sediments was cadmium in Gachioma River which ranged between 0.036 and 0.054 ppm with a mean of 0.048 ± 0.002 ppm. Zinc had the highest concentration in corms collected from Karumanthi River whose range was between 0.498 and 1.726 ppm with a mean of 0.88 ± 0.014 ppm. The metal with lowest concentration in corms was lead with a mean of 0.02 ± 0.0002 ppm and ranged between 0.008 and 0.026 ppm. The heavy metal with highest concentration in the leaves was manganese in the leaves of corms collected from Karumanthi River which ranged between1.730 and 3.776 and a mean of 2.68 ± 0.022 ppm. Lead had the lowest concentration in the leaves of taro collected from Gachioma River which ranged between 0.010 and 0.150 ppm and a mean of 0.012 ± 0.00

Statistical analysis indicated that both leaves and corms bio-accumulated heavy metals. Results indicate that the plant can accumulate heavy metals if grown in heavily polluted water bodies. These results showed that the amounts of heavy metals in the two rivers were very low and did not pose any potential health hazard to consumers as they were below the and National Environmental Management Authority (NEMA) permitted levels. The potential use of the plant in water treatment is worth further investigation.

CHAPTER 1

1.0 INTRODUCTION

1.1 GENERAL INTRODUCTION

Soils and water contamination by heavy metals will produce unhealthy food. Heavy metals enter the food chain and are consumed by human beings (Setyorin *et al.,* 2000). In modern economies, various types of activities including agriculture, transport and industry produce a large amount of waste and new pollutants. Soil, water and air have traditionally been used as the sites for the disposal of all these wastes (Setyorin *et al.,* 2000). Clean fresh water is essential for nearly every human activity. Perhaps more than any other environmental factor, availability of water sources free from pollution is primarily important for any country as part of water conservation (Barneji, 2005). The history of human civilization reveals that water supply and civilization are almost synonymous. Several cities and civilizations have disappeared due to climatic changes and water shortages (Kumar, 1994).

All living organisms are composed of cells that contain at least 60% water. Organisms can only exist where there is access to adequate supplies of water. Water is also a unique and necessary resource because it has remarkable physical properties (Cunningham *et al.,* 2005). As a solvent, water has the ability that makes it able to dissolve and carry substances ranging from nutrients to industrial and domestic wastes. A look at any urban sewer will quickly point out the value of water in its ability to dissolve and transport wastes (Enger and Smith, 1992).

1.2 Types and Sources of Water Pollution

Water pollution occurs when the use by one segment of society interferes with the health and well-being of other members. Water quality is related to the use that is intended of

it. Adding material to water may cause it to become unfit for some uses but may not affect others. If silt, for example, is added to a lake, the water may still be drinkable but not an acceptable place to swim. If salts are added to a lake, the water may then be less acceptable for drinking but the salts may not interfere with the lake's recreational value. There are also economic considerations. The cost of removing the last few percentages of some materials from the water may not be justifiable. This is certainly true of organic matter, which is biodegradable (Enger and Smith, 1992). However, radioactive wastes, heavy metals wastes and other toxins that may accumulate in living tissues must be removed because of their potential harm to humans and other living organisms (Enger and Smith, 1992).

1.2.1 Municipal Water Pollution

Municipal water pollution is associated with wastes such as storm-water run-off, from industry and from domestic and commercial establishments. Wastes consists primarily of organic matter from garbage, food preparation, cleaning of clothes, dishes and human wastes which are mostly undigested food material and a concentrated population of bacteria, such as coliform and *streptococcus feacalis*. These particular bacteria normally grow in the human large intestines (Enger and Smith, 1992). Non living organic matter in sewage presents a different kind of pollution problems in water because it decays and depletes the amount of dissolved oxygen in water. The impact of these materials on water quality is expressed in terms of biochemical oxygen demand (BOD), (Cunningham *et al*, 2005).

1.2.2 Industrial Pollution

This occurs frequently when a factory or an industrial complex discharges some or all of its wastes into a municipal sewage system. Depending on the type of the industry involved, the wastes are likely to be a combination of organic and inorganic material, petroleum products, metals or even acids.

The metals, acids and other ions need special treatment depending on their nature and concentration. As a result, municipal sewage treatment plants must be designed with their industrial customers in mind. Industries are required to take care of their own wastes before they discharge them into natural waterways and design a wastewater facility that meets its specific needs. This allows the industry to segregate and control toxic wastes (Enger and Smith, 1992).

1.2.3 Agricultural Run off

The major water pollutants from agricultural run-off include nitrates and phosphates which come from fertilizers (Enger and Smith, 1992). The Environmental Protection Agency, (EPA) of U.S.A. estimates that 60% of all threatened surface waters are affected by sediments from eroded fields and overgrazed pastures (Cunningham *et al*., 2005). Beef cattle in the United States of America for example, are estimated to produce 92 million metric tons while dairy cattle produce 27 million metric tons of manure per year (Tan, 1995). Fertilizers and nutrients from croplands in areas of intensive agriculture contribute to the surface water pollution (Cunningham e*t al*., 2005).

Pesticides used in agriculture to control weeds, crop diseases, and kill insects which destroy crops and spread disease. Pesticides include herbicides, fungicides, insecticides

and rodenticides among others. Several water pollution from agricultural run off have been associated with extensive use of pesticides to boost crop production (Kumar, 1994).

1.3   Heavy Metal Poisoning

More than half of the elements known are metals. These elements have a wide and diversified use which is increasing all the time. Plants and animals contain a considerable amount of sodium, potassium, magnesium, and calcium, boron, chromium, cobalt, copper, iron, manganese, vanadium and zinc are present in very small amounts. Many of those elements which are required in micro- amounts are toxic to plants and animals when present in large amounts (Barneji, 2005).

Industrial activities are responsible for the increasing level of heavy metal pollution beyond the tolerance limits. Lead and mercury pollution are particularly of concern after incidents across the globe in which their involvements have come to light during the recent years (Barneji, 2005). Some elements which are essential micronutrients such as beryllium, boron, calcium, chromium, copper, nickel, selenium and zinc cause toxicity when present in large amounts. The degree of toxicity of these metals also depends on the form in which it is present. Organo-mercury and organo-lead are much more toxic than their inorganic form (Kumar, 1994). The oxidation state of metals also plays an important role in this regard. In the environment, microbial oxidation and reduction of metals also contribute to the problem of toxicity by metals as such reactions bring about changes in the oxidation states of metals (Barneji, 2005).

Meru town is rapidly expanding in terms of commerce and population. Recent years have seen rapid increase in the volume of motor vehicles in the town and corresponding increase in Jua Kali workshops involved in diversified activities including metal fablication, motor vehicle garages and wood workshops. These activities generate metallic waste which finds its way into water bodies. Arrowroots are widely eaten in Meru and they are commonly planted along rivers or in swamps. The metals cadmium, chromium, copper, lead manganese, mercury and zinc were studied due to their association with the activities that take place in Meru town and its peri-urban area. Small scale coffee farming is an agricultural activity that takes place within Meru Municipality area.

1.3.1 Cadmium (Cd)

Cadmium is present in water and soil in very low amounts in the order of $0.4\mu g$ l^{-1}(Barneji, 2005), and in the earth's crust cadmium lvels have been estimated to be in the range of 0.06 and 1.0 ppm (Skirant and Veniggopal, 1994). The primary concern regarding pollution caused by cadmium arises from the capacity of some plants to absorb and concentrate the metal. This poses a real threat to the carnivores (Barneji, 2005) as the metal gets accumulated in the food chain higher from one trophic level to the next (Enger and Smith, 1992).

With the increased use of the metal in industry, the daily intake of cadmium by humans and animals is in the order of 300 to 400 $\mu g l^{-1}$ (Barneji, 2005). A condition known as *Itai-Itai* disease developed in the Japanese people living near the Jinstsu River was traced to cadmium poisoning from the mining and smelting waste-water discharges (Cunningham *et al*., 2005). Many people suffered from this disease in which their bones

became fragile. Cadmium causes kidney problems, anemia and bone marrow disorders. At daily intake of 175 µ g of cadmium for three years, the metal causes hypertension (Barneji, 2005)

1.3.2   Chromium (Cr)

The existence of chromium in various oxidation states offers scope of microbial oxidation. For instance chromium (VI) is more toxic than chromium (III). In high concentrations it causes brochiogenic carcinoma and nasal perforations (Barneji, 2005). As a trace element, chromium occurs in the tissues and can be detected in the dairy products, meat and in fish. It is essential for growth as shown in an experiment where severely restricted intake of chromium in the diet of rats and mice has been shown to impair growth and survival of these experimental animals (Harold, 1971).

1.3.3   Copper (Cu)

Copper is one of the essential micro-nutrients in human diets. It is taken up by plants and the amount taken up depends on the soil pH, plant species and the amount of copper in the soil (Kabata and Alina, 1984). The daily requirement is about 2.0 mg. In the body copper is either a constituent of certain enzymes or is essential in their activity including cytochrome and cytochrome oxidase. The adult human body contains 100 − 150 mg of copper (Harold, 1971).

Copper salts are used in water supply system for controlling biological growth in reservoirs and distribution pipes. Corrosion of copper containing alloys in pipe fittings introduce measurable amounts of copper into the water in a localized pipe system (Kumar, 1994). Copper enters drinking water due to leaching of copper pipes by acidic or alkaline waters (Townshed, 1995).

In agriculture, inorganic copper pesticides and fungicides, like Bordeaux mixtures have been used in orchards (Kabata and Alina, 1984), while copper fungicides such as *Cocide* DF have been used by coffee farmers in Kenya (GoK, 1979). Copper fungicides are broad spectrum and moderately toxic to animals and algae but essentially indestructible, remaining in the environment for a very long time (Cunningham *et al.*, 2005). Copper contamination also occurs from excessive use of fertilizers and fungicides. Copper ranges between 1 - 300 mg/Kg in phosphate fertilizers, 2 – 172 mg/Kg in farmyard manure and 13-3580 mg/Kg in composted manure (Kabata and Alina, 1984).

Food sources of copper include liver, kidney, shellfish, whole grain cereals and nuts (Macrae *et al.*, 1993). Soft or acidic water passing through copper pipes can also enter into diet copper (Bradley and Bernet, 1995). Copper occurs in almost all food stuffs and the amount in food varies with the copper content of the soil on which it is grown (Salmon and Wright 1977). Vegetables, flour, dairy and meat products normally have copper content less than 0.01 mg/gm (Macrae *et al.*, 1993). Mean copper content of 9.76 μg/gm of cooked food has been reported (Padya, 1978). Defficiency of copper in human body leads to a condition known as hypochromic anemia and neutropenia (O'Dell, 1976, 1982; Williams, 1994).

Copper plays a role as an anti-oxidant (O'Dell, 1982; Cotzias, 1977; Macrae *et al.*, 1993). Menkes disease is caused by genetic copper deficiency (Carl, 1975; Danks *et al.*, 1972). This syndrome is manifested in infants and is characterized by poor growth, evidenced by white hair with peculiar twisting, arterial defects, focal cerebral

degeneration and mental retardation (Cordano et al.,1964; Danks et al., 1972; Carl, 1975;). Cardiovascular disorders are evident in almost all species subjected to copper deficiency, whether genetic or nutritional in origin (Carnes, 1969; Underwood, 1977). An excess of copper intake is toxic. Symptoms of copper poisoning are nausea, vomiting, coma, diarrhea, hypertension, jaundice, haematuria, anurria and death (Chuttani *et al*., 1965). Cigarette smoking is a prominent source of excess copper accumulation (Crews *et al*., 1980). Oral contraceptives interact with nutrient copper by increasing plasma levels of ceruloplasmin (Williams, 1994).

1.3.4   Lead (Pb)

World production of Lead is about five million tons (Barnerji, 2005). Half of this quantity is used in the manufacture of lead batteries and about 25% in sheet and pipe production. Lead is also used in the manufacture of industrial chemicals, paints and in making tetraethyl lead (Et_4Pb), the anti knock additive agent used in gasoline (Barnerji, 2005).

Natural process in the disposal of lead is restricted due to its insolubility. Lead present in the Antarctic soil which is taken as a standard reference or background level, is in the order of 10 ppm. This level becomes 100 ppm near busy roads due to vehicular emissions. In the vicinity of smelters, the concentration has been known to increase even more and in sewages the value varies from 100 to 8000 ppm. The increase in concentration is attributed to deposition of aerosol on water and limited mobilization of lead which is 0.001 $\mu g/m^3$. In dense traffic areas it goes up to 80 $\mu g/m^3$. In natural water, the level of lead contamination is about 0.1 $\mu g/l$ (Barnerji, 2005).

Lead poisoning has been known since Roman times to be dangerous to human health. In older homes, lead remains a source of drinking water pollution where water is acidic and therefore, leaches more lead from pipes. Lead solder in pipe joints and metal containers can be hazardous. In 1990, the EPA lowered the maximum limit for lead in public drinking water from 50 ppb to 20 ppb (Cunningham, *et al.*, 2005).

The major biochemical effect of lead is in its interference with heme synthesis which leads to hematological damage, thus reducing oxygen carrying capacity at high levels. At lower levels, lead causes long-term damage to critical neurons in the brain that results to mental and physical impairment and developmental retardation. Due to the chemical analogy of Pb^{2+} with Ca^{2+}, bones act as repository for lead accumulated by the body (Kumar, 1994). Subsequently, this lead may be remobilized along with phosphates from bones which exert a toxic effect when transported to soft tissues (Kumar, 1994).

Lead poisoning can be cured by treatment with chelating agents which strongly bind Pb^{2+}. To do this, calcium chelate in solution is fed to the victim of lead poisoning, where Pb^{2+} displaces Ca^{2+} from the chelate and the resulting Pb^{2+} chelate is rapidly excreted in the urine (Kumar, 1994).

Ecological aspects of lead pollution can be understood from its effects on organisms. Researchers have found out that snails from populations in areas where lead mining has been carried out have been able to concentrate lead into their shells where it cannot harm them. Snails from other populations are not able to do this and suffer lead accumulation in body tissues (Catherine and Edward, 2006).

1.3.5   Manganese (Mn)

Manganese metal ore is widely spread throughout much of the earth's crust but it is in combined state. The chief ores of manganese include psilomelane and pyrolusite among others. Most of manganese occurs in iron ores such as manganiferous ores with $5 - 10\%$ manganese, ferruginous manganese ores with $10 - 35\%$ manganese and those with more than 35% manganese are known as manganese ores (Emily, 2001).

1.3.5.1 Manganese in the Environment

Manganese enters the environment through discarded steel items. In the manufacture of steel, manganese is used to remove oxygen and sulfur from the molten steel and forms manganous oxide or manganous sulfide. These manganese compounds are then discarded as slag, which is poured off (Harrison, 1981). Electronic appliances such as radios, computers and dry cells contribute large quantities of manganese which finds entry into the environment. Potassium permanganate is used as a disinfectant and a deodorizer in water purification (Emily, 2001), and in pharmaceutical products (Cotzias, 1975; Gong and Amemiya 1990, Hussain and Ali, 1999).

1.3.5.2 Manganese as a Fertilizer

Manganese sulfate is an important ingredient in some kinds of fertilizers. Crops such as tomatoes, potatoes, beans and maize cannot do well in soils containing large amounts of lime. Such soils are treated with fertilizers containing manganese. In Texas and Florida in U.S.A, citrus fruits are hard to grow in those soils unless manganese fertilizers are

added (Harrison, 1981). Manganese is an essential nutrient for all crops in very low concentration but may be toxic if present in large concentrations (Harrison, 1981).

1.3.5.3 Manganese in Tea Leaves

In tea bushes, leaf content of manganese can reach extremely high levels (Tea Research Foundation, TRF, 2002). No proof of toxicity has been established however, and it is known that tea of the greatest vigor can apparently maintain its state while still absorbing manganese in high quantity (TRF, 2002). The green tint of a shed tea leaf is due to the presence of manganese salts (Wilson and Clifford, 1992) and ranges from 40 - 2000 mg/Kg in phosphate fertilizers, 30 - 969 mg/Kg in farmyard manure and 40 - 1200 mg/Kg in lime and animal feeds (Townshed, 1995).

1.3.5.4 Manganese as an essential micro-nutrient

Manganese is also an essential micronutrient. The total adult body content of manganese is about 10 mg, occurring mainly in the kidney, liver, bones, pancreas and pituitary (Harold, 1971). It is an essential part of cell enzymes that catalyze important metabolic reactions. Manganese deficiency, evidenced by low serum levels, has been reported in diabetes and pancreatic insufficiency, as well as in protein-energy malnutrition states such as kwashiorkor (Williams, 1994). Toxicity of manganese in humans occurs as an industrial disease syndrome, inhalation toxicity, in mineral and other workers who have had prolonged exposure to manganese dust. In such cases excess manganese accumulates in the liver and central nervous systems, producing severe neuromuscular symptoms that resemble those of Parkinson's disease. The RDA estimates are safe and adequate dietary intake of manganese of 2 to 5 mg/day (Williams, 1994). Food sources of manganese are

plant foods such as cereal grains, legumes, seeds, nuts and leafy vegetables (Williams, 1994), as well as tea and coffee (Kleen *et al.*, 1999).

1.3.6 Zinc (Zn)

Zinc (Zn) is one of the most important heavy metals biologically (Cotton and Wilkinson, 1972). It is an essential micronutrient for plants, animals and micro organisms (Barneji, 2005). It has come to nutritional prominence as an essential trace element with wide clinical significance. The wide tissue distribution of zinc reflects its broad metabolic activity as a component of key cell enzymes (Williams, 1994). When experimental animals (rats) were maintained on a diet which was very low in zinc, impaired growth and poor developments of their coats were noted (Harold, 1971). Insulin is known to contain zinc and it has been noted that the pancreas of the diabetics contain only 50% the normal amount of zinc (Harold, 1971).

Zinc deficiency can cause a number of clinical problems such as diminished function of the gonads and dwarfism (*hypogonadism*), taste and smell defects (*hypogeusia*), and retarded wound healing (Williams, 1994). An adult's total zinc content ranges form 1.3 to 2.3 g and is distributed in many tissues including pancreas, liver, kidney, lungs, muscle, bones, eye, endocrine glands, prostate secretions and spermatozoa (Williams, 1994). The best sources of dietary zinc are sea food, especially oysters, meat and eggs. Other less rich sources are legumes and whole grains (William, 1994).

An aspect of zinc pollution has arisen from the development and ramification of viscose rayon industry. The metal is essentially used for proper coagulation of the cellulose xanthate in the spinning baths where the whole of zinc used goes into the effluent.

Attempts to recover part of the zinc from the effluent have been successful but developments for complete recovery method have been unsuccessful (Barneji, 2005). Coal burning releases zinc into the atmosphere. This zinc, along with other heavy metals is absorbed by plants and they concentrate it in the process of coal formation (Cunningham *et al.,* 2005).

1.3.7   Mercury (Hg)

In nature, Mercury occurs as a trace component of many minerals. The main ore is Cinnabar (HgS). Fossil fuels, coal and lignite contain about 100 ppb of mercury. The natural abundance in soil is 0.1 ppm (Kumar, 1994). Mercury in nature is usually concentrated in the sedimentary rather than in the igneous rocks. Due to dilution effects, the levels of the metals present in water are rarely above 10^{-4} ppm, however, in a coastal region, its concentration increases to an order of 10^{-3} ppm due to storm water from industries and urban settlements in the interior (Barneji, 2005).

Mercury has a wide range of applications, the largest being chlor-alkali industry which manufactures chlorine and sodium hydroxide. The second largest use of mercury is in the production of electrical apparatus, switches, mercury batteries and laboratory apparatus. Agricultural industry constitutes another major consumer of mercury due to large number of fungicides used for seed dressings such as methylmercurynitrile, methylmercuryacetate and ethylmercurychloride (Kumar, 1994). The impact of seed dressing with mercury fungicides is enormous because it is applied to a large volume of seed, which is subsequently sowed over millions of acres. This causes a widespread dispersal of mercury compounds. This way the metal undergoes translocation in plants and animals and then finds way into the human food chain (Kumar, 1994).

Mercury metal is toxic, but the metal is also not reactive (Solomons, 1984). Mercury metal present in industrial wastes has been disposed of by dumping such water into streams, lakes and seas. Since mercury is toxic, many bacteria protect themselves from its effect by converting mercury metal to methylmercury ions (CH_3Hg^+) and to gaseous dimethylmercury ((CH_3)$_2$Hg) (Solomons, 1984). These organic mercuric compounds are passed up the food chain, with modification through fish to humans where methylmercury ions act as deadly nerve poison. Between 1953 and 1964, more than 100 Japanese were poisoned in Minamata Bay by fish that contained large amounts of methylmercury compounds (Solomons, 1984; Cunningham, 2005;). The cause of this mercury poisoning has been attributed to the discharge of the effluents of various chlor-alkali industries situated around Minamata Bay (Barneji, 2005). In 1997, Minamata Bay was declared officially clean again (Cunningham, 2005).

In 1970, an out break of mercury poisoning in the United States was traced to mercury in the meat of sword fish and tuna (Enger and Smith, 1992). The Minamata and the other incident have both boosted the awareness of mercury as a pollutant and this has been extensively studied following the two events (Enger and Smith, 1992).

The severity of mercury pollution varies with the form in which the metal is present. Inorganic mercury compounds are more toxic than the organomercurials (Barneji, 2005). However, the organomercurials pose a long-term hazard to the environment. In nature some of the reactions that convert mercury metal to organomercury compounds especially where bacteria are involved are:

- Reduction of methyl, ethyl, or phenyl-mercury to mercury.

- Aerobic conversion of phenyl-mercury acetate to elemental mercury and biphenyl mercury.

- Reduction of divalent mercury ion Hg^{2+} to the metal form (Barneji, 2005)

In the non-biological conversions, the following reactions have been identified (Barneji, 2005).

$$Hg^{2+} \xrightarrow[\substack{\text{Eutropic} \\ \text{condition}}]{H_2S} \underset{\substack{\text{Less} \\ \text{soluble}}}{HgS} \xrightarrow{\text{Aeration}} \underset{\substack{\text{More} \\ \text{soluble}}}{HgSO_4} \longrightarrow \underset{\substack{\text{Methyl} \\ \text{mercury}}}{CH_3Hg^+}$$
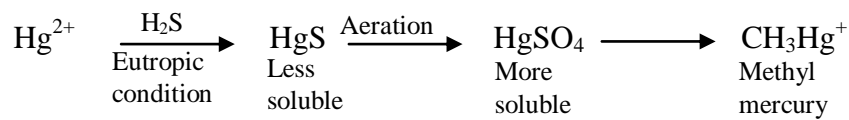
Equation 1

Most enzymes have amino acids with sulfhydryl (-SH) group at or near the active sites. Heavy metals tie up these groups and render the enzymes inactive as shown in scheme 1.
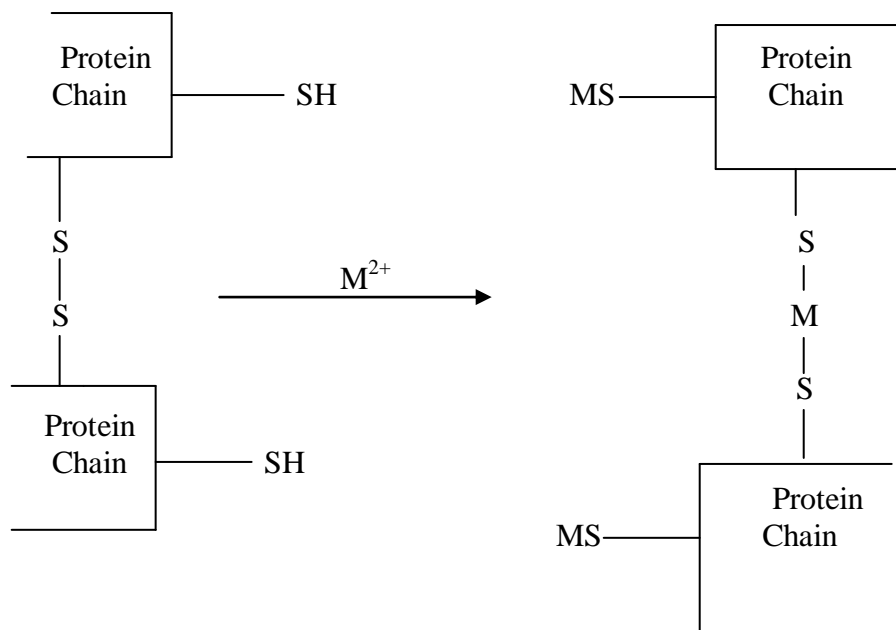
Scheme 1: S- H bonds in a section of an enzyme   (Source: Hill and Petrucci)

Thus mercury poisons the body's system by interfering with the sulfur containing enzymes (Hill and Petrucci, 1999). An open container or a few droplets of mercury spilled on the floor can put enough mercury vapors into the air to exceed the maximum safe level by a factor of 200. Levels exceeding 0.05 mg Hg/m^3 are unsafe. Subjects working with mercury such as dentist who make amalgams for filling of teeth cavities or laboratory workers who use it in various ways are exposed to great hazards due to its poisoning (Hill and Petrucci, 1999).

Mercury is a cumulative poison with half-life of 70 days in the body and therefore chronic poisoning is a real threat to those who are continuously exposed to it. Mercury poisons brain and the nervous system with symptoms manifested in loss of equilibrium, sight, feeling and hearing (Hill and Petrucci, 1999). Mercury poisoning also causes birth defects (Enger and Smith, 1992). Damage caused by mercury poisoning is irreversible. However, the British Anti-Lewisite (BAL) antidote can be administered but effective only when a person knows that he or she has been poisoned by mercury and seeks medical treatment immediately. BAL acts by chelating the metal so that it does not attack the active sites of the vital enzymes (Hill, 1984).

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter briefly discusses heavy metals in plants and the role that plants play in removing heavy metals from polluted soils. The chapter discusses phytoremediation, Phytoextraction and the mechanism of Phytoextraction. The chapter also gives an outline of the taro plant (*Colocasia esculenta*), its origin and its use as food in parts of the World, in Kenya and its traditional use as food among the Meru community. Theory of the Atomic Absorption Spectroscopy (AAS), the analytical tool used in the study is also briefly discussed.

2.2 Heavy metals in plants

Plants have been known to extract minerals from the soil and accumulate them in their tissues. Heavy metals accumulate in plant materials and they enter into the food chain (Setyorin *et al.,* 2002). Work done in Auckland Municipality, New Zealand (Howard, 1946, 1947) showed that the water-hyacinth (*Eichhornia crassipes*) is a highly efficient absorber of the mineral elements normally found in inorganic fertilizers. Concentration of cadmium and lead has been reduced from contaminated soils in soils polluted by fertilizers in West Java, Indonesia (Setyorin *et al.,* 2002).

In another study on industrial pollution in low land rice areas in the district of Rancaekek, West Java, it was shown that soils were polluted by heavy metals from sewage sludge produced by textile industry. The surveys of the soils showed that there were very high concentrations of boron, cadmium lead copper, chromium and boron in three villages in Rancaekek district (Setyorin *et al*., 2002).

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Another study conducted in tea plantations in an area West of Java (Indonesia) showed high levels of lead and cadmium in the soil. Tea plants were able to accumulate lead and cadmium taken up from the soil. The content of lead and cadmium in the plants (on a dry matter basis) was observed to have reached as high as 400 ppm (Setyorin *et al.*, 2002).

2.3 Phytoremediation

Removing contaminants out of soil and ground water is one of the most widespread and persistent problem in waste clean up. Once leaked into the ground, solvents, metals, radioactive elements and other contaminants are dispersed and difficult to collect and treat. The main method of cleaning up contaminated soil is to dig it up, move it and store it away in a landfill for ever (Cunningham *et al*., 2005).

Another method is to move it and incinerate it which involves moving thousands of tons of tainted soil and rock for this type of treatment. Cleaning up of contaminated ground water usually involves pumping vast amounts of it out of the ground. Where there are many sites of contaminated ground water or soil such as factories, farms, gas stations or military facilities, cleaning up these sites may be very costly to a country (Cunningham *et a*l., 2005).

A number of promising alternatives have been developed using plants, fungi and bacteria to clean up this type of contamination of the terrestrial and aquatic environment. The process is referred to as phytoremediation and may include a variety of strategies for absorbing, extracting or neutralizing toxic compounds (Cunningham *et al*., 2005).

Lead is an element which has not been known to be of any value to plants or animals even as a micro or macro nutrient. However, many plants are known to be tolerant to lead, and tend to remove the metal from the soil. Such plants develop genotropic characteristics and fail to grow in areas free from lead when transplanted. This ability of plants to accumulate lead is used in the investigations on the changes in the environmental levels of lead. Deposition of lead on mosses and tree rings are employed in such studies (Bernerji, 2005).

Research carried out in France and Belgium using the vintage wine, *Châteauneuf du-Pape* has been able to monitor lead pollution from vehicular emissions (Catherine and Edward, 2006). Wines made from 1961 to 1991 were analyzed for lead content and the concentration of tetraethyl lead (Et_4Pb), the anti-knock gasoline additive, and its decomposition product tetramethyl lead (Me_4Pb), showed that from the early to late 1970s, there was an initial rise in lead content in the wine and by extension in the amount absorbed by the grape vines. After 1978 when unleaded gasoline was introduced in the market, there was a drastic fall in the concentration of lead in the vintage wines (Catherine and Edward, 2006). Thus grape plants can effectively be used to remove lead from the lead contaminated soils (Catherine and Edward, 2006).

2.4 Phytoextraction

Certain types of mustards and sunflowers can extract lead, arsenic, zinc and other metals. Reeds and other water-loving plants can filter water tainted with sewage, metals or other contaminants (Cunningham *et al.*, 2005). Radioactive strontium and cesium have been extracted from the soil near the Chernobyl power plant using common sunflower (Scheerbak, 1996).

2.4.1 Phytoextraction Mechanism.

Plants are able to extract the metals by absorbing them through their roots which are designed to efficiently extract the nutrients, water and minerals from the soil and the underground water. Some plants also use toxic elements as defense against herbivores for example; locoweed selectively absorbs elements such as selenium, concentrating toxic levels in its leaves. Blacken fern growing in Florida was found to contain arsenic at concentrations more than 200 times higher than the soil in which it was growing (Cunningham *et al.,* 2005). Mangroves generally grow in the intertidal area between land and the sea where fresh water mixes with sea water. Although the water there is much saltier than most plants can stand, mangroves handle the condition with ease by letting the salt into their system and accumulating it. These tropical trees are able to excrete salt from their leaves or other parts of the plant, which then drop away (Enger and Smith, 1992).

2.4.2 Phytoextraction by aquatic plants

Three aquatic plants, parrot feather *(Myriophylhum aquaticum),* creeping primrose *(Ludwigina palustris)* and water mint *(Menthe aquatic)*, were studied for their ability to remove heavy metals from contaminated water. The plants were obtained from a solar aquatic system treating municipal waste water. All the three plants were able to remove iron, zinc copper and mercury from the contaminated water (Kamal *et al.,* 2008). It was shown that the average removal efficiency for the three plant species was 99.8% of mercury, 76.7% of iron, 41.62% of copper and 33.9% of zinc. The removal rates of zinc and copper was constant at 0.48 mg/l/day for zinc and 0.11 mg/l/day for copper, whereas those for iron and mercury were dependent on the concentration of these elements in the

contaminated water and ranged between 0.41 and 7.00 mg/l/day for iron and 0.0002 - 0.787 mg/l/day for mercury (Kamal *et al.*, 2008).

The aquatic plants *Potomogeton pectinatus L.* and *P. malaianus Miq.* were studied for their potential use and indicators in waste water contamination and treatment (Kejiang *et al.*, 2008). The concentrations of heavy metals in the leaves of two aquatic plants and the corresponding water sediment samples from the Donghe River in Jishon City of Hunan Province, China were studied to investigate metal contamination from the intensive industrial activities in the surrounding area (Kejiang *et al.*, 2008). Results showed that the concentrations of heavy metals in the sediments, especially cadmium, manganese and lead, were much higher than the eco-toxic threshold values developed by the U.S Environment Protection Agency (EPA) (Kejiang *et al., 2008).* Between the two plant species, *P. pectinatus* showed the higher capacity in metal accumulation. The highest concentration of the metals, cadmium, lead, copper, zinc and Manganese were found in the leaves of *P. pectinatus (*Kejiang *et al., 2008).*

Significant positive relationships were observed among the concentrations of zinc, copper and manganese in the leaves of both aquatic plants and those in water. This indicated the potential use of the two plants for pollution monitoring of these metals (Kejiang *et al.,* 2008). A laboratory experiment was conducted to investigate the ability of the two aquatic plants to remove heavy metals from the contaminated river water. Results showed that the average removal efficiencies by the two plants for cadmium, lead, manganese, zinc and copper from the polluted river were 92%, 79%, 86%, 67%, and 70%, respectively. The results indicated that *P. pectinatus* and *P. malatanus* had

high capabilities to remove heavy metals directly from the contaminated water (Kejiang *et al.*, 2008).

An experiment was carried out to investigate the effects of inorganic fertilizers and poultry liter on sweet potatoes and taro in the University of Technology at Lae in Papua New Guinea. It was shown that for sweet potatoes and taro, sweet potatoes had higher intake of nitrogen and magnesium in the plots where inorganic fertilizer was not applied (Hartermink *et al.*, 2000). Where taro was planted in soils applied with Diammonium phosphate fertilizer (DAP), the nutrient uptake increased in respect to boron and zinc and decreased in respect to the elements, phosphorus, potassium, manganese, magnesium and copper at harvest time but increases significantly in respect to zinc (Hartemink *et al.*, 2002).

2.5 Taro /Arrowroots use in parts of the World

The origin of taro has been a subject of debate (Schippers, 2000). In Africa, it is indicated to have been in existent in Ghana for a very long time. Malaysian origin is however more likely. Recent indications are that two of King Solomon's four gold mines were located one in Malaysia and another most likely in the present-day Ashanti gold mine in Ghana, indicating that about 7000 BC, taro seedlings could have been carried by travelers from South East Asia and planted in Ghana (Schippers, 2000).

In North India taro is a very common dish prepared in almost all households where both the leaves and the corms are used. Taro was used by the Romans in the same way as the potato would later be used by Europeans. After the fall of the Roman Empire, the use of taro gradually stopped in Europe. Most of the taro used throughout the Roman Empire

was exported from Egypt (McCollum, 1998). Taro is extensively used in South East Asia. In Kerala State (India), it is a staple food. In Nepal, taro is considered a health food where both leaves and stems are used. In China and Hong Kong, taro is commonly used in Chinese cuisine mainly as a flavour enhancing ingredient among many other ways (McCollum, 1998). West Africans use taro as a staple food crop, particularly in Nigeria and Cameroon. It is referred to as cocoyam in Nigeria, Ghana and Anglophone Cameroon (Stephens and James, 1994). In United States of America, taro is traditionally cultivated in Hawaii where it is a staple crop (Gentry, 1994). Table 1 shows data for World top taro producers in the year 2005.

Table 1: Top Taro Producers in the World – 2005

Country	Yield (million metric ton/year
Nigeria	4.0
Ghana	1.8
China	1.6
Cambodia	1.1
Cote d'Ivoire	0.4
Papua New Guinea	0.3

(**Source:** UN Food & Agriculture Organization, Faostat, 2005)

In the State of Florida, taro was cultivated near the East Coast and was used in place of potatoes and dried to make flour (Wagner; *et al*, 1994). Hawaiians raise taro in plantations for food and even use it for cleaning rivers (McCollum, 1998).

In Philippines taro leaves, stems and corms are commonly used to make a variety of dishes (Wagner *et al*, 1994). In Papua New Guinea, it is a common food crop and the production is so high that it is exported to the Papua New Guinea Diaspora in Australia and New Zealand (Gentry, 1994).

Other countries that cultivate and use taro as a food crop are Japan, South Korea, Taiwan, West Indies, Turkey, Cyprus and South Africa. In Cyprus where taro has been in use since the Roman Empire, the people of Ikaria Island credit the taro for saving them from famine during the Second World War (Gentry, 1994).

2.6 Taro / Arrowroots in Kenya

The species of Taro, also known in Kenya as Arrow roots are *Colocosia antiquorum* and *C. esculenta* (Maundu *et al.*, 1999). The earliest forms of taro to be cultivated by Kenya's Central Bantu community had small, less tasty corms that left an itchy sensation in the throat and on the opening of the rectum (Kikuyu – *"Nduma ya Mwanake"*) after eating them (Maundu *et al.*, 1999) . In Kenya, most of the taro is cultivated in valley bottoms along streams and where water collects (Maundu *et al.,* 1999). It has been observed that the disappearance of some rivers has resulted in a reduced area where taro can be grown hence leading to reduced production (Were and Wandibba, 1986).

Taro (*C. esculenta*) is a good source of green manure, compost humus and vegetables. It also protects the soil either against baking by the sun, and consequential loss of water, or heavy raindrops that would otherwise cause erosion (Muhia, 2000; Mathai, 2007). Comparative nutritional value of some common root crops and cereals for 100 g edible portion shows taro with 34.0% carbohydrate, 0.06% fiber, 1.9% protein and 0.1% fat is a

good source of nutrients and compares well with Irish potatoes and cassava (Muhia, 2000).

Taro is a source for minerals such as calcium, iron and phosphorus (Muhia, 2000). Other minerals found in taro/arrowroots especially in the leaves are zinc, potassium, copper and manganese, thus comparing favorably with cassava leaves (Muhia, 2000). Taro leaves are rich in the vitamins thiamin, riboflavin, vitamin B_6, vitamin C and niacin. The corms are a good source of dietary fiber (Muhia, 2000) and rich in starch (Muhia, 2000; Mathai, 2007).

Among the Meru community of Central Kenya, both taro corms and leaves have been used for food. It was a taboo among the Meru men to eat taro/arrowroot leaves or the relish prepared from them (Were and Wandibba, 1986). Boys aged ten years and above and men in general, except the very old ones were prohibited from eating the meal made from the taro or any other meal made from any green vegetable. Meals made from taro leaves were reserved for breast feeding mothers and young girls (M'Imanyara, 1992). Traditionally, a gruel made from the leaves (Kimeru, *ruguru*) has been fed to cows so that they would facilitate the removal of delayed placenta after calving. Elsewhere, in a case study that was carried out in Kiambu and Muranga Districts for fifteen years (1975 – 1991), it was shown that taro has been important for riverbank protection and national food security (Muhia, 2000).

Observations made in Central Kenya on taro plots, have revealed that the soils have literally grown, and where it has been planted astride the river, the river bed has gone

down and thus making taro a major soil conservation crop along river banks (Muhia, 2000). Economic role of taro in food security is two fold namely, soil conservation and food production. Taro has a grain equivalent of 3.5 times that of maize (Muhia, 2000).

In a National survey for data collection for the formulation of root crops policy in Kenya, it was revealed by the data for greater Meru covering the period 1997 to 2007 (Table 2), that the production of taro/arrowroot was declining. The decrease was attributed to shrinking acreage of the cultivated taro, receding water levels in rivers and drying swamps (GoK, 2008). Mean annual production of taro in the Meru region for that period was only 2107.3 tons. This yield was very small compared with what the top six countries in the world produced in the year 2005 (Table 1).

Table 2: Taro yield data in Meru in Tons 1993 – 2007

Year	1993	1994	1995	1996	1997	1998	1999
Ha	300	300	305	300	164	192	200
Yield	3000	3000	3050	2100	1640	1920	2000

Year	2000	2001	2001	2003	2004	2005	2006	2007
Ha	130	130	130	200	200	250	250	200
Yield	1300	1300	1300	2000	2000	2500	2500	2000

(**Source:** District Agricultural Office Meru, 2010)

2.7 Theory of Atomic Absorption Spectroscopy (AAS)

Atomic absorption Spectroscopy (AAS) is one of the analytical techniques utilized for quantitative analysis of trace metals. The technique is applicable directly to some elements including some metalloids. This technique is essentially solution based with only very limited application for the direct analysis of solids or gases. AAS technique depends on the interpretation of atomic spectra and quantification interaction between atoms and energy, which causes electronic transitions (Agarwal, *et al* 1975). Electrons within an atom can occupy only discrete levels. Electron transitions between such levels give rise to atomic spectra. When an atom is in its lowest energy level, it is said to be in its ground state. In their ground state, atoms absorb radiation of their specific wave length and get excited to higher energy levels.

In a case of steady states **m** and **n**, associated with energies E_m and E_n, where $E_n > E_m$ the transition **m→n** will result in the absorption of light of frequency υ_m which is given by the Plank's equation,

$$\upsilon_m = (E_n - E_m)/h \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 1$$

Where **h** is the Plank's constant.

The transitions **m →n** are simulated by absorption of external radiation. This forms the integral part of atomic absorption. The relationship between the ground-state and excited state population at a given temperature is given by the Maxwell-Boltzman relation (Agarwal *et al.,* 1975);

$$N_n/N_m = G_n/G_m \exp\{(E_m - E_n)\}/kT\}\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2$$

Where N_m = Number of atoms in the ground state,

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N_n = Number of atoms in the excited state,

G_n / G_m = ratio of statistical weights for ground and excited states,

$E_m - E_n$ = Energy of excitation,

k = Boltzmann constant,

T = Thermodynamic temperature.

From equation (2) above, it can be seen that the ratio G_n / G_m is dependent upon both the excitation energy and temperature T. Calculations show that only a small fraction of the atoms are excited, even under very favorable conditions, that is when the temperature is high and the excitation temperature low (Jeffery *et al*., 1989). Absorption by atoms takes place within very narrow spectral regions of the order of hundredths of angstrom.

In the laboratory analytical experiments, absorptions involving the ground state are observed. These absorptions are normally referred to as resonance lines. The absorptions of most elements are simple in character and less prone to inter element interference than is flame emission spectroscopy (Jeffery *et al*, 1989).

The degree of absorption of specific radiation a particular frequency by an atomic vapor is related to the path traversed and to the concentration of the absorbing atoms in the vapor. This is described by the Beer – Lambert law (Christian, 2004). When incident radiation of power P_0, passing through a solution of an absorbing species at concentration **c** and path length **b**, and the emergent radiation has radiant power **P**, then absorbance is given by;

A = log [P_0 /P] = abc, …………………………………………………………...**3**

Where:

A = absorbance

a = absorptivity

b = path length in centimeters and

c = concentration

Absorbance is directly proportional to the concentration (Christian, 2004) and thus by measuring absorbance, concentration can be determined. The relationship discussed is linear for small values of absorbance. Beer's law is obeyed over a wide range except at very high concentrations (Jeffreys *et al*, 1989).

2.8 Statement of the problem

In view of the fact that taro is widely cultivated in Central Province and, to a smaller extent in, Embu, Meru, Machakos, Nandi and Kakamega Districts (Muhia, 2000) it is imperative that Kenya as a Nation should recognize this crop as a staple food. Taro is cultivated in heavily polluted rivers in Nairobi and other urban centers in this country. Within homesteads, it is not unusual to find taro being cultivated and watered using waste water from kitchens and bathrooms. Under these conditions, taro may accumulate large quantities of heavy metals which are then ingested into the human body through food and hence become a health hazard due to heavy metal poisoning. This not withstanding, such taro may be used to remove heavy metals from contaminated rivers.

In Meru region, like other parts of Kenya where it is cultivated, taro is planted along river bottoms and on swamps. Ngachioma and Karumanthi rivers are such waterways where taro is cultivated by peasant farmers. These two waterways pass through

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agriculturally busy area and *Jua Kali* (open air) garages within Meru town. The purpose of this study is to determine the amount of heavy metals cadmium, chromium, copper, lead, manganese, mercury and zinc present in taro plants cultivated these two waterways.

2.9 Rationale and justification

Evaluation of the phyto-accumulation of heavy metals in water and sediments by taro cultivated in polluted water ways will generate data which will assist to determine whether taro can be used to clean heavily polluted rivers in the City of Nairobi and other major urban centers in Kenya. When cleaned, these waters including those of Gachioma and Karumanthi Rivers will then be available for use by Kenyans. The Ministry of Public Health and Sanitation may then use the data to formulate policies to guide the general populace on the use of taro grown in highly polluted areas which eventually find their way in major supermarkets within the country and bought for food. The Ministry of Water and Irrigation together with the Meru Water and Sewerage Services (MEWASS) may also use the data to incorporate phytoremediation approach as a strategy for water pollution remediation in line with vision 2030.

Water from Gachioma River has been piped for domestic use by the local communities of Kaaga within the Municipality of Meru and by Kithoka and Munithu community. The two areas are located within Mirigamieru East Division of Imenti North District in Meru County. Taro is widely consumed by the Meru community (table 2) and is readily found on sale in supermarkets and open air markets. Meru town is rapidly expanding and thus increasing the likelihood of enhanced municipal pollution.

The Ministry of Agriculture on the other hand, would also use the data to revise policies to promote both national and local food security, recognize and classify taro as a major staple crop which can be cultivated throughout the year if proper policies and practices are provided for. In matters pertaining to environment, the National Environmental Management Authority (NEMA) may also use the data to establish the standards for setting of acceptable levels of various heavy metals in the root food crops eaten in the country.

2.10 Study Area

The study was carried out in two streams flowing through Meru Town, Kenya. The source of these two streams is in the Upper Imenti Forest section of the Mt. Kenya Forest, within the boundaries of Meru Municipality. The rivers flow through the town and the agricultural neighborhood. The study area lies between longitudes 37º 35' 30" E and 37º 42'E and latitudes 0º 02' 25" N and 0º 06' N. Figure 2c, shows the map of the study area

2.11 Hypothesis

2.11.1 Null Hypothesis

Taro (C .*esculenta*), does not bioaccumulate heavy metals in the corms and leaves

2.12 Objectives

2.12.1 General objective

To determine concentration of heavy metals phyto-accumulated by taro plant in the corms and leaves

2.12.2 Specific objectives

1) To determine the concentration levels of cadmium, chromium, copper, lead, manganese, mercury and zinc in water and sediments of Gachioma and Karumanthi rivers in Meru town.

2) To determine the concentration levels of the metals, cadmium, chromium, copper, lead, manganese, mercury and zinc in the leaves and corms of taro growing along Gachioma and Karumanthi Rivers.

3) To determine viability of phytoremediation of heavy metals in water using taro plant by establishing the correlation between levels of the metals in corms and leaves of the plants and those in the water and sediments.

4) To assess the suitability of taro plant grown along Karumanthi and Gachioma Rivers for use as food by comparing the heavy metal levels bioaccumulated in the plant with the recommended level.

(a)
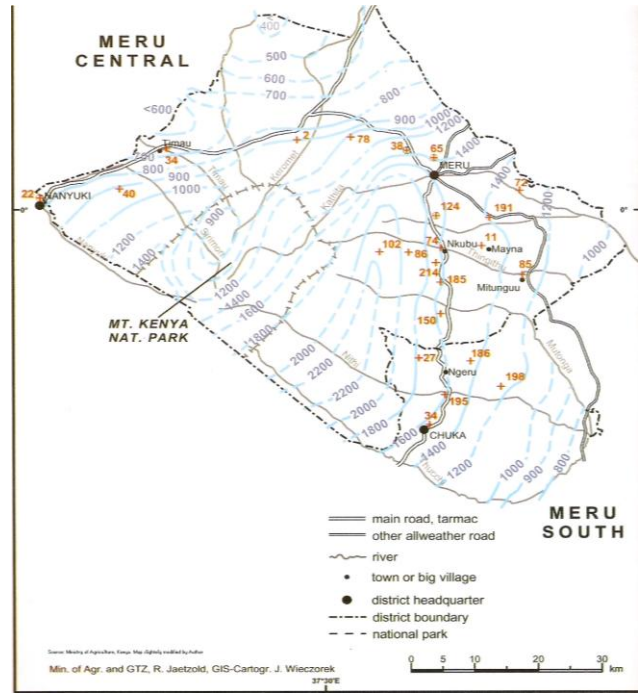
(b)

(c)

Figure 1: (a) - Map of Kenya; (b) - Map of Meru Central District and (c) -Map of Meru Town

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Introduction

Common apparatus and glassware found in a chemistry laboratory were used in this work. Digital analytical balance and Atomic Absorption Spectrophometer (AAS), Buck Scientific Model 210 VGP were used.

3.2 Cleaning of glassware

The glassware was cleaned thoroughly using 2% hot dilute detergent (Christian, 1980) and tap water then soaked in 20% (v/v) nitric acid. The glassware apparatus was then rinsed with distilled water and dried overnight in the oven at 110ºC (Christian, 1980). Volumetric flasks and pipettes were left to dry overnight in the rack and stored in an environment free of dust and moisture.

3.3 Sample collection

The leaves and corms of taro growing along the two rivers, Gachioma and Karumanthi, and the water and the sediments of the two rivers were collected. The water samples were collected in polytetrafluoroethylene /PTFE bottles (APHA, 2005). Taro corms, leaves and sediments were collected from the same point as the water samples. Samples were obtained from five different sampling sites in each river; approximately one kilometer apart from each other and a composite sample for each sampling point was obtained by combining portions of multiple grab samples (APHA, 2005). This was done for all samples of the taro corms and leaves, water and sediments. Discrete grab samples

used to obtain composite samples were taken at the selected locations described in paragraph 3.3.2. Sampling was done between the months of June and September 2009.

3.3.1 Water samples

Three replicate samples of water, each of 250 ml and taken at three points of equal distance across the stream, were collected from each of the rivers (APHA, 2005). The replicate samples were mixed in a 3 L plastic bottle previously cleaned and rinsed with concentrated nitric acid and further rinsed with de-ionized distilled water. After constituting the composite water sample, 250 ml of it were removed and stored in 500 ml PTFE plastic bottles which were appropriately labeled ready for transport and analysis.

3.3.2 Corm samples

At each sampling point, three taro plants were picked at random and uprooted to remove the corms. The corms were cleaned with water and from each whole corm, 10 g sample were taken then combined to make a total of 30 g from the sampling point. They were then dried in the sun before being transported to the laboratory for analysis. This amount of 30g constituted the composite sample from which 10 g was extracted and then ashed in the muffle furnace.

3.3.3 Leaf samples

The middle leaves of the corresponding taro plants where the corms were dug were picked as the representative sample. The leaves selected from each taro plant (Plate 1) were then dried in the sun after which the dry leaves were ground in a pestle and mortar and then mixed thoroughly to make 30 g of the composite sample which was ashed in the muffle furnace .A sample of 10 g of ashed leaves was weighed for digestion.

3.3.4 Sediment samples

About 10 g of sediment from each of the three holes where the taro corms were removed was collected using a wooden spatula and mixed thoroughly using the same spatula in a plastic bowl to make the composite sample of 30 g. The samples were sun dried before they were transported for analysis in the chemistry laboratory. Samples were heated in muffle furnace at temperature below 500^0C to avoid volatilizing lead (Christian, 2004). 10 g of the composite sample was weighed for digestion.

3.4 Sample labeling and coding

Labels were used on samples to prevent sample misidentification. Gummed paper labels were used and affixed on the containers at the time and point of sample collection (APHA, 2005). On the labels, the following information was included: a unique sample number, sample type, date, and time of collection, place of collection and the name of the river (APHA, 2005). The place of collection was identified with letters A, B, C, D and E. All this information was coded in a way that was easily identified on the labels (Christian, 2004).

3.4.1 Sample coding

The collected samples were coded as shown in Tables 3 and 4

Table 3: Gachioma river sample codes

Site code	Corms	Leaves	Water	Sediment
GA	GCA	GLA	GWA	GSA
GB	GCB	GLB	GWB	GSB
GC	GCC	GLC	GWC	GSC
GD	GCD	GLD	GWD	GSD
GE	GCE	GLE	GWE	GSE

The Karumanthi River samples were coded as follows:-

Table 4: Karumanthi River sample codes

Site code	Corms	Leaves	Water	Sediment
KA	KCA	KLA	KWA	KSA
KB	KCB	KLB	KWB	KSB
KC	KCC	KLC	KWC	KSC
KD	KCD	KLD	KWD	KSD
KE	KCE	KLE	KWE	KSE

Triplicate samples for each sampling points in each river were combined to make composite samples.

KEY: For interpreting the code

1. GA, GB, GC, GD, GE and KA, KB, KC, KD, KE are sampling sites

2. G signifies Gachioma River

3. K signifies Karumanthi River

Tables 5 and 6 show the sampling site profiles for the two rivers

Table 5: Sampling Site Profile for Gachioma River

Sample site	Description
GA	Source of Gachioma river on forest edge. Sawmill nearby
GB	Meru T.T.I nearby, Primary schools, Some urban settlement, Dispensary
GC	Urban settlement, Coffee farms
GD	Meru teachers college, Coffee farms, urban settlement
GE	Coffee farms, Cattle shed,

Table 6: Sample site profile for Karumanthi River

Sample site	Description
KA	Coffee and Maize farms
KB	Coffee and Maize farms
KC	Commercial and Jua Kali garage activities
KD	Commercial and Jua kali garage activities
KE	Coffee farms, Urban Settlements

Plate 1: Sampling Taro leaves along Gachioma River

3.5 Sample preparation before analysis

Taro corms and leaves were dried in the sun then preserved in plastic paper bags, labeled with appropriate code and transported in carrier bags to JKUAT chemistry laboratory. Sediments were sun dried then preserved in plastic bags which were appropriately labeled and transported to JKUAT chemistry laboratory where they were ashed in a muffle furnace before digestion (Christian, 2004). Water samples were put in clean polytetrafluoroethylene (PTFE) plastic bottles, preserved with analar nitric acid to prevent contamination (APHA, 2005) before transportation to JKUAT chemistry laboratory. All the samples of sediment, corms, leaves and water were digested with a triadic mixture of concentrated nitric, sulfuric and perchloric acids in a volume ratio of 3:1:1 (Christian, 2004) before they were analyzed for various heavy metals.

3.6 Preparation of standard stock solutions

Appropriate amounts of various salts/oxides were transferred in 1000L volumetric flasks

(Table 3). 5 or 10 ml concentrated nitric acid was added into the respective flasks and the

reactions allowed to proceed into completion. The solutions were then diluted to the

1000 L mark with distilled water to make 10 ppm solutions and then later stored in PTFE

bottles which were appropriately labeled.

Table 7: Summary of preparations of standard stock solutions and the wavelength used for absorbance measurement

Salt/oxide	Mass used (g)	Vol. of acid used (ml)	Wavelength (nm)
Cadmium(II)nitrate	2.11	5	229
Chromium(VI)oxide	0.1923	10	358
Copper(II)sulphate	0.0393	5	325
Lead(II)nitrate	0.1598	5	405.8
Manganese(IV)oxide	0.632	10	403.1
Mercury(II)chloride	0.1354	10	253.7
Zinc(II)nitrate	2.89	5	213.9

3.7 Analysis

All the working standards were prepared serially by diluting the stock solutions using the

formula $C_1V_1 = C_2V_2$ where C_1 was the concentration of the stock solution, C_2 the

concentration of the standard; V_1 the volume of the stock solution to be taken for dilution

and V_2 was the volume of the standard that was prepared from the stock solution. All the

digested samples each of the taro corms and leaves, the river sediments and water were

analyzed in the Atomic Absorption Spectrometer (AAS) to read absorbance directly for each metal. Two absorbance readings for each of the dilutions were recorded and the mean taken to obtain the respective concentration.

3.8 Analysis for Mercury

A distillation flask of 500ml. capacity was taken and 100ml. solution of the sample introduced into it. Into the distillation flask, 5-10ml. of 5% potassium permanganate solution was added and mixed thoroughly. This mixture was refluxed for a minimum time of four hours with ice – cold water circulating in the condenser. The refluxed mixture was cooled and a few drops of 30% H_2O_2 was added to remove excess $KMnO_4$. This mixture was boiled for a few minutes to remove excess H_2O_2 then adjusted to 250 ml.   Meanwhile, 2 ml of 20% $SnCl_2$ in 10 ml concentrated HCl and 8 ml 10% HNO_3 was mixed (Kumar, 1994) in a 500 ml and the refluxed solution of the sample added. The whole mixture was vigorously mixed for five minutes using a magnetic stirrer. The resulting cold vapor was passed into the absorption cell of AAS and absorbance measured at 253.7 nm using mercury hollow cathode lamp as the light source.

3.9 Procedure for Atomic Absorption Spectroscopic (AAS) Analysis

The Atomic Absorption Spectrometer (AAS) was calibrated using the already prepared AAS standard solutions using the optimal absorption wavelength (appendix 2) for each heavy metal analyte. The stock solutions were prepared from the AAS standard solution and calibration standards prepared from the stock. The method described in the instrument's manual model, Buck Scientific 210 VGP, was used to adjust the lamp and

other parameters of the instrument to give optimal absorbance signal. After setting the instrument parameters, the calibration standards, including the blank were run. Distilled water was used as the blank. Four standard solutions previously prepared were used to cover the optimum absorbance range (Jeffrey *et al*, 1989). The standard solutions were examined in order of increasing concentrations and after making the measurements with each one of the four solutions distilled water was aspirated into the flame to remove all traces of the previous solution before proceeding to the next solution (Jeffery *et al*, 1989).

Three absorption readings were taken with each solution and the mean value for the closest two readings calculated. The accuracy and precision of the instrument was determined by running a standard sample of known concentration after every five samples. Absorbance was recorded in tables and a plot of concentration against absorbance was plotted for the standards and the blank. Regression analysis was used to get the line of best fit.

Samples were run in triplicate and absorbance corrected for background signal (Jeffery *et al*, 1989). The concentrations of the analytes were calculated using Excel computer software. The standard deviations of the concentrations were calculated and the concentrations were expressed as the mean, plus or minus the standard error. Where the concentration of the sample was higher than the signal of the highest or the lowest standard, the samples were diluted and their absorbance taken (Jeffery *et al*. 1989).

3.10 Data analysis and presentation

Data obtained was subjected to statistical analysis using SPSS (Version 19) Software.

Mean concentrations of heavy metals in various analytes were expressed as mean ±standard deviations and significant differences were determined using t-tests at 95% confidence level.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Introduction

The concentration of cadmium, chromium, copper, lead, manganese, mercury and zinc present in the corms and leaves of Taro plant cultivated in the Gachioma and Karumanthi Rivers, and the water and sediments of these two rivers were determined using Buck Scientific Atomic Absorption Spectrophotometer (AAS) model 210VGP. The results are presented and discussed in this chapter.

4.2 Heavy Metals in Karumanthi and Gachioma River Water

Heavy metal content in Karumanthi and Gachioma River water are shown in Tables 8 and 9.

Table 8: Heavy Metal concentration (ppm) in the water from Karumanthi River

Sample	Metals						
	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Zinc
KWA	Bdl*	Bdl	0.04	0.02	0.007	Bdl	0.50
KWB	Bdl	Bdl	0.04	0.05	0.008	Bdl	0.13
KWC	Bdl	Bdl	Bdl	0.01	0.012	Bdl	0.05
KWD	Bdl	0.27	0.02	Bdl	0.015	Bdl	0.02
KWE	Bdl	0.19	Bdl	0.01	0.035	Bdl	Bdl
Mean	Bdl	0.09 ± 0.001	0.02 ± 0.001	0.02 ± 0.001	0.02 ± 0.001	Bdl	0.14 ± 0.001

Table 9: Heavy metal concentrations (ppm) in the water from Gachioma River

Sample	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Zinc
GWA	Bdl	0.154	Bdl	0.003	0.183	Bdl	0.17
GWB	Bdl	0.269	Bdl	0.006	0.136	Bdl	0.06
GWC	Bdl	Bdl	0.02	0.002	0.089	Bdl	0.19
GWD	Bdl	0.14	Bdl	Bdl	0.078	Bdl	0.09
GWE	Bdl	0.25	Bdl	0.003	0.389	Bdl	0.13
Mean	Bdl	0.160 ± 0.003	0.004 ± 0.001	0.003 ± 0.002	0.180 ± 0.001	Bdl	0.13 ± 0.01

* Bdl appearing in the tables means particular metal was below detection limit

In both rivers, concentrations of cadmium and mercury were below detection limits.

4.2.1 Heavy metal concentrations in Karumanthi river water

Chromium was detected only in two sampling points in Karumanthi River, namely KD and KE. This may be attributed to the fact that samples KWD and KWE were obtained from within the urban and commercial activity near a *Jua Kali* garage and a carwash yard area in Meru Town. The mean concentration of chromium in Karumanthi River water was 0.092 ± 0.004 ppm. Figure 2 shows the concentration of heavy metals in Karumanthi and Gachioma River waters

Heavy metal concentration in water
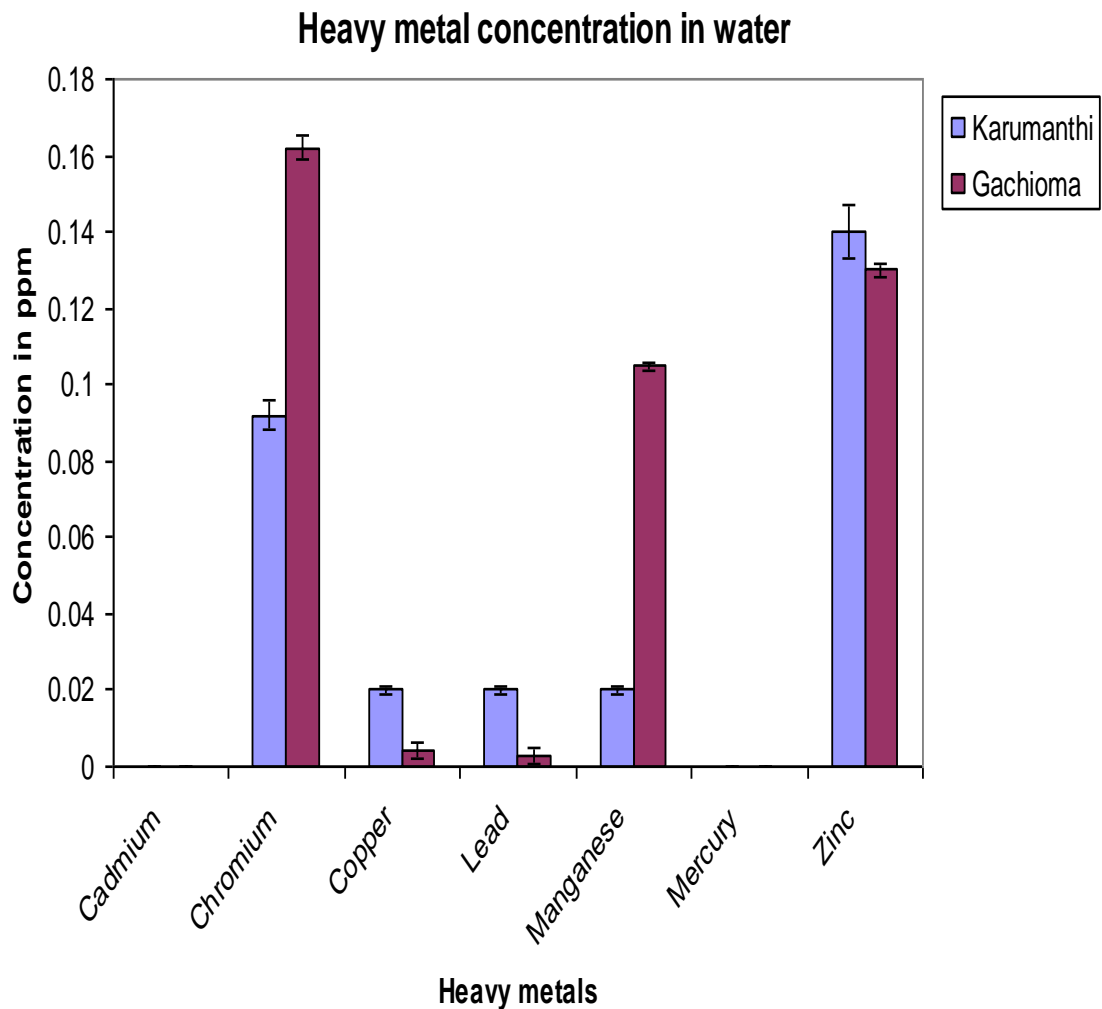
Figure 2: Concentration of heavy metals in the waters of Karumanthi and Gachioma River

Some copper was detected in samples KWA and KWB, which were collected from a coffee growing region of the study area. Coffee farmers are known to use copper based fungicides to spray their coffee (GoK, 1979), or by the application of farmyard manure to their coffee plants (Kabata and Alina, 1984). There was little copper detected in samples collected in the main town area indicating that the main source of copper in this

river is agricultural activity. The mean concentration of copper in the waters of Karumanthi was 0.020 ± 0.001 ppm. The area has also an urban domestic settlement. Traces of lead were detected in the water of Karumanthi River. There was lead in the water sampled in the farming area. This may be due to the use of inorganic fertilizer applied to the coffee and maize farms, where fertilizers have been attributed to lead contamination in agricultural land. Lead in concentration range of 7 - 225 mg/kg has been reported in phosphate fertilizers (Kabata and Alina, 1984). Lead detected in water samples obtained in the town area may be attributed to the *Jua Kali* activities such spray painting, soldering and lead acid battery repairs and environmental factors of inappropriate solid waste management (Plates 4 & 5). The mean concentration of lead in the water was 0.02 ± 0.001 ppm. This value was slightly lower than the NEMA maximum permissible level (Appendix 6).

Manganese was found in the water of Karumanthi River in all sampling points. Amounts detected ranged between 0.007 and 0.035 ppm with the mean content of 0.02 ± 0.001 ppm. From Table 8, it is observed that the sampling points KWD and KWE have the highest concentration of manganese. These two sampling points were within the town and the high levels may be linked to environmental factors of solid waste management in the disposal of manganese containing wastes such as dry cell batteries (Plate 5). *Jua Kali* activities such as woodwork and dyeing may also have introduced manganese into the river.

Manganese compounds are used in the production of dyes and wood preservatives (Cotzias, 1977; Gong and Amemiya, 1999; Hussain and Ali, 1999). It was observed that

close to the sampling point KWD, wood workshops and a women group workshop involved in dyeing are some of the activities found there.

The concentration of mercury in this river was below detection limit, an indication that there is apparently no known activity in Meru town that would introduce detectable amounts of mercury into the environment. Concentration of zinc ranged between 0.09 and 0.5 ppm in Karumanthi River. The mean concentration of zinc was 0.14 ± 0.01 ppm. The highest concentration was found in the sample KA, which is in the farming region of the study area. The information shown in table 8 is displayed graphically in Fig. 2. From the graph in Fig. 2, zinc and chromium were found in larger quantities than other metals while cadmium and mercury were below detection limit. Copper and lead were both found with a mean concentrations of 0.02 ppm each.

4.2.2 Heavy Metals concentrations in the Water of Gachioma River

 The results of heavy metal concentration in Gachioma River are displayed in Table 9. Both mercury and cadmium were below detection limit in all water samples collected along this river. Sampling point GA, the source of Gachioma River is a swamp consisting of several small springs and is located on the edge of upper Imenti forest. The heavy metals chromium, lead, manganese, and zinc whose concentrations were 0.154, 0.003, 0.183 and 0.17 ppm respectively were detected in sampling site GA. Concentration of copper was below detection limit at this site . Some urban settlement near the source of the river may account for the observed presence of these heavy metals.

Down stream, copper was detected only in sampling point GC while three other metals namely: lead, manganese and zinc were detected in all the sampling points. Chromium was not detected in the sampling point GC. Manganese and zinc were detected in all the

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sampling points down the river. Lead was detected in four sampling points but in small amounts whose range was between 0.002 and 0.006 ppm. Concentration of chromium in the water was as high as 0.269 ppm at point GB. This elevated level may be attributed to the chromium content in the natural water, which ranges between $0.1 - 0.6$ µg/L for fresh water (Townshed, 1995) and may also be as a result of farming activities in the surrounding area.

The mean concentrations of heavy metals in Gachioma River are recorded in Table 5 and shown in Fig. 2. From Table 9 it is observed that manganese was distributed in all the sampling points with concentrations ranging from 0.078 to 0.389 ppm with a mean concentration of 0.180 ± 0.002 ppm. Presence of manganese at the source of this river may be due to the weathering of the metallic parts of the sawmill which has been located and operating there for more than sixty years and therefore, has been releasing heavy metals and other contaminants into the river (Plate 2).

Table 9 shows that mean concentrations of chromium and manganese were 0.16 and 0.18 ppm respectively. The concentrations of the two metals were higher than was the case with the other metals. Cadmium and mercury were below detection limit in Gachioma River (Table 9 & Appendix 2). Zinc like manganese, was distributed throughout the river. The concentration of zinc ranged between 0.06 and 0.19 ppm with a mean of 0.13 ppm.

Plate 2: Sawmill at the source of Gachioma River

Plate 3 indicates a leachate which emanates from the sawmill (Plate 2) and flows into the swamp that forms the source of Gachioma River. The leachate may be responsible for the elevated levels of heavy metals detected in this River. This leachate could have contributed to the noticeable levels of the heavy metals detected at the source of the river. The concentration levels of all metals except cadmium and mercury which were not detected were less than the maximum allowable values for respective metals for domestic water (GoK, 2006, Appendix 6 and 7). The water from the two rivers is therefore, safe for domestic use in respect to the heavy metals under study.

Plate 3: Leachate from the sawmill

4.3 Heavy Metals in the Sediments

Table 10 shows the concentration of heavy metals in the sediments of Karumanthi and Gachioma Rivers where taro plant samples were collected. Except for mercury whose concentration was below detection limit, all other six metals under study were detected in the sediments of the two Rivers.

4.3.1 Heavy Metals in sediments of Karumanthi River

The concentration of manganese was the highest among the heavy metals with a mean value of 6.153 ± 0.099 ppm. The least concentration value among the heavy metals was found in lead whose mean concentration was 0.036 ± 0.002 ppm and the range was between 0.032 and 0.05 ppm. Concentration of manganese was highest at the sampling point KB, whose value was 10.702 ppm. This place was in a farming region of the study

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area. Coffee and maize are cultivated here and farmers apply farmyard manure and fertilizer to their crops both of which are known to contain traces of manganese (Townshend, 1995; Kabata and Alina, 1984). Appendix 5 shows that the main fertilizers used by coffee and maize farmers in Meru region are compound (NPK) fertilizers and some of them contain trace elements including manganese.

Table 10: Heavy Metal concentration (ppm) in the sediment from Karumanthi and Gachioma Rivers

Sample	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Zinc
KSA	0.037	0.962	0.644	0.032	1.628	Bdl	1.226
KSB	0.063	0.442	0.571	0.032	10.702	Bdl	1.513
KSC	0.047	1.019	0.754	0.051	3.955	Bdl	1.805
KSD	0.038	0.365	0.737	0.03	8.134	Bdl	1.753
KSE	0.041	0.923	0.694	0.035	6.348	Bdl	1.868
Mean	0.045 ± 0.001	0.742 ± 0.021	0.680 ± 0.002	0.036 ± 0.002	6.153 ± 0.099	Bdl	1.633± 0.007
GSA	0.052	0.615	0.752	0.026	7.475	Bdl	1.539
GSB	0.053	0.904	0.751	0.033	10.950	Bdl	1.782
GSC	0.054	0.712	0.546	0.024	4.948	Bdl	1.092
GSD	0.045	1.212	1.006	0.027	11.000	Bdl	1.469
GSE	0.036	0.462	0.412	0.021	4.755	Bdl	0.939
Mean	0.048 ± 0.002	0.781 ± 0.008	0.694 ± 0.006	0.026 ± 0.00	7.823 ± 0.172	Bdl	1.364 ± 0.01

The presence of cadmium in the sediments may be due to use of phosphate fertilizers in the farms (Stagg and Millin, 1978). The distribution of cadmium in the sediments was almost uniform with the peak occurring in the sampling point KB, which is a farming

area. Sampling point KC is in town with *Jua* Kali activity and a solid waste dumping site (Plate 4). Sampling point KE is the source of Karumanthi River and it indicates enhanced levels of all the heavy metals studied except for mercury which was below detection limit. The source of this river is in a basin which lies in a place surrounded by a heavily populated and built up area. There are also some coffee farms around the river source basin. Surface runoff from the surrounding area deposits agricultural wastes into the basin sediments and the growing plant, taro in this case takes up the metal (Kumar, 1994). Concentration of cadmium in the sediments was between 0.037 and 0.063 ppm, while the mean concentration was 0.05 ± 0.02 ppm. Concentration of chromium in the sediments ranged between 0.365 ppm and 1.019 ppm. The highest value was detected at the sampling point KC (Table 6). Around this point there were *Jua Kali* motor vehicle garages (Plate 5) and a solid waste dump site (Plate 4).

Plate 4: Dump site along Karumanthi River near sampling point KC

Table 10 and Figure 3 show the presence of copper in all the sampling points in Karumanthi River. Concentration values ranged between 0.571 and 0.754 ppm with the highest amount at point KA while the lowest was at point KB (Table 6). The mean concentration of copper in the sediments was 0.68 ± 0.002 ppm. The distribution of copper in Karumanthi River may be attributed to a variety of activities such as the application of fertilizers and farmyard manure in the coffee and maize farms (Kabata and Alina, 1984) and the use of copper based fungicides on coffee trees (appendices 3 and 4) Copper may also be introduced into water via the leaching of copper pipes by acidic or alkaline water (Townshend, 1995) which may in turn introduce copper into the river sediments due to the waste water disposal practices especially in the urban area of the study. The bar graph in Fig. 3 indicates that manganese was found in high concentration while cadmium and lead were detected with mean concentration of 0.045 ± 0.05 and 0.036 ± 0.002 ppm respectively.
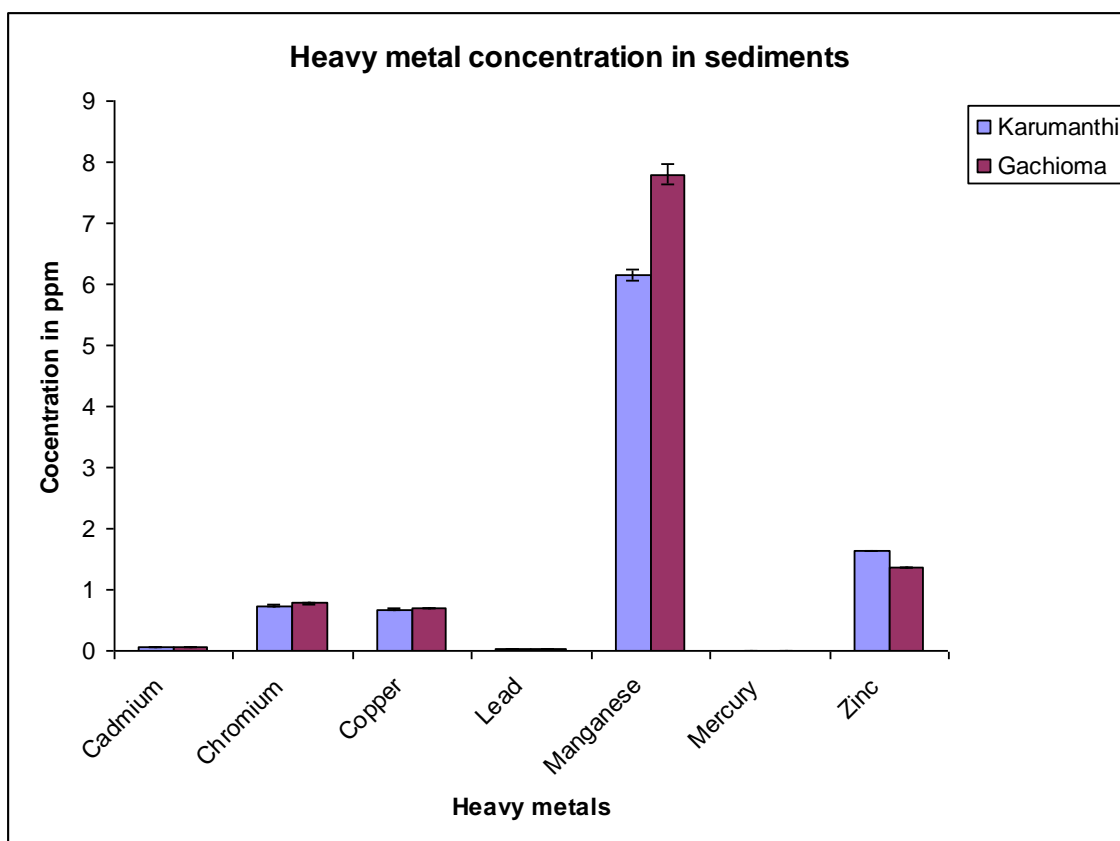
Figure 3: Concentration of heavy metals in Karumanthi and Gachioma River sediments

Table 10 also shows that lead was distributed in all sediment samples with the highest concentration occurring in the sampling point KC whose value was 0.051 ppm, while the lowest concentration was at the sampling point KD with a value of 0.031 ppm. The distribution of lead was almost uniform except for the point KC where the maximum concentration was observed as evidenced by the *Jua kali* motor vehicle garages carrying out activities such as spray painting and lead batteries repair (Plates 1, 2 and 3). Mercury level in the sediment was below detection limit.

Plate 5: Spray painting of a motor vehicle in a Jua Kali garage along Karumanthi River

Zinc was detected in the sediments at concentrations ranging from 1.226 to 1.868 ppm and the mean concentration was 1.633 ± 0.007 ppm. Disposal of solid waste, such as dry cell batteries and *Jua Kali* soldering activities may have contributed for the presence of zinc in this area (Plate 6).

Plate 6: *Jua Kali* **garage along the banks of Karumanthi River**

4.3.2 Heavy metal concentrations in the sediments of Gachioma River

Table 10 also shows concentration of heavy metals in Gachioma River sediments. All the metals were detected except mercury. Cadmium was almost uniformly distributed in the sediment and its concentration ranged between 0.036 and 0.054 ppm with a mean of 0.048 ± 0.002 ppm. Some agricultural activities along the banks of Gachoima River could have contributed to the observed levels of cadmium.

Concentration of chromium in the sediment of Gachioma River ranged between 0.462 and 1.212 ppm with a mean concentration of 0.781 ± 0.008 ppm. Highest concentration of chromium in the sediments was detected at the sampling point GD, which was in agricultural land. It was followed by point GB which was also in the agricultural land on one side of the river while several education institutions lie on the other side of the river. The amount of chromium detected in the sediments was below the average chromium

content in the soils which is approximately 50 mg/Kg for the world soils (Kabata and Alina, 1984; Townshend, 1995).

Copper was distributed in the sediments in quantities ranging from 0.412 ppm at point GE, to 1.006 ppm at point GD which is in agricultural land. Copper enters into the agricultural land as a result of excessive use of inorganic fertilizers. It has been reported (Kabata and Alina, 1984) that concentration of copper in phosphate fertilizers ranges from 1 – 300 mg/Kg. Agrochemicals such as fungicides as used in coffee farms also contain copper. Fungicides used by coffee farmers in the area where this study was conducted are given in appendices 3 and 4. The fungicides include red copper (cuprous oxide 75 WP), copper green (copper oxychloride 50 WP) and blue copper/cocide DF (copper hydroxide 500g/Kg).

Presence of metal workshops in MTTI and the saw-mill along Gachioma River may also account for the levels of copper observed in the sediments. In aqueous solutions, copper salts, especially halides can be precipitated from solutions by large cations of similar charge such as $[Cr(NH_3)_6]^{3+}$ which precipitates $[CuCl_4]^{2+}$ (Cotton and Wilkinson, 1972). This effect may have precipitated copper from water into the sediments as observed.

Lead was detected in the samples in concentrations ranging between 0.021 and 0.033 ppm. Distribution was almost uniform with a mean concentration of 0.026 ± 0.0001 ppm. Gachioma River flows through a built up area consisting of education institutions, residential houses, *Jua Kali* garages, metal and wood workshops. The river also runs approximately parallel to the Meru – Maua road from Makutano part of Meru town

before it crosses the same road near the main gate of the Kenya Methodist University (KeMU). Several petrol stations are built between Makutano shopping centre and KeMU along Meru – Maua road. The surface runoff from the road, the non-point runoff from the area and the agricultural land could be responsible for the lead in the sediments (Enger and Smith, 1992). The mean concentration of the heavy metals in the sediments of Gachioma River is illustrated in figure 3. It is observed that concentration of manganese in Gachioma River sediments is higher than the concentration of the same heavy metal observed in Karumanthi River sediment.

Along Gachioma River, there are education institutions such as Meru Technical Training Institute, Meru Teachers College, Consolata Primary School and Gitoro Primary school all within the precincts of Gachioma River. There is also Consolata Dispensary in this area and Makutano shopping centre of Meru town. These institutions could be the source of the elevated levels of manganese in the sediments from such solid wastes as scrap metal and metal filings from *Jua Kali* workshops, discarded dry cell batteries, and pharmaceuticals. Sampling point GB was near Meru Technical training Institute and it recorded manganese concentration of 10.95 ppm in the sediments. The institution's metal workshops which generate metal filings and metallic sprays could be responsible for the elevated levels. A dispensary near the sampling point GB (Table 5), may also have contributed to the observed levels of manganese as a result of pharmaceutical waste products (Cotzias, 1977; Gong and Amemiya, 1977; Hussain and Ali, 1999).

Sampling point GA was at the source of the river. The concentration of manganese there was found to be 7.475 ppm, the values observed at point GA may be due to the wearing

off of the sawmill machinery's metallic components such as the ferromanganese steel parts (Townshend, 1995). Sampling point GD is an agricultural area and the manganese level in the sediments may have been as a result of the application of fertilizers on coffee farms (Townshend, 1995; Kabata and Alina, 1984).

At sampling point GC, low concentration of manganese was recorded whose value was 4.948 ppm. The observed low level could be due to dilution effect of a stream that is a tributary of Gachioma River. The same observation is also made in the sampling point GE down stream away from the education institutions and where there are few agricultural activities. The mean concentration of manganese in Gachioma River sediment was 7.83 ± 0.172 ppm.

Zinc was uniformly distributed in the sediments of Gachioma River. The lowest concentration was recorded at the sampling point GE whose value was 0.939 ppm and the highest value was at point GB with a value of 1.782 ppm. This quantity may be attributed to the metal workshop wastes of Meru Technical Training Institute. The mean concentration of zinc in the sediments was 1.364 ± 0.01 ppm. Other sources of zinc may be attributed to the surface run off from the settled urban areas upstream of the Gachioma River. Mercury was however, not detected in the sediments of Gachioma River.

4.4 Heavy Metals in the Corms
 The results on the concentrations of heavy metals in the corms of taro plant collected in Karumanthi and Gachioma Rivers are shown in Table 8. With the exception of mercury

whose concentration was below detection limit, all other metals were detected in the taro corms.

4.4.1 Heavy metals in corms of taro growing along Karumanthi River

Distribution of cadmium in the corms collected from Karumanthi River ranged between 0.019 and 1.318 ppm with a mean concentration of 0.28 ± 0.016 ppm. The peak occurred in sampling point KA. The observed high value may have been from the phosphate fertilizer (Kabata and Alina, 1984) used by coffee and maize farmers in the study area (appendix 5). Sampling point KA is in an area where both coffee and maize are cultivated extensively.

Table 11: Heavy Metal concentration (ppm) in Taro corms from Karumanthi and Gachioma River

Metals Concentration (ppm)						
Sample site	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Zinc
KA	1.318	0.217	0.246	0.012	0.621	Bdl	0.632
KB	0.019	0.019	0.029	0.008	0.867	Bdl	0.498
KC	0.031	0.254	0.076	0.014	0.680	Bdl	1.726
KD	0.019	0.016	0.067	0.026	0.299	Bdl	0.548
KE	0.027	0.040	0.056	0.014	0.207	Bdl	1.016
Mean	0.28 ± 0.016	0.110 ± 0.001	0.10 ± 0.002	0.02 ± 0.0002	0.53 ± 0.008	Bdl	0.88± 0.014
GA	0.027	0.157	0.070	0.012	0.151	Bdl	0.388
GB	0.023	0.231	0.107	0.018	0.220	Bdl	0.751
GC	0.024	0.539	0.006	0.297	0.344	Bdl	0.491
GD	0.024	0.139	0.012	0.010	0.787	Bdl	0.191
GE	0.023	0.231	0.056	Bdl	0.374	Bdl	0.280
Mean	0.024 ± 0.000	0.260 ± 0.000	0.050 ± 0.006	0.07± 0.01	0.38 ± 0.007	Bdl	0.42 ± 0.006

Zinc occurred in the corms at higher concentrations than all other heavy metals with its peak occurring at sampling site KC which was within the *Jua Kali* activities environment

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(Plates 6 and 7). Zinc also being an essential micro nutrient may have been bio-accumulated by the plant from natural sources (Berneji, 2005). Zinc is important in carbohydrate, lipid and protein metabolism in virtually all organisms (Cotton and Wilkinson, 1972). This may therefore, be attributed to the observed bioaccumulation in the corms.

The concentration of zinc in the taro corms collected along Karumanthi River ranged between 0.498 and 1.726 ppm with a mean concentration of 0.884 ± 0.014 ppm. Other heavy metals were also bio-accumulated in the corms as follows; copper 0.029 - 0.246 ppm with a mean concentration of 0.095 ± 0.002 ppm. The high concentration of copper in the corms obtained from sampling point KA (table 6), may be due to both the application of fertilizers and copper based fungicides in the coffee farms (Kabata and Alina, 1984).

Lead was detected in the taro corms in concentrations ranging between 0.008 and 0.026 ppm with a mean of 0.014 ± 0.0002 ppm. Sampling point KD recorded the highest concentration of lead in the corms. KD was located in town and therefore, this amount of lead could have had its origin from the exhaust gases of leaded gasoline which are absorbed through roots and leaves of plants (Tyagi and Mehra, 1990). The presence of lead in the taro corms in Karumanthi River may also have been due to activities such as car spray painting and soldering in the *Jua kali* garages (Plate 5). Mean concentration of heavy metals in the corms of taro plant growing in Karumanthi and Gachioma Rivers are given in Table 11. Plate 7 shows taro plants growing along the banks of Karumanthi

River which receives surface runoffs from the agricultural land and wastes from the *Jua Kali* garages that are located along the river.
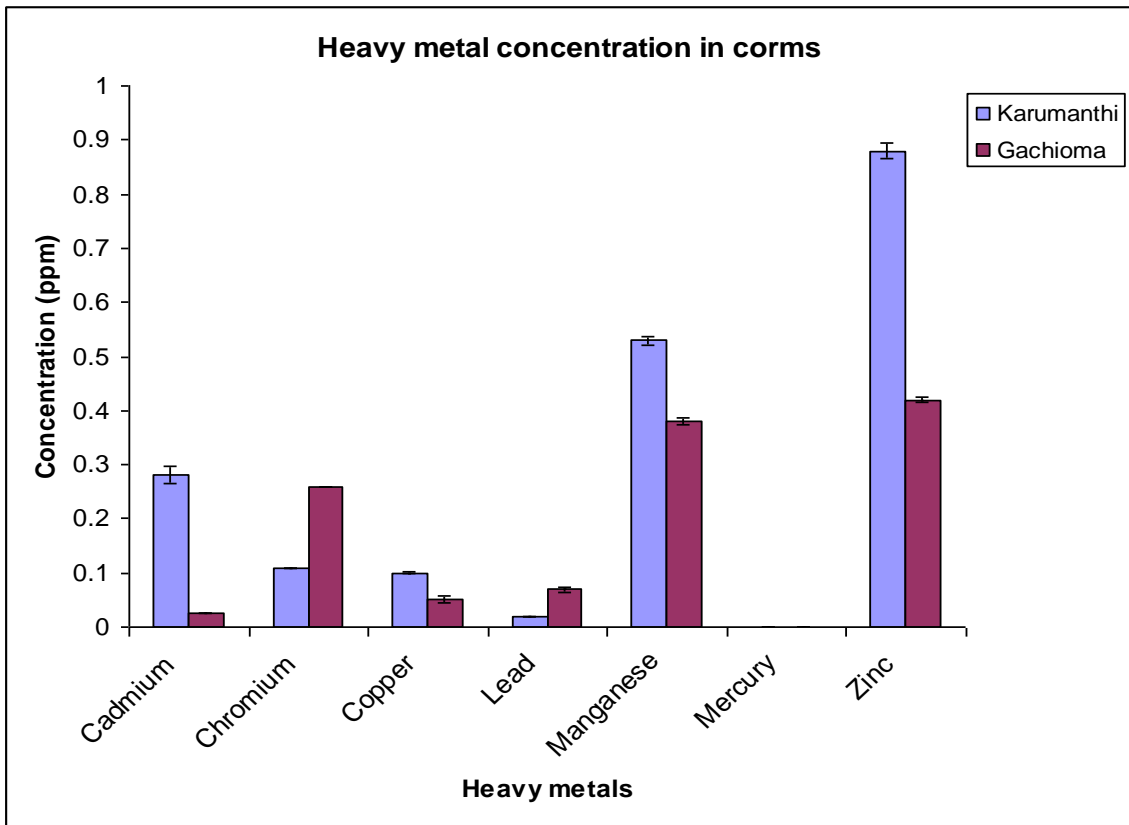
Figure 4: Concentration of heavy metals in corms of taro growing along Karumanthi River

Plate 7: Taro plants growing along the banks of Karumanthi River near the river's source

The mean concentrations of heavy metals in the corms of taro plants collected in Karumanthi River are shown in Fig. 3. From the graph, it is observed that the mean concentration of zinc recorded highest value of 0.88 ± 0.014 ppm among other metals, followed by manganese with a mean value of 0.53 ± 0.008 ppm. Manganese is an essential nutrient in plants and the source of manganese in the corm samples KA and KB may have come from the phosphate fertilizers which are added as an essential trace element in the manufacture of such fertilizers (Kabata and Alina, 1984).

Taro samples from site KA indicated cadmium concentration of 1.318 ppm, which was the highest among the samples collected in this river. Concentration of the metal in corm samples ranged between 0.019 and 1.318 ppm with mean concentration of 0.282 ± 0.016 ppm. This was in a coffee growing area which may be attributed to the application of phosphate fertilizers in the agricultural land (Kabata and Alina, 1984). Fertilizers are also

important sources of cadmium in agricultural land (Stagg and Millin, 1975). Plant roots absorb cadmium effectively (Pandya, 1978), and its availability in polluted soil makes plants growing on these soils (Plate 7) to concentrate it especially in the roots (Kabata and Alina, 1984). Chromium in the corms was detected in concentrations ranging between 0.016 and 0.254 ppm near the sampling point KC, which was in an area with *Jua Kali* garages. The mean value was 0.11±0.01 ppm. The observed mean heavy metal concentration in the corms was in the following descending order Zn > Mn > Cd > Cr > Cu > Pb.

4.4.2 Heavy Metals in corms of taro growing along Gachioma River

Results on the concentration of heavy metals in the corms of taro collected from Gachioma River are given in Table 11 and indicated in Fig. 3. All the metals except mercury were detected in the corms. Distribution of cadmium in the corms was almost uniform, ranging between 0.023 and 0.027 ppm with a mean of 0.024 ± 0.001 ppm. The main source of this metal may have been as a result of abrasion from automobile tyres on the road surface (Rahlenbeck *et al*., 1999). Distribution of chromium in the taro corm samples ranged between 0.139 and 0.539 ppm. The highest concentration occurred at the sampling point GC. It has been reported that plant uptake of chromium depends on the bio-availability of chromium, the soil solution, soil pH and background chromium (Kabata and Alina, 1984). The mean concentration of chromium in the corms was 0.223 $\pm$ 0.01 ppm and that of copper was 0.05 ± 0.001 ppm.

The lowest value for the concentration of copper was 0.01 ppm and the highest was 0.11 ppm, corresponding to sampling point GB, near Meru Technical Training Institute and the Consolata dispensary. Most of the copper may have originated from the metal

workshops of the Institute. The concentration of lead in sampling point GE was below detection limit. Concentration level in sampling site GC was the highest with a value of 0.297 ppm. This amount of lead in the corms may have had its origin from the surface runoff from the Meru - Maua road and the non point run-offs from Makutano area where there are several petrol stations. Phosphate fertilizers and leaded gasoline emissions are probably the primary sources of lead detected in the corms of taro plant growing in Gachioma River. It has been observed that lead contents in gasoline sold in African countries are among the highest in the World (Nriagu *et al*, 1996) and therefore this may have contributed to the emissions absorbed by the corms of taro growing in Gachioma River.

Concentration of manganese in the corms ranged between 0.151 and 0.787 ppm. The mean concentration was 0.375 ± 0.007 ppm. The highest concentration of manganese in the sediment and corms was recorded at the same sampling point GD, which was located near Meru Teachers College sewage lagoons. Zinc was detected in the taro corms that were collected from all the sampling sites. The concentration of zinc in the corms ranged between 0.191 and 0.751 ppm with mean concentration of 0.420 ± 0.006 ppm. From the graph (Fig.4) and Table 11, it is observed that the mean heavy metal concentration in the corms were in descending order Zn > Mn > Cr > Pb > Cu > Cd. However, concentration of mercury in the taro corms was below detection limit.

4.5 Heavy Metals in the leaves of taro

Table 12 shows the concentration of heavy metals in the leaves of taro growing in Karumanthi and Gachioma Rivers.

4.5.1 Heavy metals in leaves of taro growing along Karumanthi River

The graphical illustration of the heavy metal concentration in the taro leaves collected in Karumanthi River is shown in Fig.5. Observations indicate that except for mercury metal which was below detection limit and chromium which was detected in only one sampling point KC, all other metals were detected in the leaves of taro plants. Concentration of manganese was the highest with a mean of 2.68 ± 0.022 ppm.

The mean heavy metal concentration in the leaves of taro plants found in Karumanthi River were in the descending order of manganese > zinc > copper > cadmium > lead. Chromium metal in taro leaves was detected in only one sampling point, at site KC with a concentration of 0.154 ppm. The photograph (Plate 7) shows taro plant growing in Karumanthi River course. The plants are growing in water that receives runoff from agricultural land and wastes from the *Jua Kali* workshops and garages.

Table 12: Heavy Metal concentration (ppm) in the leaves of Taro from Karumanthi and Gachioma Rivers

Sample site	Metals (conc. Ppm)						
	Cd	Cr	Cu	Pb	Mn	Hg	Zn
KLA	0.018	Bdl	0.088	0.008	1.730	Bdl	0.551
KLB	0.037	Bdl	0.108	0.011	3.776	Bdl	0.239
KLC	0.019	0.154	0.166	0.013	2.215	Bdl	0.439
KLD	0.027	Bdl	0.099	0.014	2.883	Bdl	0.272
KLE	0.025	Bdl	0.150	0.012	2.818	Bdl	0.363
Mean	0.03 ± 0.002	0.003 ± 0.001	0.102 ± 0.001	0.01 ± 0.000	2.68 ± 0.022	Bdl	0.37 ± 0.004
GLA	0.030	Bdl	0.104	0.010	1.598	Bdl	0.368
GLB	0.039	Bdl	0.206	0.011	1.221	Bdl	0.363
GLC	0.020	0.154	0.071	0.015	3.778	Bdl	0.273
GLD	0.040	0.212	0.125	0.012	3.354	Bdl	0.463
GLE	0.026	0.423	0.118	0.014	2.282	Bdl	0.320
Mean	0.03 ± 0.002	0.16 ± 0.004	0.125 ± 0.001	0.012 ± 0.000	2.45 ± 0.03	Bdl	0.36 ± 0.002

The mean concentrations of heavy metals are demonstrated graphically in Fig. 5. Cadmium and lead were detected in all leaf samples albeit in low quantities. Use of phosphate fertilizers and abrasion from automobile tyres could be the main source of these metals. Vegetables absorb these metals from the soil and atmosphere by dusts deposited on their surfaces (Ndiokwere 1984; Tumbo-Oeri, 1988). Mercury concentration level was below detection limit in the leaves.
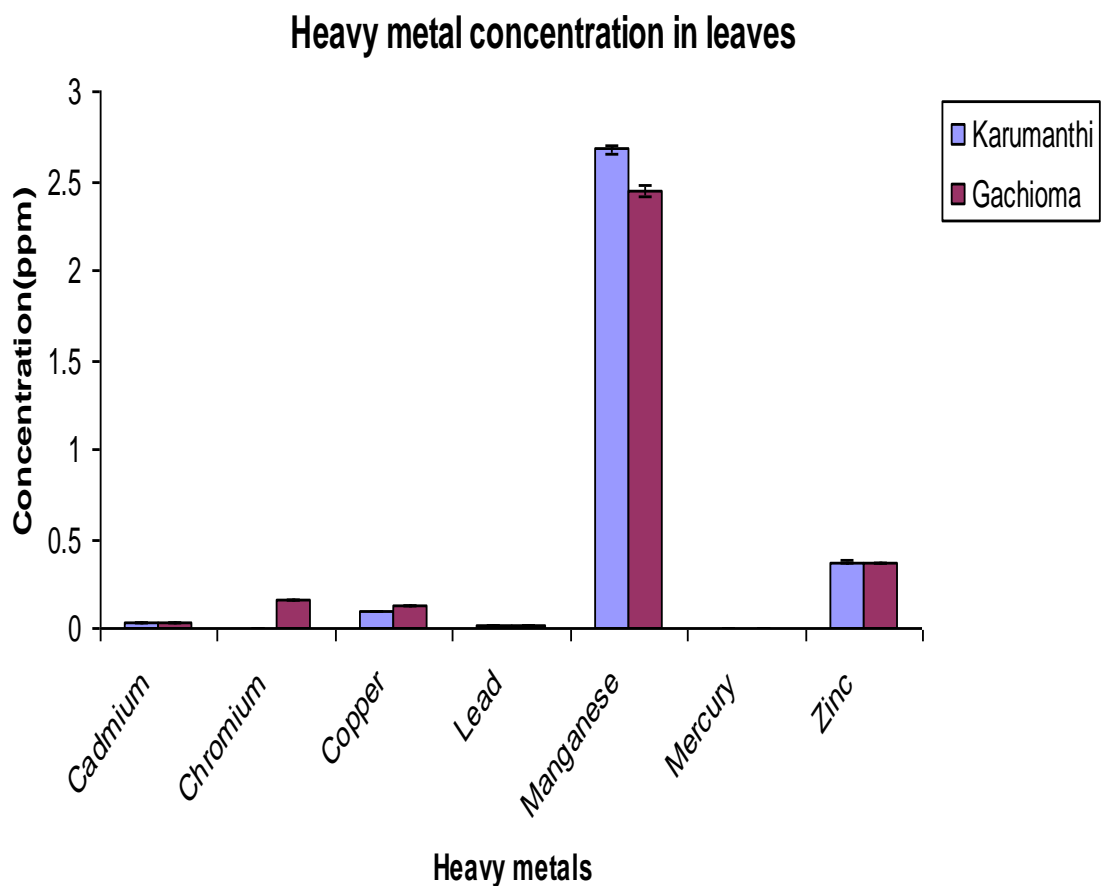
Figure 5: Concentration of heavy metals in the leaves of taro growing along Karumanthi and Gachioma Rivers

From Fig. 5 taro leaves accumulate manganese more than any other heavy metal. This is followed by zinc then copper and lead is least absorbed. The three metals manganese, copper and zinc are micro -nutrients for both plants and animals and it may be the reason why they are accumulated in relatively greater quantities than other heavy metals under study. Leafy vegetables are particularly good sources of manganese (Williams, 1994).

4.5.2 Heavy metals in the leaves of taro plants collected along Gachioma River

Appendices 3 and 4 show those fungicides and folia feed used in Meru region by coffee farmers. The concentrations of heavy metals in leaves of taro plant growing in Gachioma River are shown in figure 5. Except for mercury, all the heavy metals under investigation were detected in the leaves of the taro plant growing in Gachioma River. Traces of cadmium were observed in all the leaf samples of the taro plant studied. The distribution was almost uniform with the lowest concentration being 0.020 ppm and the highest was 0.040 ppm.

Mean concentration of Cadmium was 0.032 ± 0.002 ppm. Chromium was detected in all the leaf samples of taro plant except in two, namely from sampling points GA and GB. The mean concentration of chromium was 0.16 ± 0.004 ppm. It has been observed (Kabata and Alina, 1984) that the uptake of chromium by plants depends on the bio-available chromium in the soil solution, the soil pH and background chromium content in the soil. This may have reduced transport of the metal to the leaves (Kabata and Alina, 1984) which may explain the unavailability of chromium in the leaves collected at sampling point GA. Sampling point GE had the highest concentration of chromium whose value was 0.423 ppm. In the backyard of the sampling point was a zero grazing

unit of dairy cows (plate 8). Farmyard manure is known to contain as much as 1.1 – 55 mg of chromium per kilogram of manure (Stagg and Millin, 1975). The results are depicted in Fig. 5.

Concentration of copper in the leaves of taro ranged between 0.071 and 0.206 ppm with a mean value of 0.123 ± 0.0014 ppm. Copper sources may have been from the application of phosphate fertilizers and copper fungicides in the coffee farms (Appendices 3 & 4). The lowest amount of lead detected was 0.010 ppm while the highest value was 0.015 ppm. Lead may have originated from the Meru - Maua road surface runoff. The road runs almost parallel to the course of Gachioma River for a distance of about three kilometers. The mean concentration of lead in the leaves was 0.012 ± 0.001 ppm.

There was more manganese in the taro leaves than in the corms. The concentration ranged between 1.221 and 3.778 ppm and the mean was 2.45 ± 0.028 ppm. Manganese is taken up by the roots and leaves and the amount depends on the concentration of the metal in the soil solution and the soil pH (Kabata and Alina, 1984). Taro leaves are known to be rich in manganese (Muhia, 2000). The enhanced levels of manganese in all the leaf samples of taro in Gachioma River may be attributed to application of phosphate fertilizer, (sites; GC and GD), the use of farmyard manure and animal feeds in site GE (Townshend, 1995). Plate 8 shows a zero grazing unit for dairy cows (site GE) set close to the banks of Gachioma River. The washout of this cow shed drains into the river which may explain the presence of the observed enhanced levels of manganese.

Plate 8: Cow dung washout from a zero grazing unit cowshed

Concentration level of mercury was below detection limit in the taro leaves. The concentration of zinc in the taro leaves ranged between 0.273 and 0.463 ppm. The average concentration was 0.36 ± 0.002 ppm. As a green vegetable, taro is known to contain zinc (Williams, 1994) and it appears that the amount of zinc present in the taro leaves is the natural zinc found in green vegetables. The mean concentration level of zinc in the leaves was found to be about one third the mean concentrations in the sediments suggesting bioaccumulation of the heavy metals by the taro plant (table 14).

4.6 Comparison of concentrations of heavy metals in water, sediments, corms and leaves of taro

The mean concentration of the heavy metals in the analytes, sediment, water, corms and water for both Karumanthi and Gachioma River are given in Table 13 on page 69. The order of metal concentration of the six metals cadmium, chromium, copper, lead, manganese and zinc were observed as follows: Concentration of cadmium was in the order; corms > sediment > leaves > water. The order for chromium concentration in the analytes was; sediment > water > leaves > corms. For copper, the concentration was in the order; sediment > leaves > corms > water. The concentration of lead in the analytes was in the order; sediment > water > corms > leaves. The order of concentration of manganese was; sediment > corms > leaves > water, while that of zinc was; sediment > water > corms >leaves. The concentration of metals in the analytes from Karumanthi River is highest in the sediment and lowest in water. Cadmium however, had highest concentration in the corms. The observed order was therefore; sediment > leaves > corms > water.

Similar observations were made in Gachioma River samples. The concentration of cadmium in the analytes was in the order; sediment > corms > leaves > water. For chromium, the order of concentration was; sediment > leaves > corms >water. Concentration of copper was in the order; sediment > leaves > corms > water. Manganese concentration in the analytes was in the order; sediment > leaves > corms > water, while the order of concentration of zinc was; sediment > corms > leaves > water. Sediment had the highest concentration of all the metals while water had the least concentration. It is concluded therefore that the order of concentration was; sediment > corms > leaves > water.

Table13: Mean concentrations (ppm) of heavy metals in water, sediments, corms and leaves from both Karumanthi and Gachiuma Rivers

Analyte	METALS (concentration in ppm)						
	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Zinc
KW	Bdl	0.09	0.02	0.02	0.04	Bdl	0.13
KS	0.045	0.74	0.68	0.04	6.15	Bdl	1.63
KC	0.28	0.004	0.10	0.02	0.53	Bdl	0.88
KL	0.03	0.03	0.12	0.01	2.7	Bdl	0.37
GW	Bdl	0.16	0.003	0.003	0.11	Bdl	0.014
GS	0.05	0.78	0.70	0.03	7.83	Bdl	1.36
GC	0.02	0.02	0.05	0.10	0.38	Bdl	0.42
GL	0.03	0.16	0.13	0.01	2.45	Bdl	0.36

The mean concentrations for the analytes are indicated in Table 13. Observations show that in both rivers the concentration of cadmium and mercury metals were below detection limits in water samples, while concentration of mercury metal was below detection limit in all the analytes (Appendix 2). Zinc had the highest concentration in Karumanthi River with a value of 0.13 ppm while in Gachioma River; chromium had the highest concentration with a value of 0.16 ppm. Both of these values are higher than the maximum allowable concentration of the metals for the standards required for the sources of domestic water (GoK, 2006), and (Appendix 6).

In the sediments, manganese registered the highest concentration of 6.15 and 7.83 ppm in both Karumanthi and Gachioma rivers respectively than all the other metals. Concentration of zinc in the sediments was higher in Karumanthi River (1.63 ppm) than in Gachioma River (1.36 ppm). Concentration of lead and cadmium metals in the sediment was the least among the other metals with mean values of 0.04 and 0.03 ppm in Karumanthi and Gachioma rivers respectively. In the corms, zinc registered the highest

concentrations with values of 0.88 ppm in Karumanthi and 0.42 ppm in Gachioma Rivers respectively while chromium recorded the least concentration at 0.004 ppm in Karumanthi and 0.02 ppm in Gachioma River. The mean concentrations of both cadmium and lead in corms for both rivers showed that the levels were slightly higher than the maximum allowable levels of 0.01 mg/l and 0.05 mg/l for domestic water content of cadmium and lead respectively (GoK, 2006). Quality standards for sources of domestic water are shown in Appendix 6.

4.7 Data analysis

To compare the accumulation of the heavy metals in the analytes in both rivers Karumanthi and Gachioma, paired t-test analysis was done for corms and sediments, leaves and sediments, sediments and water, corms and leaves, corms and water and, leaves and water. The results are indicated in the following tables.

Table 14: Results for Paired t-test between Sediments and taro corms heavy metal accumulation in the Karumanthi and Gachioma Rivers.

Pair	Mean	N	Std.Deviation	SEM	P. correlation	P value
Ka Sedimemts	0.470	7	0.598	0.226	-0.059	0.900
Ga Sediments	1.530	7	1.062	1.606		
Ka Corms	0.274	7	0.324	0.122	0.818	0.0024
Ga Corms	0.172	7	0.178	0.067		

Key: Ka-   stands for Karumanthi River

            Ga-   stands for Gachioma River

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SEM- Standard Error of Mean

From table 14, it is observed that heavy metal accumulation in the sediments between the two rivers, Karumanthi and Gachioma are not correlated, p > 0.05, at 0.900. There is however, correlation between the concentration of the heavy metals in the corms and the sediments in the two rivers. This is an indication that there is accumulation of heavy metals in the corms where p < 0.05 (at 0.024) showing they are significantly correlated.

Table 15: Results for Paired t-test between sediments and taro leaves heavy metal accumulation in Karumanthi and Gachioma Rivers

Pair	Mean	N	Std. Deviation	SEM	P. correlation	P value
Ka Sediments	0.471	7	0.598	0.226	-0.059	0.900
Ga Sediments	1.530	7	2.810	1.062		
Ka Leaves	0.456	7	0.989	0.374	0.000	0.000
Ga leaves	0.448	7	0.891	0.337		

Table 15 shows the Pearson's correlation between the two pairs of taro leaves and the sediments from the two rivers. For sediments the Pearson's correlation is -0.059, indicating that there is no correlation (p = 0.900; > 0.05) of heavy metal concentration between the sediments of the two rivers. There is however, a very strong correlation between the sediments and the taro leaves in the two rivers. This indicates that there is accumulation of heavy metals in the leaves of taro growing in the two rivers, p = 0.000 < 0.05.

Table 16: Results for Paired t – test between sediments and water heavy metal concentration in the rivers Karumanthi and Gachioma.

Pairs	Mean	N	Std. Deviation	SEM	P. Correlation	P value
Ka Sediments	0.470	7	0.598	0.226	-0.059	0.900
Ga Sediments	1.530	7	2.810	1.062		
Ka Water	0.042	7	0.053	0.020		
Ga Water	0.067	7	0.065	0.025	0.820	0.024

Table 16 shows that the Pearson's correlation for sediments between the two pairs is negative 0.059, indicating that there was no correlation of heavy metal accumulation between the sediments in the two rivers. There is however, a strong correlation for the water in the two rivers, which means that there is strong correlation of heavy metal in the water as a carrier of the heavy metals. It is further concluded that the sediments in the two rivers are not significantly correlated as the value of $p = 0.900 > 0.05$. For the water, value of $p = 0.024 < 0.05$ showing that they are significantly correlated.

The Pearson's correlation values are shown in table 17 for the corms and leaves. They are 0.818 and 0.998 for corms and leaves between the two pairs of samples respectively. For the corms, $p = 0.024$, showing strong correlation of heavy metal accumulation of heavy metals between the two rivers and an evidence against null hypothesis when $p < \alpha$ The results also indicate that taro corms bio-accumulate heavy metals from the two rivers. It is also observed that taro corms and leaves found in the two rivers are significantly correlated, $p < 0.05$ in both cases (0.024 and 0.000 respectively).

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Table 17: Results for Paired t – test between taro corms and leaves heavy metal concentration Karumanthi and Gachioma Rivers.

Pairs	Mean	N	Std. Deviation	Std. error mean	P correlation	P value
Ka Corms	0.274	7	0.324	0.122	0.818	0.024
Ga Corms	0.172	7	0.178	0.067		
Ka Leaves	0.456	7	0.989	0.374	0.998	0.000
Ga Leaves	0.448	7	0.891	0.337		

Table 18: Results for Paired t – test between taro corms and water heavy metal accumulation in Karumanthi and Gachioma Rivers.

Pair	Mean	N	Std. Deviation	SEM	P. correlation	P value
Ka Corms	0.274	7	0.324	0.122	0.818	0.024
Ga Corms	0.172	7	0.178	0.067		
Ka Water	0.417	7	0.053	0.020	0.820	0.024
Ga Water	0.067	7	0.065	0.025		

Table 18 shows the values of Pearson's correlation between the two pairs of samples. The p- value for the corms is 0.024. This value is less than 0.05 and therefore, indicating a strong correlation of heavy metal bio-accumulation between the corms in the two rivers. A strong correlation is also observed for water in the two rivers that carry the heavy metals, a further indication that there is accumulation of heavy metals in the water in rivers Karumanthi and Gachioma. It can also be concluded that the corms in the two

rivers are significantly correlated as the value of $p < 0.05$ ($p = 0.024$) where as that for the water is $p < 0.05$ ($p = 0.024$) showing they are significantly correlated. These observations indicate that heavy metals were found in both the water and the corms thus showing heavy metal bio-accumulation.

Table 19 shows the value of Pearson's correlation between the two pairs of leaves and water respectively. For the taro leaves the Pearson's correlation is 0.000, which shows there is a correlation of heavy metal accumulation between the taro leaves found in the two rivers. Similarly from the results, there is correlation for the water in the two rivers which act as the carrier for the heavy metals found there. Conclusion is also drawn that the leaves in the two rivers are significantly correlated as the value of $p = 0.000 < 0.05$. For water, $p = 0.024 < 0.05$ showing that they are also significantly correlated (table 19).

Table 19: Results for Paired t- test between taro leaves and water heavy metal accumulation in Karumanthi and Gachioma Rivers

Pair	Mean	N	Std. Deviation	SEM	P-correlation	P-value
Ka Leaves	0.456	7	0.989	0.374	0.998	0.000
Ga Leaves	0.448	7	0.891	0.337		
Ka Water	0.042	7	0.053	0.020	0.820	0.024
Ga Water	0.067	7	0.065	0.025		

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Taro also known as arrowroot in East Africa is a tuber crop which has been used in some parts of Kenya in the past for many years. The popularity of this crop has decreased due to introduction of exotic temperate crops such as Irish potatoes as source of carbohydrates and various types of cabbages among other vegetables as source of vitamins and other nutrients. Secondly, taro grows well in river valley bottoms where there is a well supply of water. Encroachment of wetlands where taro was traditionally planted and the diversion of water from the natural water courses resulting to low levels of water in rivers, drying swamps and wet lands, have left this important crop deprived of its major requirement for its growth and survival. These combined effects have reduced the yields of taro in the traditional producing regions of Kenya (Table 2). Taro is an important source of both carbohydrates from the corms and vitamins from the leaves.

Taro corms and leaves can absorb minerals and bio-accumulate them in the tissues. Water sampled from Karumanthi and Gachioma Rivers indicated that there was presence of the heavy metals, cadmium, chromium, copper, lead, manganese and zinc. The concentrations were however, within the maximum allowed levels by National Environmental Management Authority, NEMA(Appendix 6) . Periodic monitoring of the concentration levels of the heavy metals should be carried out to check for any possible heavy metal pollution.

The concentrations of chromium, copper, manganese and zinc in both corms and leaves were below the RDA levels. Heavy metal analysis showed that taro that was growing in areas which had *Jua Kali* activities absorbed the heavy metal pollutants. In the agricultural active areas, especially where coffee is cultivated, there was strong evidence that heavy metal wastes from copper based coffee fungicides, such as Cocide DF (Appendix 5) was being washed into the rivers which was in turn absorbed by taro.

Concentration of Copper in the corms and leaves of taro was higher in the coffee growing area of the study than it was in those areas where there were no coffee farms. Manganese was also detected in agricultural areas where fertilizers were applied to coffee and maize plantations. The study shows that lead was available in the taro that was sampled near *Jua Kali* garages in both rivers, and from corms and leaves of taro growing in Gachioma River where it runs almost parallel along Meru – Maua road between Makutano business District of Meru Town and The Kenya Methodist University main gate.

The study also shows that the presence of heavy metals at the source of Gachioma River may be attributed to the existence of a saw mill which has been in operation at the source of the river for more than fifty years. The presence of heavy metals near the source of Gachioma River was also observed and may be attributed to contribution by workshop wastes from Meru Technical Training Institute and the surrounding slum urban settlements at Gitoro whose storm runoff drain into Gachioma River.

The study further shows that the ability of taro to absorb heavy metals, under very low concentrations in the environment is a positive indicator that taro can absorb even more quantities of heavy metals if the plant was cultivated in polluted soils or wet areas. Thus taro can be used for the purpose of phyto-remediation of polluted water bodies, sediments and soil. The plant carrying heavy metal pollutants can then be uprooted and incinerated as a method of clean up.

General conclusion therefore, is that taro is a rich source of both macro and micro-nutrients. When the plant is grown in polluted places such as soils or in sewages, taro can absorb high concentrations of minerals, including heavy metals which are poisonous. Using such taro for food therefore, would lead to eventual heavy metal poisoning which is not the desired end benefit to the consumer. Taro growing along Karumanthi and Gachioma Rivers is safe to be used for food.

5.2 Recommendations

- Taro should not be cultivated for food in polluted areas such as polluted springs, swamps, wetlands, or in polluted soils where it would absorb poisonous heavy metals.

- Taro should also not be cultivated along busy motorways where it would be exposed to lead emission from the vehicular exhaust fumes.

- Application of inorganic fertilizers on taro plantations should be avoided in order to minimize the chances of the plant absorbing cadmium.

- The Meru Water and Sewerage Company and the Ministry of Water and Irrigation should regularly monitor the heavy metal pollution in the piped water which has been drawn by respective communities from Gachioma and

Karumanthi Rivers before the respective consumers use it in Kaaga, Kithoka and Munithu areas.

- Both the Ministry of Public Health and Sanitation, and the National Environmental Management Authority (NEMA) should enact legislation and guidelines on the use of polluted rivers or busy road reserves for the cultivation of taro plant.

- Further research on the interaction of heavy metals with taro plant is highly recommended.

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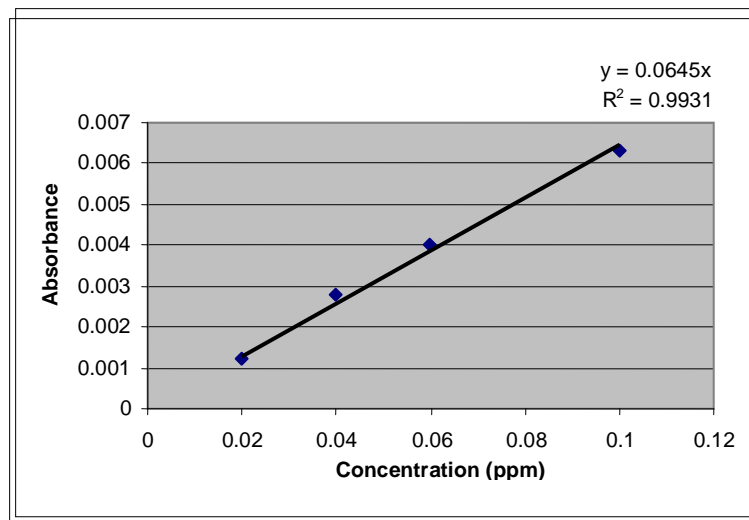
APPENDICES

Appendix I: Calibration curves for heavy metals

Appendix 1.1 Cadmium

Absorbance	Concentration
0.0012	0.02
0.0028	0.04
0.004	0.06
0.0063	0.10

Cadmium

$y = 0.0645x$
$R^2 = 0.9931$

Appendix 1.2 Chromium

Absorbance	Concentration
0.0014	0.5
0.0026	1.0
0.0038	1.5
0.0048	2.0
0.0066	2.5

Chromium
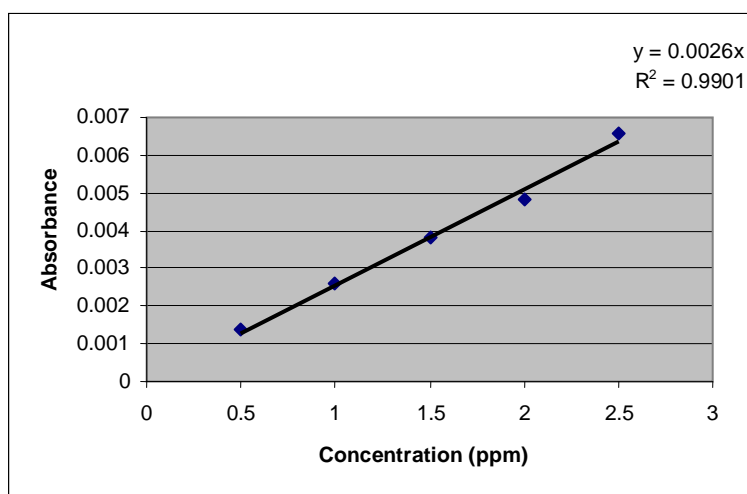
Absorbance	Concentration
0	0
0.0078	0.2
0.0129	0.4
0.0253	0.8
0.0310	1.0

Copper
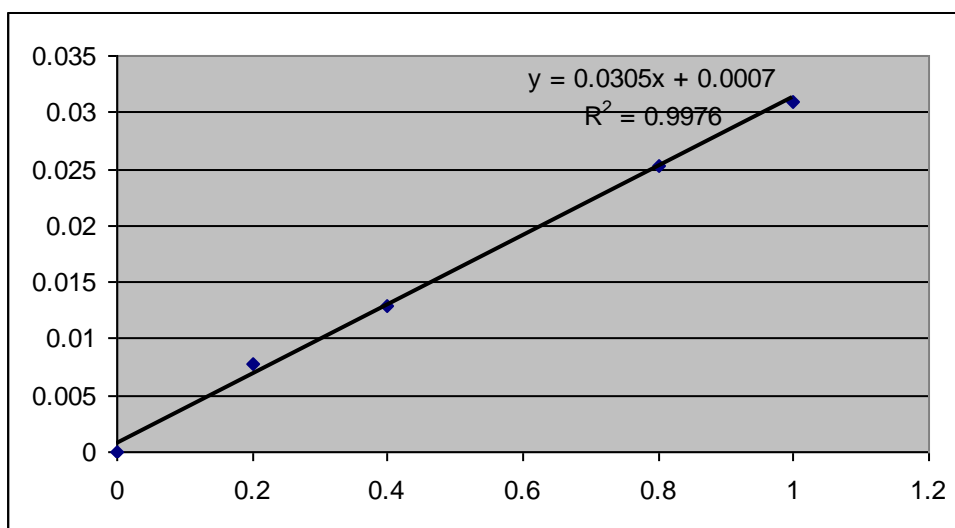
Appendix 1.4: Lead

Absorbance	Concentration (ppm)
0.0018	1
0.0047	2
0.0072	3
0.0094	4
0.0113	5

Lead

$y = 0.0023x$

$R^2 = 0.9924$
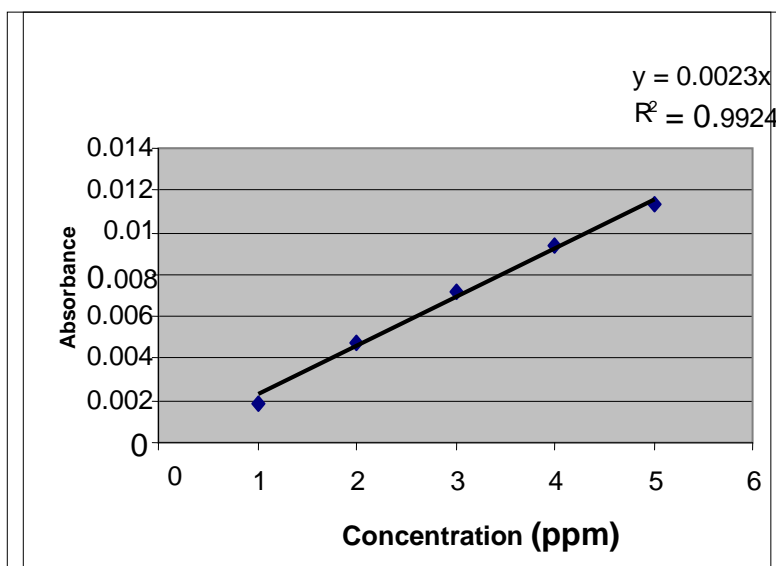
Appendix 1.5: Manganese

Absorbance	Concentration (ppm)
0.016	0.5
0.1271	2.5
0.3585	7.5

Manganese

$y = 0.048x$
$R^2 = 0.9981$
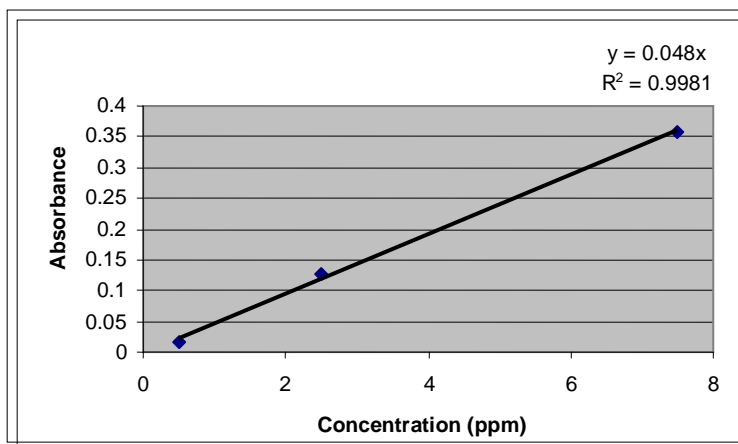
Appendix 1.6: Mercury

Absorbance	Concentration (ppm)
0.0504	10
0.112	30
0.1862	50

Mercury

y = 0.0038x
$R^2 = 0.9819$
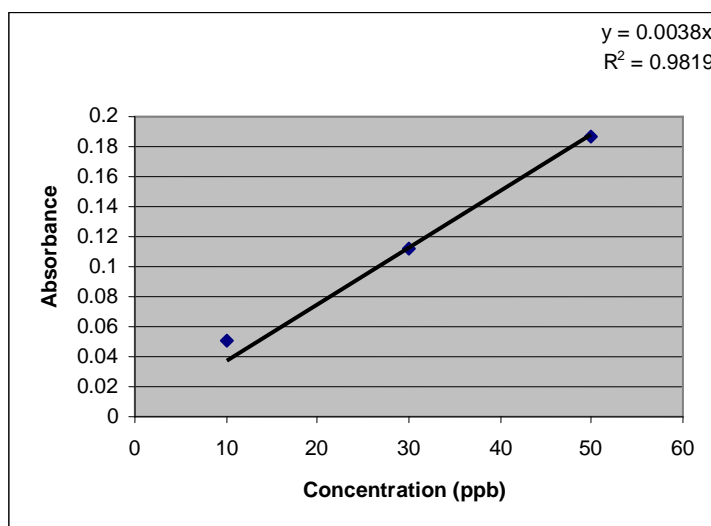
Appendix 1.7: Zinc

Absorbance	Concentration (ppm)
0	0
0.0364	0.5
0.0723	0.8
0.1361	1.5
0.1648	2.0
0.2086	2.5

Zinc

$y = 0.0841x + 0.0007$

$R^2 = 0.9948$
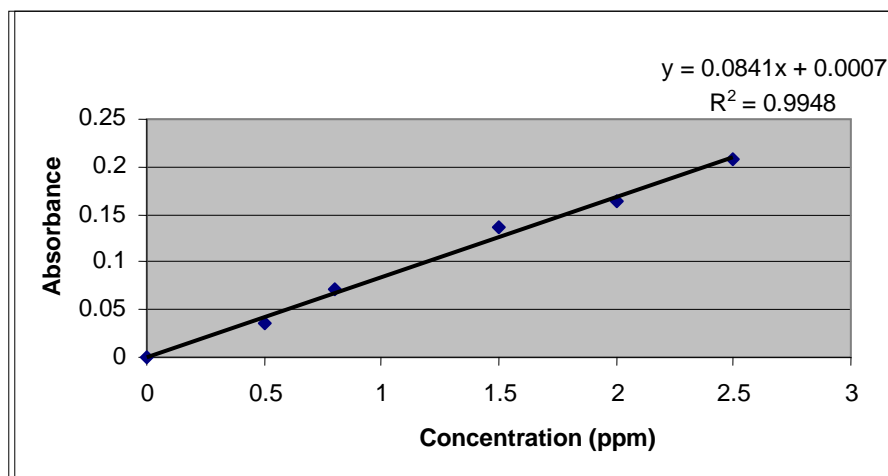
Appendix II: **Detection Limits for Metals**

Metal	Wavelength (Nm)	Detection Limit (mg/L)
Cadmium	228.9	0.005
Chromium	357.9	0.05
Copper	324.8	0.02
Lead	283.3	0.10
Manganese	279.5	0.01
Mercury	253.7	0.7
Zinc	213.9	0.005

(**Source**: Buck Scientific Model 210 VGP AAS Manual)

Appendix III: **Copper fungicides used by coffee farmers in Meru region**.

	Fungicide	Trade Name	Composition
1	Red Copper	Copper Nordox	Cuprous Oxide 75WP
2	Copper Green	Isacop	Copper Oxychloride 50WP
3	Blue Copper	Cocide DF	Copper hydroxide 500g/Kg

(**Source**: Farmers Centre, Meru)

Appendix IV: **Folia feeds used by maize farmers in Meru region.**

Folia feeds	Trade Name	Composition	Manufacturer
1	Phosgard Plus	B,Co,Fe,Mg,Mo,Zn	Juanco SPS LTD
2	Maize Plus	Cu,510mgl,432mg/Kg Mn 510mgl,432mg/kg Zn684mg/l,mg/Kg	Hygrotech E.Africa
3	Amiran Maize Grow	Cu,110mg/Kg Mn,500mg/Kg Mo,70mg/Kg Zn,150mg/Kg	Amiran
4	Omex	N 24% P 24% K 18%	Murphy

(**Source**: Farmers Centre Meru)

Appendix V: **Fertilizers used by both maize and coffee farmers in the study area Meru region.**

Fertilizer	Composition			
	N	P	K	Trace elements
DAP	18%	46%	0%	———
NPK	20%	20%	0%	———
NPK	17%	17%	17%	———
NPK	23%	23%	0	———
CAN	26%	———	———	———
Mavuno (For Planting)	10%	26%	6.0%	Mg 4%,S4%, Bo, Mn, Zn, Mo, Cu.
Mavuno (Top dressing)	30% (Ammonium N)	———	———	Ca10%,S 4%

(**Source:** Farmers Centre Meru.)

Appendix VI: **Quality Standards for Sources of Domestic Water**

Metal	Maximum allowable (mg/L)
Cadmium	0.01
Chromium	0.05*
Copper	0.05
Lead	0.05
Manganese	0.4*
Mercury	0.006*
Zinc	1.5

Source: Environmental Management and Co-ordination (Water Quality) Regulation, 2006

*WHO Guidelines for Drinking – Water Quality, 3rd. Edition. Vol. 1, 2008.

Appendix VII: **Recommended Dietary Allowance (RDA), USA.**

Metal	Maximum RDA
Copper	3.0 mg (adults)
Chromium	200 µg (adolescents and adults)
Manganese	5.0 mg for people aged above 11 years
Zinc	15 mg for people between 10 and 50 years

Source: Essentials of Nutrition and Diet Therapy
By Sue Rodwell Williams (1994), Mosby: (Adopted from National Research Council, USA, Revised 1989)