ASSESSMENT OF LEVELS OF SELECTED HEAVY METALS AND COLIFORM BACTERIA IN SOIL AND VEGETABLES GROWN AT ELDORET MUNICIPAL DUMPSITE

BY

CHOGE PHOEBE

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DECLARATION

Declaration by the Candidate

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CHOGE PHOEBE

REG. NO. SC/PGC/076/11

Signature: …………………………………. Date: ………………........

Approval by Supervisors

This thesis has been submitted with our approval as University supervisors:

Prof. SAMWEL T. LUTTA

Department of Chemistry and Biochemistry,

University of Eldoret, Kenya.

Signature: …………………………………. Date …………………...

Dr. EDWARD ANINO

Department of Chemistry and Biochemistry,

University of Eldoret, Kenya.

Signature: …………………………………. Date ……………………

DEDICATION

This work is dedicated to my parents; Mr. Kipchoge Maru and Mrs. Pauline Maru and the entire family for their tireless support, love and understanding and to my sons; Alvan and Ivan for their endurance during the entire period of this study. I love you all.

ABSTRACT

Agricultural practices are on the rise in urban areas of developing countries; Kenya included due to the high rate of urbanization which comes with associated challenges such as increased demand for food and employment. Urban farming is viewed as an important practice since it is a source of income and food. However, limited land spaces in urban areas and the rising cost of artificial fertilizers have been a major challenge to urban farming. Consequently, farmers especially the low income earners are forced to use free land to grow food crops and use raw sewage sludge to enhance fertility of the food crops. In Eldoret, the old municipal dumpsite has become an ideal site for growing vegetables. Sewage sludge is applied to the vegetables without regard to risks caused by toxic heavy metals and pathogenic contamination. Heavy metals are known to accumulate along the food chain. Prolonged consumption of unsafe concentrations of heavy metals may lead to their accumulation in the human body causing disruption of numerous biochemical processes. Pathogenic organisms on the other hand are known to be precursors to diseases like dysentery, typhoid, tetanus and cholera among others. This research was conducted to determine levels of lead, cadmium, copper, zinc, iron, nickel, total coliform, faecal coliform and *E. coli* contamination in soil, kales (B*rassica oleracea*), spinach (*Spinacea oleracea*) and bulb onions (*Allium cepa*) grown at the old Eldoret municipal dumpsite and irrigated using raw sewage sludge. Levels of coliform bacteria were assessed using multiple tube fermentation technique while heavy metal contaminants were analysed using atomic absorption spectroscopy (AAS). A total of 60 samples were used in two experimental runs carried out between July 2013 and January 2014 to cater for both dry and wet seasons. All data were analysed using SPSS version 20.0 and significance was considered at $p \leq 0.05$. Comparison of mean concentration of heavy metals in soil and vegetables and the mean concentration of heavy metals in soil and vegetables during dry and wet seasons was done using paired t-test. The results obtained from municipal dumpsite soil indicated the following mean concentrations: Pb, 1.630 mg/kg, Cd, 0.070 mg/kg, Cu, 0.380 mg/kg, Zn, 2.310 mg/kg, Fe, 101.530 mg/kg and Ni, 10.370 mg/kg. In kales mean concentration of heavy metals were as follows: Pb, 1.356 mg/kg; Cd, 0.110 mg/kg; Cu, 0.095 mg/kg; Fe, 42.070 mg/kg; Zn, 0.875 mg/kg and Ni, 9.240 mg/kg. In spinach the following concentrations were obtained: Pb, 1.088 mg/kg; Cd, 0.090 mg/kg; Cu, 0.103 mg/kg; Zn, 0.800 mg/kg; Fe, 22.110 mg/kg and Ni, 9.190 mg/kg. In onions mean concentration of heavy metals were as follows: Pb, 0.404 mg/kg; Cd, 0.345 mg/kg; Cu, 0.109 mg/kg; Zn, 2.650 mg/kg and Fe, 2.650 mg/kg. Levels of total coliform and feacal coliform in the soil were 3,893 and 3,068 MPN/100 ml respectively while in onions the levels were 10,576 and 5,861 MPN/100 ml respectively. Levels of all the heavy metals were within the acceptable range of WHO/FAO in soil. In vegetables, Pb and Cd were above the acceptable limit while Cu, Zn, Fe and Ni were within the acceptable standard. Levels of faecal coliform in soil and onions were above recommended standard. It was therefore concluded that the vegetables grown in the old Eldoret municipal dumpsite and irrigated using raw sewage sludge are not good for human consumption since they have high levels of Pb, Cd and faecal coliform which are likely to pose health complications to consumers.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS - Atomic absorption spectroscopy

APHA- American Public Health Association

ATSDR – Agency for Toxic Substances and Disease Registry

BEH - Bureau of Environmental Health

EC - European Commission

EMB - Eosin Methylene Blue

EPA - Environmental Protection Agency

FAO – Food and Agricultural Organisation

FDA - Food and Drug Administration

FEPA - Federal Environmental Protection Agency

HPA – Health Protection Agency

IARC -International Agricultural Research Centers.

IOSHIC - International Occupational Safety and Health Information Centre

IPCS – International Programme on Chemical safety

IWMI - International Water Management Institute

MDH- Minnesota Department of Health

MPN - Most probable number

SACN- Scientific Advisory Committee on Nutrition

SD - Standard deviation

SPCR – Soil Pollution Control Regulation

UNDP- United Nation Development Programme

UNSGAB – United Nation Secretary General’s Advisory Board

USDHHS – United States Department of Health and Human Services

USEPA - United States Environmental Protection Agency

UV- Ultra Violet

WHO - World Health Organization

WSIS - Water Stewardship Information Series

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

There has been an increase in urban agricultural practices in developing countries due to the high rate of urbanization that comes with associated challenges, especially the increased demand for food and employment. Urban agriculture is known to provide a complementary strategy to reduce urban poverty, food insecurity, enhance urban environmental management and ensure productive use of urban wastes. To a large extent, urban agriculture compliments rural agriculture as it provides products that rural agriculture cannot supply easily like the perishable food products. In Kenya, urban agriculture is a common practice as it acts as a source of income and food that would have otherwise been scarce (Githongo, 2010). Indeed most urban and peri-urban residents in Kenya engage in agricultural activities on a full time basis while those who are not full time farmers are also involved in agriculture to support their income.

Although urban agriculture has many benefits, precaution should be taken to ensure safety of the produce for consumption. Rapid and relatively unorganized urban expansion, industrial development coupled with inadequate waste management causes significant alterations in the physical environment. One of the primary concerns of urbanization in the developing world especially in Africa; Kenya included, has been the problem of solid, liquid and toxic waste management. Most cities lack proper solid waste regulations and proper disposal facilities for harmful wastes which may be toxic or radioactive (Wong *et al.*, 2003; UNDP, 2006; Kimani, 2007). These cities reveal aspects of waste management problem such as heaps of uncontrolled garbage, roadsides littered with refuse, streams blocked with rubbish, inappropriately disposed of toxic waste and disposal sites that constitute a health hazard to residential areas (Kibwage, 2002; Rotich *et al.*, 2006; Ebong *et al.*, 2008). The problem of waste management in cities of developing countries is a challenge to urban agriculture since food crops can accumulate toxic elements to high levels rendering the crops unfit for consumption.

Availability of land for farming is another challenge to urban farming. Urban and peri-urban areas are characterized with high population density due to the search of better livelihoods in towns and cities. The high population density has led to increased pressure on urban infrastructure especially land space (Tinker, 1994). Limited or no land is available for farming since fertile lands in the urban and peri-urban settlements are being used for building and other industrial activities. As a result, urban residents especially the low income earners make use of free land spaces ‘no man’s land’ to grow food crops. Most often, the free land spaces include waste disposal sites, rail and road reserves, close to market places, beside polluted water bodies, mechanic workshops and industrial areas among others. The direct use of dumpsites for cultivating vegetables and the on-farm use of compost sourced from the dumpsites is a common practice in urban and peri urban centers in developing countries. This practice is potentially harmful to the health and well being of adjacent population and consumers of the produced food crops. Studies conducted earlier on vegetables grown in a dumpsite have shown that dumpsites increase heavy metal concentration in food crops to levels that are harmful for human health (Kimani, 2007; Ebong *et al.*, 2008; Shemdoe, 2010).

Additionally, farming in urban and peri-urban areas in developing countries is characterized by the use of wastewater which is regarded as a resource of global importance (Bruechler *et al.*, 2002). The use of wastewater helps to circumvent the problem of water scarcity and nutrient deficiency in agricultural farms (McKenzie, 2005; Kassan, 2010). However, occurrence of uncontrolled urban sewage farming like the use of untreated or partially treated wastewater is a common practice in African cities. This practice exposes consumers of such produce to poisoning from heavy metals and other contaminants (Ebong *et al*., 2008).

In Kenya, solid waste management has remained a challenge for the last decades. Most cities/estates in the country are littered with garbage which when eventually collected finds its way into open dumps. The use of open dumps for municipal solid waste in Kenya makes environmental pollution highly probable. These wastes attract birds, rats, flies and other animals to the dump. Animals feeding at the dump may transmit diseases to human beings living in the vicinity (Eddy *et al*., 2006; Oyelola *et al*., 2009). Soil, plants, surface water and underground water remain vulnerable to solid waste pollution because disposal dumps are chosen for convenience rather than based on environmental safety considerations. Additionally, the use of untreated sewage wastewater across urban and rural cities in Kenya has also increased with water scarcity and the rising cost of artificial fertilizer (Kutto *et al.*, 2012). When such water is used for irrigation, the food crops absorb appreciable amounts of contaminants which are finally transferred to the consumers.

This study was conducted in the old Eldoret municipal dumpsite which is located near Huruma settlement scheme in Eldoret town, Uasin Gishu County, Kenya. Huruma is a highly populated region that is occupied by middle and low class people living in an overcrowded area with poor sanitation and inadequate or unsafe water sources for domestic use and other activities. In an attempt to cater for basic needs, residents of Huruma especially the low income earners, grow vegetables and grains in the old Eldoret municipal dumpsite because of limited land spaces. These farmers use liquid slurry from the Eldoret sewage to enhance fertility of food crops. The sewage sludge is readily available and apart from providing water to the crops, it is also regarded as a rich source of nutrients like nitrogen and these enable farmers to avoid the high cost of artificial fertilizers. However, an earlier study conducted by Khazenzi (1996) showed that domestic and industrial sewage in Eldoret is not properly treated because both the sewage treatment works cannot cope with total sewage discharge rendering the wastewater a potential source of pollutants. The food crops are also exposed to faecal contamination because residents of Huruma frequently have to rely on unsewered communal toilets or use open spaces for toilets. As a result the faecal wastes are washed to the farming areas and water bodies. In addition, the available sewage system in the area is very poor; some pipes are broken and therefore effluents find its way to the river and consequently to the vegetable farm. It is with this understanding therefore that this study was undertaken in an attempt to address part of this problem by assessing levels of heavy metal contaminants and coliform bacteria in soil and vegetables grown on the dumpsite and are frequently consumed in the region. Plate 1.1 provides photographs of vegetables grown in the old Eldoret municipal dumpsite.

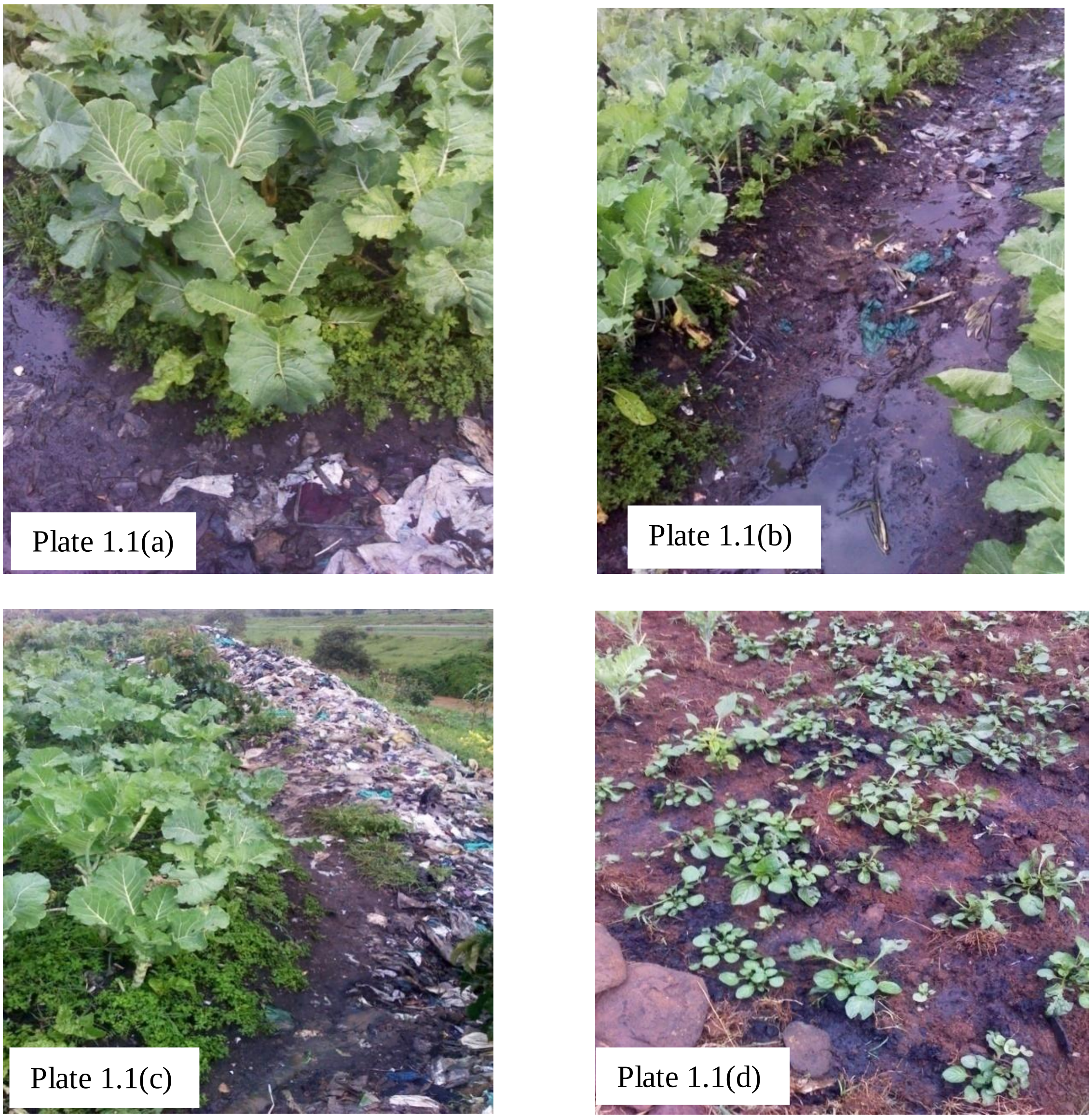

Plate 1 1: Photographs of vegetables grown in the old Eldoret municipal dumpsite (Source: Author, 2015).

Plates 1.1 (a) and (b) show vegetables surrounded by streams of dirty effluent, plate 1.1 (c) shows vegetables surrounded by a heap of wastes while plate 1.1 (d) shows vegetables in a virgin land in which sewage sludge has been applied to enhance fertility.

1.2 Statement of the Problem

The old Eldoret municipal dumpsite has become an ideal site for farming activities because of limited land spaces yet the use of a dumpsite for farming activities is a great environmental hazard and a threat to public health. Since the dumpsite is uncovered and unlined, it allows leachates to soak into the soil and underground water. The leachates can increase heavy metal concentration in the soil and underground water to levels that may have harmful effects on food crops and human health (Ebong *et al.*, 2008). Human health is at risk because food crops absorb the hazardous heavy metals from the soil and are finally transferred to man and animals through consumption of the crops. Therefore consumers of vegetables grown in the old Eldoret municipal dumpsite are vulnerable to health risks associated with heavy metal contamination. Exposure to heavy metal toxicity leads to brain damage, mental retardation, cerebral palsy, lung cancer, gastrointestinal abnormalities, dermatitis and death of foetus among other complications (USEPA, 2002; Rotich *et al.*, 2006; UNDP, 2006).

The use of sewage wastewater for irrigation provides farmers with renewable nutrients giving rise to healthy and eye catching vegetables (McKenzie, 2005; Kassan, 2010). However, the wastewater of Eldoret municipal sewage system can be regarded as a potential source of pollutants to food crops since the wastewater is not properly treated and thus a vector of diseases (Khazenzi, 1996). Wastewater contains a significant amount of toxic heavy metals such as arsenic, chromium, cadmium, copper, lead, nickel, zinc, cobalt and iron which will accumulate in the soil and get transferred to food crops grown in these soils posing threat to health of consumers. Disease-causing pathogenic organisms (bacteria, virus, protozoa among others) along with other parasitic helminthes which can give rise to health hazards on human beings, animals and plants are also found in untreated or partially treated sewage slurry (Oboubie *et al*., 2006; Chaurasia & Dwivedi, 2008). The pathogens are transmitted by direct contact with farmers and to the general public through consumption of irrigated produce especially crops eaten raw (Blumenthal *et al*., 2000). The poor sewerage system in the area and the use of open space increases the risk of pathogenic contamination which are precursors to different diseases such as dysentery, typhoid, tetanus, worm infections and cholera among other health complications.

Vegetable contamination in the old Eldoret municipal dumpsite does not only affect farmers who have a direct contact with the vegetables but also the Eldoret region at large. Through water runoffs, some wastes from the dumpsite including the applied sewage sludge end up in Sosiani River extending environmental and health risks to communities living within the vicinity as well as those living downstream who could be using the water. Vegetable vendors are also responsible for extending the health risks to other regions since most of them buy vegetables at a wholesale price from the dumpsite then sell at a retail price in Eldoret market and other places within the region.

To safe guard public health, it was necessary to carry out an extensive screening on vegetables grown in the old Eldoret municipal dumpsite to determine the extent of heavy metals and bacterial contamination so as to identify where precautionary action ought to be taken to reduce health risks associated with the contamination.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this study was to determine whether levels of selected heavy metal contaminants and coliform bacteria in soil and vegetables grown at the old Eldoret municipal dumpsite meet the WHO/FAO standards.

1.3.2 Specific Objectives

The specific objectives of the study were:

i. To determine levels of lead, cadmium, copper, zinc, iron and nickel in soil, kales, spinach and bulb onions grown at the old Eldoret municipal dumpsite and irrigated using raw sewage sludge.
ii. To compare levels of the heavy metal contaminants in the samples during dry and wet seasons.
iii. To determine levels of both total and faecal coliform in bulb onions grown at the old Eldoret municipal dumpsite and irrigated using raw sewage sludge.
iv. To determine whether soil and bulb onions grown at the old Eldoret municipal dumpsite and irrigated using raw sewage sludge are contaminated with *E. coli*.
v. To compare levels of heavy metal contaminants and coliform bacteria in soil and vegetables with acceptable standards of WHO/FAO.

1.4 Hypotheses

Based on literature reviewed, the following hypotheses were formulated and tested:

1. Soil, kales, spinach and bulb onions grown at the old Eldoret municipal dumpsite and irrigated using raw sewage sludge are contaminated with lead, cadmium, copper, zinc, iron and nickel.
2. Levels of the heavy metal contaminants in the samples are higher during wet season than dry season.
3. Soil and bulb onions grown at the old Eldoret municipal dumpsite and irrigated using raw sewage sludge are contaminated with total and faecal coliform.
4. Soil and bulb onions grown at the old Eldoret municipal dumpsite and irrigated using raw sewage sludge are contaminated with *E. coli*.
5. Levels of heavy metal contaminants and coliform bacteria in soil and vegetables are higher than the acceptable standards of WHO/FAO.

1.5 Justification

The World Health Organization (WHO) estimates that about a quarter of the diseases facing mankind today occur due to prolonged exposure to environmental pollution (Prüss-Üstün and Corvalán, 2006; Kimani, 2007). Eldoret town with its high population density generates large quantities of wastes daily. This has led to the formation of a huge heap of garbage in the old Eldoret municipal dumpsite which exposes residents to environmental pollution. The city just like most cities in Kenya does not have any environmentally friendly method of wastes disposal; wastes are being indiscriminately and improperly disposed of within the dumpsite. The dumpsite is not covered and unlined therefore leachates find their way to the soil and underground water. Leachates from municipal wastes are known to contribute a significant amount of heavy metals (Oboubie *et al*., 2006; Chaurasia & Dwivedi, 2008). Since heavy metals persist in the environment for long, their levels in both soil and plants grown in the old Eldoret municipal dumpsite are expected to be considerably high.

Due to the rise in water scarcity and increase in cost of artificial fertilizers, residents opt to use untreated liquid slurry from the Eldoret sewage to irrigate their vegetables in order to enhance fertility of the food crops. However, an earlier study conducted by Khazenzi (1996) showed that domestic and industrial sewage in Eldoret treatment plant is not properly treated. Thus, the sewage wastewater can be regarded as a potential source of contaminants which are likely to be harmful for human health.

In the year 2006, the World Health Organization published guidelines for the safe use of wastewater, excreta and grey water in agriculture to protect farmers and consumers health. The guidelines encouraged specific measures and adoption of a combination of other protective procedures. These measures include: practice of good personal hygiene, keeping harvesting equipment and storage facilities clean and dry, protecting fields from faecal contamination by animals including birds, use of treated manure and treated faecal waste for fertilizers and use of safe water for irrigation. Furthermore, King Willem-Alexander of the Netherlands, in his former role as chairman of the UN Secretary-General's Advisory Board on water and sanitation addressing the 6th World Water Forum in Marseille, France (12th March 2012) stressed the convergence of drinking water and sanitation issues in wastewater. He stated that "… wastewater is a challenge for which we need multiple solutions from all sectors and at all levels. This is a disaster in slow motion that will grow in proportion and impact. We know that in many parts of the world, wastewater is already used for agriculture. This practice should be encouraged, but it must be done safely, with the use of guidelines such as the globally accepted World Health Organisation guidelines for wastewater reuse" (UNSGAB, 2013). These guidelines have not been adhered to in Huruma because of some reasons: the high cost of artificial fertilizers and desire for quick income have forced farmers especially the low income earners to use raw slurry from the Eldoret sewage which apart from providing water to the crops is also regarded to be rich in nutrients hence giving rise to a high yield at a lower cost of production. The slurry relieves farmers from the high cost of artificial fertilisers although it is not only a good source of nutrients but also pollutants. Wastewater treatment to the levels recommended for unrestricted irrigation is not a realistic option in the area due to financial constraints and poor sewerage systems. The poor sewerage systems expose the vegetables to faecal contamination since some sewage pipes are broken and the effluents find their way into the vegetable farm.

Owing to serious health risks associated with heavy metal and pathogenic contaminants, it was of practical importance to determine the levels of selected heavy metal contaminants and coliform bacteria in vegetables grown at the old Eldoret municipal dumpsite. Moreover, from literature search, it was evident that no study had been done to assess levels of pollutants in soil and vegetables grown at the old Eldoret municipal dumpsite. Therefore this research intended to also fill the existing gap and equip the locals with full knowledge on suitability or otherwise of such food crops for human consumption and give a suggestion on precautionary actions that ought to be undertaken.

1.6 Scope of the Study

The study was limited to soil and three different vegetable species: spinach (*Spinacea oleracea*), kales (*Brassica oleracea*) and bulb onions (*Allium cepa*) grown at the old Eldoret municipal dumpsite. The three vegetable species represented the major species grown at the dumpsite and are commonly consumed in Eldoret. Vegetables grown on contaminated soil of a dumpsite and irrigated using untreated or partially treated sewage sludge are known to contain various contaminants. However, due to limited time and financial constrains, the analysis was based on few heavy metal contaminants and coliform bacteria. The heavy metal contaminants analysed were lead, cadmium, copper, zinc, iron and nickel based on wastes that are frequently disposed of at the dumpsite. Coliform bacteria (total coliform, faecal coliform and *E. coli*) were analysed in soil and bulb onions which are sometimes consumed raw in vegetable salads. The coliform bacteria were analysed because the vegetables are exposed to faecal contamination due to the application of raw sewage sludge and the poor sewage system in the area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Vegetables

Vegetables are part of a special and culturally specific plants usually used in soups and sauces as an accompaniment for the main staples either when raw, cooked, dried or in any suitable form for the promotion of good health (Keller, 2003). Vegetables constitute an important part of human diet; they are considered as “protective supplementary food” since they contain large quantities of minerals, vitamins, carbohydrates, essential amino acids and dietary fibers which are required for normal functioning of human metabolic processes (Thompson & Kelly, 1990). They also act as a neutralizing agent for acidic substances formed during digestion (Arai, 2002; Hashmi *et al.*, 2007; Magaji, 2012). Report by WHO/FAO (2004) showed that vegetables help in the prevention and alleviation of several micronutrient deficiency diseases especially in the less developed countries which are prone to hunger and malnutrition.

2.1.1 Contamination of Vegetables

As human activities increase especially with increase in modern technologies and application of organic fertilizers such as sewage sludge, manure and wastewater; contamination of the vegetables and food chain has become inevitable (Hamilton *et al.*, 2006; Heaton & Jones, 2008).

Contaminants accumulate in the soil then get transferred to food chain causing serious health hazards to human beings and animals (Haiyan & Stuanes, 2003; Al-Jassir *et al.*, 2005; Kachenko & Singh, 2006; Malla *et al.*, 2007; Sharma *et al.*, 2008; Muhammad, 2009). Many researchers have revealed that some common vegetables are capable of accumulating high levels of heavy metals from the soil (Xiong, 1998; Cobb *et al.*, 2000). In a study carried out by Othman (2001) on edible portions of five varieties of green vegetables: amaranthus, Chinese cabbage, cowpea leaves, leafy cabbage and pumpkin leaves collected from several areas in Dar es Salaam, Tanzania; results showed that there was a direct positive correlation between levels of Zn and Pb in soils with their levels in vegetables.

Uptake and bioaccumulation of heavy metals by plants and vegetables depend on many factors such as species and nature of different vegetables (Rattan *et al*., 2001; Lukšienė & Račaitė, 2008; Arora *et al*., 2008). Itanna (2002) reported that leafy vegetables accumulate much higher contents of heavy metals as compare to other vegetables because leafy vegetables are most exposed to environmental pollution due to large surface area.

Many people could be at risk of adverse health effects from consuming common market vegetables cultivated in contaminated soil since the condition of the soil is often unknown or undocumented. The populations most affected by heavy metal toxicity are pregnant women or very young children (Boon & Soltanpour, 1992). Neurological disorders, central nervous system destruction and cancers of various body organs are some of the reported effects of heavy metal poisoning (ATSDR, 1994a, b; ATSDR, 1999a,b; ATSDR, 2000).

Microbial contaminants in vegetables also represent a risk factor for consumer’s health since most vegetable produce are consumed when raw or without further processing (Musa & Okande, 2002). The consumption of fresh vegetables has greatly increased over the past years as consumers strive to eat healthy diets. Fresh vegetables are perceived to be more nutritious than their processed counterparts (Pollack, 2001; Lynch *et al*., 2009).

2.2 Urban Wastewater

Urban wastewater is defined as a combination of liquid wastes from different sources like domestic effluent consisting of black water that is toilet wastewater (excreta, urine and faecal sludge), grey water (kitchen and bathing waste water), industrial effluents, agricultural effluents, hospital effluents and storm water (Raschid-Sally & Jayacody, 2008).

2.2.1 Use of Wastewater in Urban Agriculture

As demand for fresh water intensifies, the use of urban wastewater (municipal or industrial) in agricultural sector is frequently seen as a common practice in many parts of the world (Sharma *et al*., 2007). An estimated twenty million hectares in 50 countries worldwide are irrigated with raw or partially treated wastewater and this is likely to increase during the next few decades as water scarcity intensifies (Hussein *et al*., 2001; Scott *et al*., 2004; Hamilton *et al*., 2007). Research results reported by Raschid-Sally and Jayacody (2008) indicated that on a global level, around 200 million farmers use treated, partially treated and untreated wastewater to irrigate their crops. It is also estimated that 10 per cent of the world’s population relies on food grown with contaminated wastewater (Corcoran *et al*., 2010). The use of untreated and partially treated wastewater for irrigation is particularly intense in arid/semi-arid regions and urban areas where unpolluted water is a scarce resource and wastewater enriched with nutrients is an important, drought-resistant resource for farmers (Scott *et al.*, 2004; WHO, 2006). In general, the main drivers of wastewater reuse in agriculture include increasing urban water demand, increasing urban food demand, lack of alternative water sources, high nutrition value of wastewater and its consistency in supply (Raschid-Sally & Jayakody, 2008). Farmers' ignorance on dangers associated with sewage wastewater and their need for plant nutrients has also contributed to the use of untreated sewage waste.

2.2.2 Effects of Wastewater on Food Crops

Wastewater contains several plant macronutrients principally nitrogen and phosphorus and in most cases varying amounts of micronutrients such as boron, copper, iron, manganese, molybdenum and zinc (EPA, 1995). The nutrients aid in increasing crop yields without resorting to the use of artificial fertilizers and hence a reduction of the environmental impacts associated with the use and production of artificial fertilizers (WHO, 2006). Report of Murtaza *et al.* (2003) showed that leafy vegetables like cauliflower, cabbage, spinach among others grow quite well in the presence of sewage wastewater. An overview conducted by Hussein *et al.* (2001); Rattan *et al.* (2001); Toze (2004) showed that wastewater is attractive and economically valuable for farmers because it contains important nutrients for crop growth. Similarly, Mckenzie (2005); Corcoran *et al.* (2010); Kassan (2010) showed that the use of wastewater benefits farmers through increased productivity, increased yields, faster growing cycles and additional water sources while decreasing their needs for artificial fertilizers.

Although sewage wastewater is known to be advantageous in farming giving rise to healthy and eye catching vegetables, application of sewage wastewater to farmlands carries a different set of risks to the environment and public health especially when industrial or household wastes are part of the sewage flow. The negative effects are due to the presence of various substances including PCBs, pesticides, dioxins, heavy metals, asbestos, petroleum products, pathogens and industrial solvents; many linked to threat to soil and ailments ranging from cancer to reproductive abnormalities (Blumenthal & Peasey, 2002; Githongo, 2010). Poucher *et al.* (2007) noted that although land application of sewage sludge can improve the physical properties of the soil and increase its organic matter content, there are also disadvantages like the possible transfer of contaminants such as pathogenic microorganisms from the soil. The microorganisms may include *Escherichia coli*, *faecal coliform* and *enterococci*. Similarly, Corcoran *et al*. (2010) argue that wastewater can be regarded as a vector of diseases.

The contaminants in wastewater can be brought to levels that are not harmful to plants and animals. Guideline values set by the World Health Organization (WHO) and United Nations Environment Program (UNEP) place restrictions on crops grown using wastewater and advise at least some sort of treatment of wastewater before its use (Blumenthal *et al*., 2000). Excellent treatment options exist that can remove all harmful pathogens and bring heavy metal and nutrient loads within safe limits for use or disposal. However, majority of wastewater used in developing countries does not receive any conventional treatment before being directly applied to the agricultural land due to lack of funds for treatment. Indeed planned and regulated use of wastewater remains, for many developing countries, an unobtainable goal in the near future (Scott *et al.* 2004). In Eldoret, domestic and industrial sewage is not properly treated because both the sewage treatment works cannot cope with total sewage discharge. Therefore, the sewage wastewater can be regarded as a potential source of pollutants (Khazenzi, 1996). In a study conducted by Githuku (2009), results indicated that the wastewater may not be suitable for irrigation as it poses a threat to the environment and health risks to farmers and consumers of the food crops. Similarly, an investigation conducted by Gumbo *et al*. (2010) in Malamulele, South Africa on the health implications of wastewater reuse in vegetable irrigation showed that there are potential health hazards associated with the practice since the levels of pollutants in wastewater exceeded the WHO guidelines.

Concern for public health has been the most important constraint in the use of wastewater in agriculture. Wastewater carries a wide spectrum of pathogenic organisms including bacteria, parasites and viruses which pose a risk to agricultural workers, crop handlers and consumers (Blumenthal *et al*., 2001; Van der Hoek, 2003; Amoah *et al*., 2005; Oboubie *et al*., 2006; Chaurasia & Dwivedi, 2008; Kwashie, 2009). When such water is used for irrigation, the soil becomes a reservoir of enteric pathogens and has the potential to transmit various diseases of enteric origin (Kwashie, 2009). Blumenthal and Peasey (2002); Lock and De Zeeuw (2003) reported that food grown using sewage wastewater may be contaminated with pathogenic organisms and disease vectors which are responsible for human diseases like helminthiasis, cholera, typhoid, shigellosis, gastric ulcers caused by *Helicobacter pylori*, giardiasis and amoebiasis. Similarly, report of IWMI (2006) showed that the use of wastewater for vegetable farming is a major source of diarrhoeal disease; the top cause of death among children in the developing world. In other areas where human excreta has been used as a fertilizer for crops, a high prevalence and intensity of *Ascaris* infection has often been reported for example in China (Xu *et al*., 1995). Hookworm infection is also highly prevalent in wetter climates where excreta are used for example in Vietnam (Needham *et al.*, 1998) and Southern China (Xu *et al.*, 1995). In Santiago, Chile there was evidence of the transmission of cholera**,** typhoid and shigellosis when vegetables were irrigated with untreated wastewater (Shuval, 1993). Cross-sectional studies of symptomatic diarrhoeal disease indicated that there was a two-fold or greater risk of diarrhoeal disease associated with high frequencies of consumption of uncooked onions irrigated with water consisting of wastewater (Blumenthal *et al*., 2002). Consumption of raw vegetables coming from an area where untreated wastewater was used for irrigation in Santiago was related to an increase in seroprevalence to *Helicobacter pylori* (Hopkins *et al.*, 1993). It is reported that the problem of microbial contamination becomes more serious with the vegetables because most of them are being consumed raw (Blumenthal *et al.*, 2002). The extent of microbial contamination decreases if the vegetable’s edible plant parts are above the ground while it increases if they are near the ground surface (Kwashie, 2009).

Regarding chemical compounds in wastewater, the major health concern is due to metals (Chang *et al*., 2002). Untreated sewage wastewater irrigation plays a pivotal role in significantly increasing heavy metals in soil and crops (Devkota & Schmidt, 2000; Rattan *et al.*, 2001; Mapanda *et al*., 2005; Sharma *et al*., 2007; Khan *et al*., 2008). Wastewater is known to increase individual metal in soil by 2% to 80% and in crops by 14% to 90% (Sarabjeet & Dinesh, 2007). Sewage waste has been implicated as a potential source of heavy metals such as copper, cadmium, zinc, lead, nickel and iron in the edible and non-edible parts of vegetables (Sharma *et al*., 2006). Irrigation with wastewater leads to accumulation of heavy metals in the soil which often leads to degradation of soil and contamination of food chain mainly through the vegetables grown on such soil and later exposing human beings and animals to this contamination (Qadir *et al.*, 1999; Rattan *et al*., 2001; Murtaza *et al.*, 2003; Singh *et* *al*., 2004; Khan *et al*., 2008). Sharma *et al*. (2007) concluded that the use of wastewater for irrigation increased the contamination of Cd, Pb and Ni in the edible portion of vegetables causing health risk in the long run. Similar findings have been documented from a study conducted in Harare, Zimbabwe, where farmers use wastewater for irrigating leafy vegetables (Mapanda *et al*., 2005).

2.3 Dumpsite

Dumpsite is a disposal site at which solid wastes are disposed of in a manner that does not protect the environment, is susceptible to open burning and is exposed to elements, disease vectors and scavengers (Kurian *et al*., 2003).

2.3.1 Hazards emanating from a dumpsite

Open waste dumping constitutes serious problems since most of such disposal sites are not scientifically selected nor well planned or properly managed (Magaji, 2012). They are also uncovered and unlined therefore allow leachates, to soak into the soil and underground water. Open dumping involves indiscriminate disposal of waste and limited measures to control operations, including those related to negative impacts on the environment. These unplanned heaps of uncovered wastes, often burning and surrounded by pools of stagnated polluted water, rat and fly infestations with domestic animals roaming freely and families of scavengers picking through the wastes is not only an eyesore but a great environmental hazard and a threat to public health. Moreover decomposition of organic materials produces methane which may cause explosions and produce leachates which pollute surface and underground water (Cointreau-Levine, 1997; Oyelola *et al*., 2009).

Additionally dumpsites constitute health hazard even to passers-by and those living near the dumps. This is due to the obnoxious smell oozing from the activities of microorganisms on the organic waste. Dumpsite managers in some cities have also been known to deliberately set periodic fires at the dumps in order to reduce the volume of the wastes, creating room for more wastes and thus extend the life of the dumps. Human scavengers may also cause intentional fires since metals are easier to spot and recover among ashes after the fires than among piles of mixed waste (Woodward, 1997; USEPA, 2002; UNDP, 2006). Uncontrolled burning of solid waste constitutes serious environmental pollution adversely affecting solid waste workers, pickers and surrounding population (Woodward, 1997; Oyelola *et al.*, 2009).

2.3.2 Use of a Dumpsite in Urban Agriculture

Over the past years, old dumpsites have become an ideal site for farming activities in most urban and peri-urban settlements due to limited farm that is associated to the global rise in human population. Research has shown that plants grown in these sites perform better compared to the surrounding areas because municipal wastes increase levels of nitrogen, pH, cation exchange capacity, percentage base saturation, organic matter and soil nutrients required for plant growth (Ogunyemi *et al.*, 2003). Although the municipal wastes are known to improve soil fertility, a considerable proportion of plastic, paper, metals and batteries which are known to be sources of metals which are hazardous to man and the environment are also present in a dumpsite (Pasquini & Alexander, 2004; Woodbury, 2005).

Recent studies have revealed that waste dumpsites can transfer significant levels of these toxic and persistent metals into the soil (Cobb *et al.*, 2000; Udosen *et al.*, 2006). The metals are eventually taken up by plants and get transferred into the food chain

(Benson & Ebong, 2005). Thus, assessment of dumpsite soils for levels of hazardous metals is imperative for healthy crop production. Plants grown in some dumpsites of Nigeria were found to contain higher levels of heavy metals (Amusan *et al.*, 2005; Oviasogie *et al.*, 2007; Ebong *et al.*, 2008). In Ghana, an experiment carried out on three waste dumpsites in Kumasi, where vegetable cultivation (cabbage, lettuce and spring onions) was practised, levels of the two most toxic heavy metals that is Pb and Cd were found to be far higher in the vegetables than the WHO/FAO recommended values (Odai *et al.*, 2008). In another study conducted by Kimani (2007) in Dandora waste dumpsite in Nairobi results showed high levels of heavy metals in particular Pb, Hg, Cd, Cu and Cr in the soil samples obtained from the site. A medical examination of the children and adolescents living and schooling near the dumpsite indicated a high incidence of diseases that are associated with exposure to high levels of metal contaminants. In Mtoni dumpsite bordering the Indian Ocean in Dar es Salaam, mean concentration of As and Cr in the soil samples and leachates were above the established contaminant limits of Tanzania standard soil quality (Shemdoe, 2010). A study conducted by Magaji (2012) within a dumpsite located at Mpape in Abuja revealed that the concentrations of heavy metals in some selected vegetables and tuber crop cultivated around Mpape dumpsite were higher than those from the control site and were also above the Federal Environmental Protection Agency (FEPA) acceptable limit except Fe and Zn in spinach that were within the limits. In another study conducted by Hunachew and Sandip (2011) to determine levels of various heavy metals present in soil and leachate of the Addis Ababa solid waste dumpsite and its potential ecological and public health risk, results indicated that the concentration of heavy metals: Zn, Cr, Ni, Co and Pb in the soil samples of the dumpsite and nearby open land were found to be higher than the internationally acceptable limits for the soil. No significant difference was observed in concentrations of trace elements between soil of the dumpsite and the nearby grazing land.

2.4 Heavy Metals

Heavy metals are a group of elements with density greater than 4.5 g/cm^3 and tend to release electrons in chemical reactions to form simple cations. In solid and liquid states, they are characterized by good heat and electrical conductivity, high melting and boiling points and their glossy and opaque nature (Szyczewski *et al.*, 2009).

2.4.1 Heavy Metal Contaminants and Human Health

Trace quantities of certain heavy metals such as iron, nickel, cobalt, copper, manganese, chromium and zinc are essential micronutrients for higher animals and plant growth, although excessive concentration of these heavy metals in food and feed plants are of great concern (FDA, 2001; Singh & Garg, 2006; Lokeshwari & Chandrappa, 2006; Adefemi & Awokunmi, 2009). The presence of heavy metals at abnormal levels is of great concern because they have cumulative behaviour, non-biodegradable nature, long biological half lives and lack good mechanism for elimination from the body (Akabzaa & Darimani, 2001; Yusuf *et al.*, 2002; Jarup, 2003; Sathawara *et al.,* 2004; Babel & Dacera, 2006). The heavy metal ions form complexes with proteins in which carboxylic acid (–COOH), amine (–NH_2) and thiol (–SH) groups are involved. The modified biological molecules lose their ability to function properly and result in malfunction or death of cells. When metals bind to these groups they inactivate important enzyme systems or affect protein structure which is linked to the catalytic properties of enzymes. This type of toxin may also cause the formation of radicals; dangerous chemicals that cause the oxidation of biological molecules (Neal & Guilarte, 2012).

Metals such as beryllium, mercury, lead, cadmium, aluminium, antimony, bismuth, barium and uranium are toxic and therefore non essential for higher animals. Presence of such heavy metals in the atmosphere, soil and water even in traces can cause serious health problems to man and animals particularly in elevated concentrations (Gupta & Gupta, 1998). Toxic heavy metals may disturb the normal functions of central nervous system, liver, lungs, heart, kidney and brain leading to hypertension, abdominal pain, skin eruptions, intestinal ulcer and different types of cancer (Huheey *et al*., 2000; Jarup, 2003; Sharma *et al*., 2009). Furthermore, consumption of heavy metal contaminated food can seriously deplete some essential nutrients in the body causing a decrease in immunological defenses, intrauterine growth retardation, impaired psycho-social behaviour and disabilities associated with malnutrition (Arora *et al*., 2008).

Numerous studies have linked the presence of heavy metals such as Pb and Cd to incidence of cognitive impairments especially in children (Weiss, 2000; Porterfield, 2000; Myers & Davidson, 2000; Koger *et al*., 2005). Lacatus *et al*. (1996) reported that soil and vegetables polluted with Pb and Cd in Copsa Mica and Baia Mare, Romania, significantly contributed to decreased human life expectancy within the affected areas reducing average age at death by 9–10 years. Turkdogan *et al*. (2002) suggested that the high prevalence of upper gastrointestinal cancer rates in the Van region of Turkey was related to the high concentration of heavy metals in soil, fruit and vegetables. Tricopoulos (1997) revealed carcinogenic effects of several heavy metals such as cadmium, iron, lead, mercury, zinc and nickel.

2.4.2 Sources of Heavy Metal Contaminants

The circulation and migration of metals in the natural environment are mainly related to such processes as rock decay, volcano eruptions, evaporation of oceans, forest fires and soil formation processes. Anthropogenic contamination of the environment by heavy metals include different branches of industry; the power industry, transport, municipal waste management, waste dumping sites, fertilizers and wastes used to fertilize soil (He *et al*., 2004). The heavy metals from these sources are dispersed in the environment leading to contamination of soil, water and air (He *et al*., 2004; Ho & El-Khaiary, 2009; Jamalia *et al*., 2009; Szyczewski *et al.*, 2009; Muhammad, 2009).

2.4.3 Routes of Exposure to Heavy Metal Contaminants

Human beings can be exposed to these metals through different paths such as air, water and food (Conti, 1997; Mclaughlin & Parker, 1999; Qiao-qiao *et al*., 2007; Kim *et al*., 2008; Hu *et al*., 2010). Dietary intake is the main route of exposure for most people to heavy metal contamination although inhalation can play an important role in very contaminated sites (Tripathi *et al*., 1997; Tu¨rkdogˇan *et al.*, 2002; Muchuweti *et al.,* 2006; Kachenko & Singh, 2006). Cultivation of crops for human or livestock consumption on contaminated soil can potentially lead to uptake and accumulation of trace metals in edible plant parts with a resulting risk to human and animal health when the produce is consumed (Gupta & Gupta, 1998; Ho & El-Khaiary, 2009).

2.4.4 Lead

Lead is a naturally occurring soft, bluish grey metal whose density is 11.342 g/cm^3 at 20 °C. It is the commonest of the heavy metals accounting for about 13 mg/kg of the earth’s crust. Several isotopes of Pb exist in nature in the following order of abundance: ^{208} Pb, ^{206} Pb, ^{207} Pb and ^{204} Pb (USDHHS, 1999). The melting point and boiling point of lead are 327.46 °C and 1749 °C respectively.

2.4.4.1 Main Sources of Exposure to Lead

The main source of Pb is from old Pb piping in the water distribution system. It can also be found in batteries, solder, ammunition, pigments, paint, ceramic glaze, hair dyes, fishing equipment, leaded gasoline from vehicle exhausts, mining, plumbing and coal burning (Lawrence, 2011; Brevik & Burgess, 2013). Cigarette smoke and pesticide residues are other sources (Lawrence, 2011). Pb is considered as the most significant heavy metal affecting vegetable crops (Kachenko & Singh, 2006).

2.4.4.2 Effects of Lead on Human Health

Lead is a non essential metal to human body; it is a toxic heavy metal even in trace amounts (Llobet *et al.,* 2003; Farr, 2004). Its recommended standard in leafy vegetables is 0.3 mg/kg (WHO/FAO, 2001). Lead is a commutative poison and a potential human carcinogen (Jarup, 2003; Bakare -Odunola, 2005; Szyczewski *et al*., 2009). Lead poisoning is associated with etiology of a number of diseases such as inhibition of the synthesis of haemoglobin, dysfunctions in the kidneys, joints and reproductive systems and cardiovascular system as well as acute and chronic damages to the central nervous system and peripheral nervous system (E.C., 2002; Jarup, 2003; Szyczewski *et al*., 2009; Brevik & Burgess, 2013). Lead is also known to induce renal tumours, reduce cognitive development and increase blood pressure (FDA, 2001; Ikem & Egiebor, 2005). Epidemiological studies show that exposure to Pb during the early stages of children's development is linked to a drop in intelligence quotient and that for each 10 µg /dl of blood Pb, intelligence quotient is reduced by at least 1-3 points (Canfield *et al*., 2003; Chen *et al*., 2005; Morgan, 2013). Other effects of Pb include: abdominal pain, adrenal insufficiency, anaemia, arthritis, arteriosclerosis, attention deficit, back problems, blindness, constipation, convulsions, deafness, depression, diabetes, dyslexia, epilepsy, fatigue, gout, impaired glycogen storage, hallucinations, hyperactivity, impotency, infertility, inflammation, learning disabilities, diminished libido, migraine headaches, multiple sclerosis, psychosis, thyroid imbalances and tooth decay (Lawrence, 2011).

2.4.5 Cadmium

Cadmium is a lustrous, silver white, ductile and very malleable metal. Its surface has a bluish tinge and the metal is soft enough to be cut with a knife. Its density is 8.7 g/cm^3 at 20 °C while the melting and boiling points are 321 °C and 767 °C respectively (Campbell, 2006). It is soluble in acids but not in alkalis.

2.4.5.1 Main Sources of Exposure to Cadmium

The main anthropogenic sources of Cd include mining, smelting, burning coal or garbage containing Cd, rechargeable batteries (nickel-cadmium batteries), pigments, solar cells, steel, metal plating and water pipes (WHO, 2000; Lawrence, 2011; Brevik & Burgess, 2013). Use of fertilizers, municipal sewage sludge, compost and contaminated water for irrigation can remarkably increase the Cd uptake into plant tissues (IPCS, 1992; Brevik & Burgess, 2013). Cigarette smoking is another source of Cd exposure (Jarup *et al.*, 1998; WHO, 2000). For non-smoking population, food and water is the most important source of Cd exposure (WHO, 1992). Cd just like lead is considered as the most significant heavy metal affecting vegetable crops (Kachenko & Singh, 2006).

2.4.5.2 Effects of Cadmium on Human Health

Cadmium is not essential to human body; there is no ‘safe exposure’ for the human body even at minute levels (Llobet *et al.*, 2003). The recommended standard of Cd in leafy vegetables is 0.02 mg/kg (WHO/FAO, 2001). Cd exposure to human beings may cause kidney damage, skeletal damage, irritation of the lungs and gastrointestinal tract, cancer of the lungs and prostate, abdominal pain and diarrhoea (WHO, 1992; Jarup *et al*., 1998; IOSHIC, 1999; FDA, 2001; Young, 2005; Ikem & Egiebor, 2005). The International Agency for Research on Cancer (IARC) has classified Cd and Cd compounds as carcinogenic to humans, meaning that there is sufficient evidence for their carcinogenicity in humans (IARC, 1993; Steenland & Boffetta, 2000; Brevik & Burgess, 2013). Several patients of lung cancer were found among workers in a United States Cd recovery facility (Stayner *et al.,* 1992). In Japan, Itai-itai disease; a bone and kidney disorder was associated with chronic Cd pollution of paddy water coming from the Jizu River (Kakar *et al.,* 2006). Studies in children and pregnant women are still limited but there is some evidence that elevated Cd exposure during pregnancy may affect a child’s motor skills and perception and that high Cd levels in the urine of school children are associated with a weakened immune system (Schoeters *et al.*, 2006). Other effects include hypertension, arthritis, diabetes, anaemia, arteriosclerosis, impaired bone healing, cardiovascular disease, cirrhosis, reduced fertility, hyperlipidemia, hypoglycemia, headaches, osteoporosis, schizophrenia and strokes (Lawrence, 2011).

2.4.6 Copper

Copper is a ductile, malleable, reddish-brown metallic element that is an excellent conductor of heat and electricity (HPA, 2010). Density of Cu is 8.9 g/cm^3 at 20 °C while the melting point and boiling point are 1083 °C and 2595 °C respectively.

2.4.6.1 Main Sources of Exposure to Copper

Due to heat and electrical conductivity of Cu as well as its resistance to corrosion, ductility and malleability, Cu has many industrial applications and is widely used in electrical wiring, switches, electroplating, plumbing pipes, coins, metal alloys and fireworks (HPA, 2010). The main sources of exposure of Cu to human beings include Cu water pipes, pesticides, swimming pools, intra-uterine devices, dental amalgams and nutritional supplements especially prenatal vitamins, birth control and weak adrenal glands among others (Lawrence, 2011). One may also be exposed to Cu by breathing air, eating food or drinking water containing Cu as well as through skin contact with soil, water or other Cu containing substances (Vitosh *et al*., 1994).

2.4.6.2 Effects of Copper on Human Health

Small amounts of Cu are necessary in diets to ensure good health for living organisms including human beings (Vitosh *et al*., 1994). However, if daily intake of 0.9 mg/day is not attained or exceeded deficiency and toxic effects are observed (FDA, 2001; Singh & Garg, 2006). The main problem associated with Cu is that if its concentration increases too sharply, the body's absorption of zinc will be impeded. Zinc deficiency contributes to infertility (Lawrence, 2011). Cu has also been associated with liver damage and kidney disease (MDH, 2006; Lawrence, 2011). Merck (2005) reported that copper is suspected to cause infant liver damages. Acute symptoms of excess Cu include salivation, epigastric pain, vomiting, diarrhea, stomach cramps, nausea, irritation of eyes and respiratory tract (Araya *et al*., 2001; HPA, 2010). Vomiting and diarrhoea usually prevent more serious manifestations of Cu toxicity that can include coma, shock, oliguria (dimished urine secretion), hemolytic anaemia, acute renal (kidney) failure with tubular damage, hepatic necrosis (liver cell death), vascular collapse and death. Exposure to skin can cause inflammation, itching and burns (HPA, 2010).

2.4.7 Zinc

Zinc is a lustrous bluish white metal. It is brittle and crystalline at ordinary temperatures but it becomes ductile and malleable when heated between 110 °C and 150 °C. Its density is 7.11 g/cm^3 at 20 °C. The melting and boiling points of Zn are 419.58 °C and 907 °C respectively.

2.4.7.1 Main Sources of Exposure to Zinc

Zn enters the air, water and soil as a result of both natural processes and human activities. Main sources of Zn to the environment are mining, purification of Zn, Pb and Cd ores, steel production, burning of coal and wastes. Levels of Zn in soil increases mainly from disposal of domestic waste water, Zn wastes from metal manufacturing industries and coal ash from electrical utilities. Sludge and fertilizers also contribute to increased levels of Zn in the soil (ATSDR, 2005). Other sources include corrosion and leaching of plumbing, water proofing products, anti-pest products, wood preservatives, deodorants and cosmetics, medicines and ointments, paints and pigments, printing inks and artist paints, colouring agents in various formulations and UV absorbent agent in various formulations (Lawrence, 2011).

2.4.7.2 Effects of Zinc on Human Health

Zn is an essential metal to human beings; it is extraordinarily useful in biological systems (Nriagu, 2007). However, beyond intake range of 8-11 mg/day deficiency and toxic effects are observed (FDA, 2001; Singh & Garg, 2006). The recommended standard of Zn in leafy vegetables is 99.40 mg/kg (WHO/FAO, 2001). Toxicity of Zn in human beings is minimal; its major effect is interference with Cu metabolism (Barone *et al*., 1998). Symptoms of an acute oral Zn dose may include tachycardia, vascular shock, dyspeptic nausea, vomiting, diarrhoea and damage of hepatic parenchyma (Salgueiro *et al.*, 2000; Bigdeli & Seilsepour, 2008). EPA currently classifies Zn and its compounds as carcinogenic. Similarly, Tricopoulos (1997) revealed carcinogenic effects of several heavy metals including Zn. The United States Food and Drug Administration (FDA) have stated that Zn damages nerve receptors in the nose which may cause anosmia. Reports of anosmia were also observed in the 1930s when Zn proportions were used in a failed attempt to prevent polio infections (Barceloux & Donald, 1999).

2.4.8 Iron

Fe is a heavy, malleable, ductile, magnetic and silver-white metallic element that readily rusts in moist air. Its density is 7.8 g/cm^3 at 20 °C while the melting and boiling points are 1536 ^oC and 2861 ^oC respectively. Fe is the fourth most abundant element in the Earth's crust and is mostly found as ions Fe^{2+} and Fe^{3+}. The most common ores of iron are hematite or ferric oxide ($Fe_2 O_3$); magnetite or iron oxide ($Fe_3 O_4$) and siderite or iron carbonate ($Fe CO_3$).

2.4.8.1 Main Sources of Exposure to Iron

Fe is the most used of all the metals because of its low cost and high strength. Its applications go from food containers to family cars, from screw drivers to washing machines, from cargo ships to paper staples. The major sources of exposure to iron are construction materials, drinking water pipes, pigments in paints and plastics. Other compounds of Fe are used as food colour and for treatment of Fe deficiency in humans. Various Fe salts are used as coagulants in water treatment (SACN, 2010).

2.4.8.2 Effects of Iron on Human Health

Fe is an essential metal to human body; it is vital to biological processes such as transportation of oxygen in the body. However, intake beyond 18 mg/day gives rise to toxic effects (FDA, 2001; Singh & Garg, 2006). The recommended standard of Fe in leafy vegetables is 425 mg/kg (WHO/FAO, 2001). Fe may cause conjunctivitis, choroiditis and retinitis if it contacts and remains in the tissues. The large amounts of ingested iron can cause excessive levels of iron in the blood which react with peroxides to produce free radicals, which are highly reactive and can damage DNA, proteins, lipids and other cellular components (Clifford, 2010). Acute high doses of iron can also damage the intestinal mucosa and cause systemic shock and death. Fe is also known to be carcinogenic in nature; Tricopoulos (1997) revealed carcinogenic effects of several heavy metals including Fe. Fe supplementation may favour infectious pathogens by providing them with a supply of Fe for their growth and replication (SACN, 2010).

2.4.9 Nickel

Ni is a lustrous white, hard, ductile and ferromagnetic element whose density is 8.9 g/cm^3 at 20 °C. Its melting point and boiling point are 1453 ^{0}C and 2913 ^{0}C respectively. It occurs naturally in five isotopic forms: ^{58}Ni (67.8%), ^{60}Ni (26.2%), ^{61}Ni (1.2%), ^{62}Ni (3.7%) and ^{64}Ni (1.2%). Ni usually has two valence electrons but oxidation states of +1, +3 or +4 may also exist (WHO, 2005).

2.4.9.1 Main Sources of Exposure to Nickel

Common uses of Ni include production of stainless steel and other corrosion resistant metals containing Ni. Other products which contain Ni include rechargeable (Ni-Cd) batteries, coins, welding rods and wires, electronic or computer equipment and pigments for paints or ceramics. Ni is also used in electroplating, electroforming and sintered metal coatings (WHO, 2005). The major sources of Ni contamination in the soil are metal plating industries, combustion of fossil fuels and Ni mining (Khodadoust *et al.*, 2004). It is also found in hydrogenated oils (margarine, commercial peanut butter) shellfish and cigarette smoke (Lawrence, 2011).

2.4.9.2 Effects of Nickel on Human Health

The recommended standard of Ni in leafy vegetables is 67 mg/kg (WHO/FAO, 2001). Many harmful effects of Ni are due to its interference with metabolism of essential metals such as Fe (II), Mn (II), Ca (II), Zn (II), Cu (II) or Mg (II) which can suppress or modify the toxic and carcinogenic effects of Ni. The toxic functions of Ni probably result primarily from its ability to replace other metal ions in enzymes and proteins or to bind to cellular compounds containing O-, S- and N-atoms which are then inhibited (Scott-Fordsmand, 1997). Exposure to Ni leads to cancer (oral and intestinal). Its carcinogenicity has been reported by the National Toxicology Program (NTP), the International Agency for Research on Cancer (IARC) and in a research of Tricopoulos (1997). Ni is also known to be a ubiquitous metal frequently responsible for allergic skin reactions and has been reported to be one of the most common causes of allergic contact dermatitis or asthma as reflected by positive dermal patch tests (Nielsen, 1999; Kitaura *et al.*, 2003; Cavani, 2005). In the year 2008, Ni was voted allergen of the year by the American Contact Dermatitis Society (Kornick & Zug, 2008).

2.5 Transfer Factors of Heavy Metals from Soil to Vegetables

Transfer factor of heavy metals is the ratio of concentration of heavy metals in a plant to the concentration in soil. It signifies the amount of heavy metals in the soil that end up in the vegetable crop (Smith, 1996).

2.6 Coliform Bacteria

Coliform bacteria are a collection of relatively harmless microorganisms that live in large numbers in soil, plants and in intestines of warm-blooded animals (BEH, 2004). Most coliform bacteria are harmless, however, the presence of coliform bacteria especially faecal coliform and *E. coli* in food indicate faecal contamination, presence of potential pathogens, food spoilage and unsanitary food processing conditions, therefore coliform bacteria are considered as “indicator organisms” (Geldreich, 1996; EPA, 2002; WHO, 2004). Saxena and Frost (1992) and Kwashie (2009) reported that the presence of coliform bacteria indicates the presence of pathogenic organisms and other disease causing organisms such as those that cause typhoid, dysentery, hepatitis A, cholera, fever, tetanus and worm infections (round worm, whipworm and tapeworm) among others. Thus the presence of coliform bacteria in food stuffs should alert the person responsible to take precautionary action.

Fresh vegetables carry natural non pathogenic microorganisms but during growth, harvesting, transportation and further handling, the produce is contaminated with pathogens from animal and human wastes (Brandl, 2006; Tyler & Triplett, 2008). The use of untreated sewage wastewater across urban and rural cities has increased with water scarcity and the rising cost of artificial fertilizer (Kutto *et al.*, 2012). When such water is used in agriculture; food crops, farmers and consumers of the food crops risk absorbing disease causing microorganisms. An overview developed by Hussein *et al.* (2001) on the potential benefits and risks arising from the use of wastewater in agriculture indicated that wastewater has the potential to cause diseases because it contains bacteria, viruses and parasites. Fattal *et al.* (2004) estimated that the global annual risk of contracting infectious diseases such as typhoid, fever, rotavirus infection, cholera and hepatitis A from eating raw vegetables irrigated with untreated wastewater is in the range of 5-15 %.

Disease causing organisms in food crops can be destroyed by cooking food substances although some are likely to be taken through consumption of raw vegetables. Report from Beuchat (1996) showed that raw vegetables may harbour potential food borne pathogens and should be avoided as much as possible. Most of the reported outbreaks of gastrointestinal disease linked to the fresh produce have been associated with bacterial contamination particularly with members of the *Enterobacteriaceae* family (Tauxe, 1997; Sivapalasingam *et al.*, 2004; Hamilton *et al.*, 2006; DuPont, 2007; Tyler & Triplett, 2008).

2.6.1 Sources of Pathogens in Vegetables

Fruits and vegetables can become contaminated through various routes taken during pre-harvest, harvest and post harvest season. According to Andoh (2006), the main routes of pathogenic contamination to vegetables during pre harvest include: contamination of irrigation water by faeces, poor personal hygiene practices among handlers of crops and contact with contaminated soil or faeces of wild animals.

Figure 2.1 summarizes the main routes of pathogenic contamination to vegetables by Beuchat (1996).

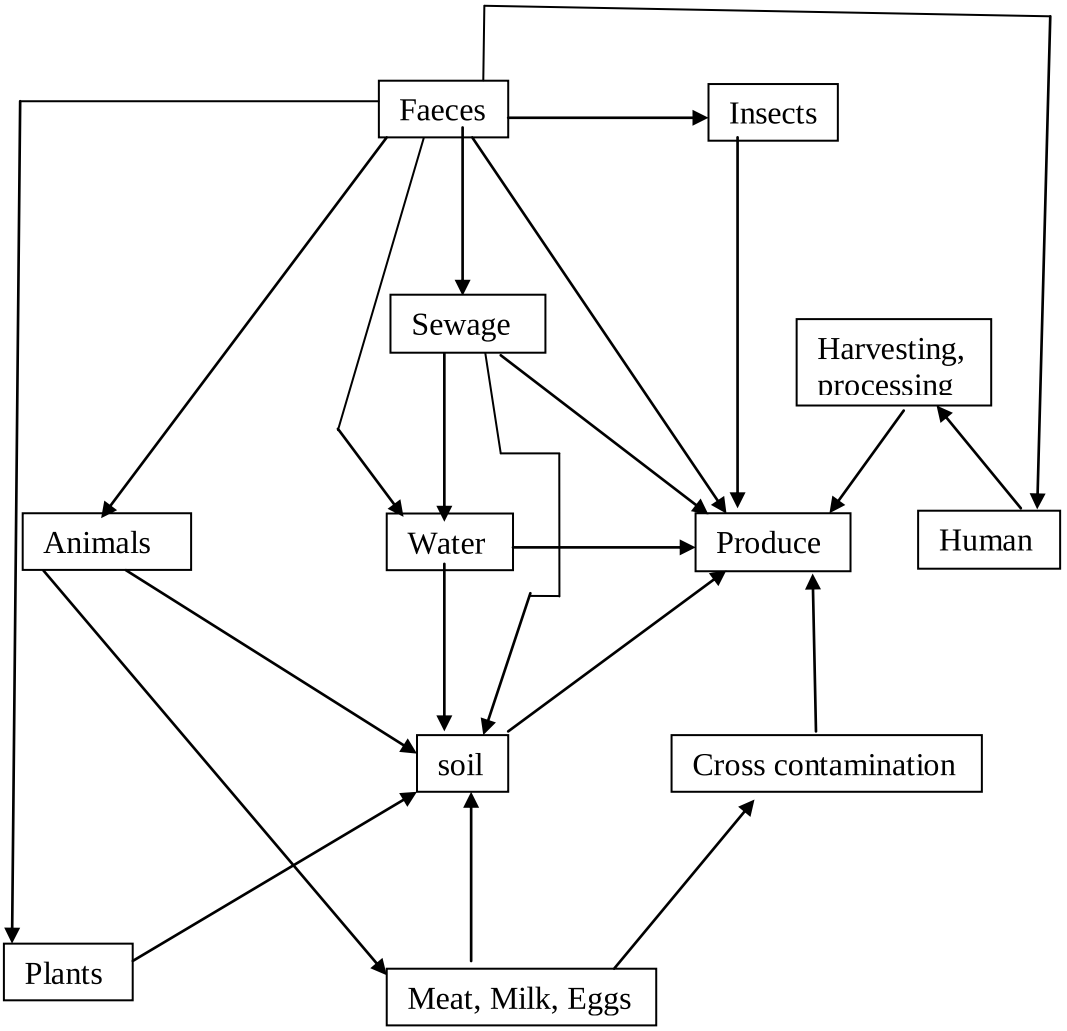

Figure 2.1: Main routes of pathogenic contamination to vegetables

(Source: Beuchat, 1996).

2.6.2 Classification of Coliform Bacteria

Coliform bacteria are described and grouped based on their common origin or characteristics as either total coliform or faecal coliform (WSIS, 2007). Total coliform refers to a large group of gram-negative, rod-shaped bacteria that share several characteristics. The group includes thermo tolerant coliform and bacteria of faecal origin as well as some bacteria that may be isolated from environmental sources. The presence of total coliform may not indicate faecal contamination; it might be caused by soil, organic matter or by conditions suitable for the growth of other types of coliform (Bartram & Pedley, 1996). However, if total coliform contamination can enter the system, there may be a way for other pathogens to enter the system. Therefore, it is important to determine the source and resolve the problem if total coliform is identified in food stuffs.

Faecal coliform bacteria are a sub-group of the total coliform group. They appear in great quantities in the intestines and faeces of people and animals. The presence of faecal coliform often indicate recent faecal contamination by human sewage or animal droppings and could contain pathogenic organisms such as bacteria, viruses and other disease causing organisms (Selecky, 2007). Faecal pathogens mainly cause symptoms like diarrhoea, vomiting, stomach cramps and fever (Launokorpi, 2007).

E. coli is a subgroup of the faecal coliform group. Most *E. coli* are harmless and are found in great quantities in the intestines of people and other warm-blooded animals. The presence of *E. coli* strains almost always indicate recent faecal contamination meaning that there is a greater risk that pathogens are present. *E. coli* outbreaks have been related to food contamination caused by a specific strain of *E. coli* known as *E.*

coli 0157:H7 which can cause serious illness such as stomach upset, urinary and respiratory ailments, diarrhoea and food poisoning (Wagner, 2008; Kutto *et al.*, 2012).

2.7 Analytical Techniques

Analytical techniques employed in the analysis of quality of food products are discussed below.

2.7.1 Atomic Absorption Spectroscopy (AAS)

It works on the principle that certain elements absorb certain wavelengths and this level of absorption is characteristic of each element. Also on principle that electrons in atoms can only exist in particular energy levels and when an electron moves to a higher energy level, electromagnetic radiation of a particular frequency is absorbed. Because of this, it’s possible to measure the concentration of certain elements in a sample depending on how much of a specific wavelength is absorbed. AAS is a form of quantitative analysis as opposed to a qualitative analysis, as the element being tested must be known. This is because a wavelength must be emitted which is specific to the element being tested. This also allows for an individual element to be analyzed even if other elements are present in a sample. Popularity of AAS in quantitative analysis of elements is not surprising due to the high sensitivity and selectivity of the technique.

Moreover, the technique is characterized by the low detection limit and high precision (Szyczewski *et al.*, 2009). In AAS, the sample is atomized then a beam of electromagnetic radiation is passed through the vapourized sample. The wavelength at which absorption occurs is characteristic of the element and the degree of absorption is the function of concentration of atoms in the vapour; the greater the number of atoms in the sample, the more radiation is absorbed.

The atomic absorption spectrophotometer needs the following three components: a light source, a sample cell to produce gaseous atoms and a means of measuring the specific light absorbed. Hollow cathode lamp emits the atomic line spectrum of the element to be determined. The monochromator isolates the desired resonance line from the spectrum emitted by the hollow cathode lamp. A detector measures the intensity of the incident light and generates an electrical signal proportional to the intensity. The electrical signals are displayed on the read out as concentration of trace element that is being analysed.

Figure 2.2 gives schematic representation of instrumentation of Atomic Absorption Spectroscopy.

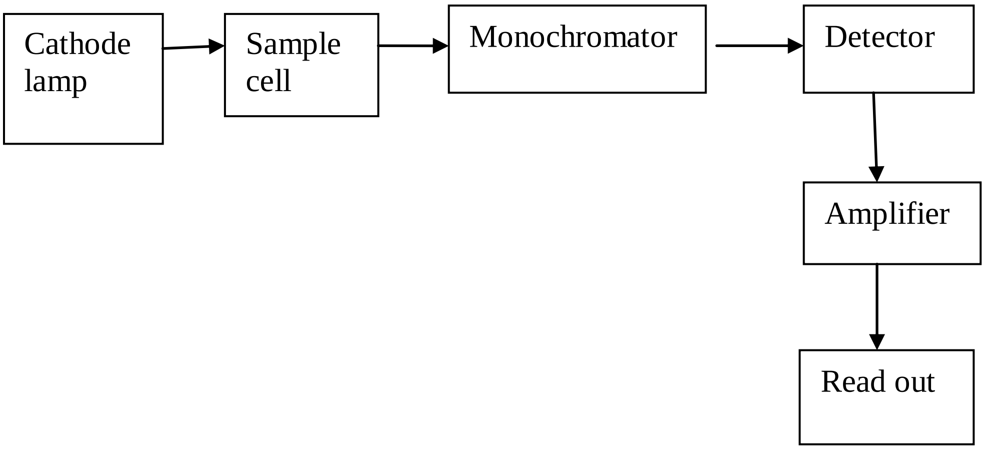

Figure 2.2: Schematic representation of instrumentation of atomic absorption spectroscopy (Source: Author, 2015).

The first step in the AAS process is to determine the element to be tested in the sample and the suitable hollow cathode lamp must be placed in the spectrophotometer. Each element absorbs different wavelengths and so a separate lamp is needed for each element. The sample is then fed into the flame with the assistance of a nebulizer, which takes the test solution and vapourises it thus converting it into atoms. The hollow cathode lamp emits radiation and as the light passes through the flame, some of it is absorbed by the vapourised element. The light passes into a monochromator then to a detector. The light that reaches the detector is measured and compared to the intensity of the light that hit the detector when the sample was not present. The data processor then calculates the results obtained by the detector and the amount that was absorbed is displayed on the screen as concentration of trace element that was being analysed. Figure 2.3 gives a representation of absorption of radiations.

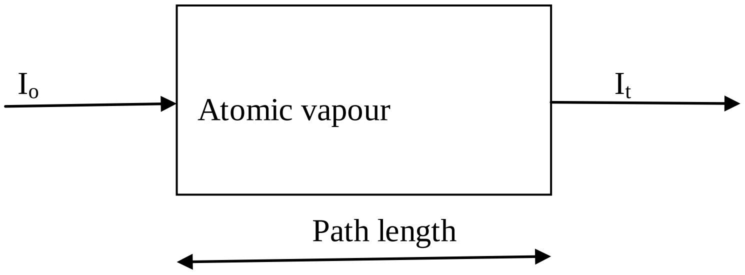

Figure 2.3: Schematic representation of light absorption (Source: Author, 2015).

Where I_o is the intensity of the radiations from the cathode lamp and

I_t is the intensity of the radiations reaching the detector after some radiations have been absorbed by the atomic vapour.

2.7.2 Multiple Tube Fermentation Technique

The technique consists of three distinct phases: presumptive phase, confirmed phase and complete test phase. According to Bartram & Pedley (1996), it is customary to report the results of the multiple fermentation tube tests for coliform as the most probable number (MPN) index. Separate analyses are usually conducted on three portions of each of three or five serial dilutions of a sample. The individual portions are used to inoculate tubes of culture medium that are then incubated at a standard temperature for a standard period of time. The presence of coliform is indicated by turbidity in the culture medium, by a pH change and/or by the presence of gas. The MPN index is determined by comparing the pattern of positive results at each dilution with statistical tables. The tabulated value is reported as MPN per 100 ml of sample.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Sample Area and Sampling

The sample area was the old Eldoret municipal dumpsite located to the west of Eldoret town; approximately 4 kilometers away from the city centre and occupies about five acres of land. Vegetables are grown in about three acres of the dumpsite land which is surrounded by the Huruma settlement scheme and the Eldoret sewage treatment plant. Sosiani River passes between the dumpsite and the sewage treatment plant. Dumping at the site was unrestricted; industrial, agricultural, domestic and medical wastes among others were deposited into the dumpsite. The dumpsite is also uncovered, unlined and open; therefore animals have access to it. Figure 3.1 provides the map of Kenya giving location of Eldoret town.

Figure 3.1: Map of Kenya showing location of Eldoret town

(Source: Google maps; accessed 15/9/2013)

Figure 3.2 gives map of Eldoret town showing location of the old Eldoret municipal dumpsite while Plate 3.1 gives photograph of the old Eldoret municipal dumpsite.

Figure 3.2: Map of Eldoret town showing location of the old Eldoret municipal dumpsite (Source: Google maps; accessed 15/9/2013)

Plate 3.1: Slope of the Old Eldoret municipal Dumpsite hanging towards Sosiani River (Source: Author, 2015).

Sampling was done between the months of July and December, 2013 to cater for both wet and dry seasons, respectively. Soil and edible portions of spinach, kales and bulb onions were collected from the vegetable farms of the old Eldoret municipal dumpsite near Eldoret sewage. Seven sites which were about 50 m apart were identified for sampling of kales and spinach while nine sample sites were identified for onions. Vegetable samples were collected randomly from the identified sample sites and put into clean new polythene bags, labeled and transported to the laboratory. Edible portions of vegetables were used in this research because edible portions come into direct contact with animals and human beings during consumption. Soil samples were collected from three different points in each of the identified sample sites in a triangular pattern at a depth of between 0-15 cm after which they were put into clean new polythene bags, labeled and transported to the laboratory. The 0-15 cm depth was considered to represent the plough layer and average root zone for nutrients uptake and heavy metal burden by plants (Eddy *et al*., 2006; Odai *et al*., 2008). For analysis of coliform bacteria, soil and edible portions of bulb onions were collected randomly from identified sample sites into sterile plastic bags and labeled. The samples were then transported to the laboratory for analysis.

3.2 Analysis of Heavy Metal Contaminants

Analysis of heavy metal contaminants was done using AAS according to the standard procedure of Okalebo *et al*. (2002) with few modifications. Concentrations of heavy metal contaminants in each sample were determined directly from a Varian Spectra 200 Atomic Absorption Spectrophotometer. Air/ Acetylene flame was used with flow rate of 13.50 L/min and 2.00 L/min, respectively. Calibration of the instrument was done using a three point calibration curve (Appendix I) while checking calibration after every 5-10 samples.

A standard mixture of hydrogen peroxide, lithium sulphate, sulphuric acid and selenium powder was used for digestion. The hydrogen peroxide oxidised organic matter while selenium powder acted as a catalyst for the process and sulphuric acid completed the digestion at elevated temperatures. The mixture was prepared by accurately weighing 0.42 g of selenium powder then added to 14 g of lithium sulphate. A 350 ml of 30% hydrogen peroxide was then added to the mixture and mixed well after which 420 ml of concentrated sulphuric acid was slowly added while cooling the mixture in an ice bath.

3.2.1 Preparation of Vegetable Samples

The vegetable samples were placed under running tap water to wash off soil particles and any other debris then rinsed with distilled water. The samples were chopped into small pieces then air-dried for 2 days after which they were dried in an oven at 60 ºC for 24 hours. The dry samples were crushed using a mortar and pestle. The resulting powder was digested by weighing 0.3 g of oven dried ground plant sample into a labeled digestion tube containing 4.4 ml of digestion mixture. The samples together with two reagent blanks were digested at 360 ºC for 2 hours till the solution became colourless. The contents were allowed to cool after which about 25 ml of distilled water was added and mixed well until no more sediment dissolved then filtered using a 0.45 µm filter paper. The filtrate was made up to 50 ml using distilled water, mixed well then allowed to settle so that a clear solution could be taken from top for analysis.

3.2.2 Preparation of Soil Samples

The soil samples were oven dried for 72 hours at 80 °C after which the samples were crushed using a pestle and a mortar then sieved. A 0.3 g of oven dried ground soil sample was transferred into a labeled, dry digestion tube after which 4.4 ml of digestion mixture was added to each tube and to two reagent blanks. The samples together with the reagent blanks were digested at 360 ºC for 2 hours till the solution became colourless. The contents were allowed to cool after which about 25 ml distilled water was added and mixed well until no more sediment dissolved then filtered using a 0.45 µm filter paper. The filtrate was made up to 50 ml using distilled water, mixed well then allowed to settle so that a clear solution could be taken from top for analysis.

3.3 Preparation of Stock and Working Solutions

3.3.1 Preparation of Stock and Working Solution of Lead

Stock solution of Pb^{2+} was prepared by dissolving 1.0 g of Pb in 20 ml of 1:1 nitric acid to water mixture then diluted to 1 litre to give 1000 ppm. A working solution of 100 ppm was prepared by pipetting 10 ml from 1000 ppm stock solution into 100 ml volumetric flask then made to the mark using distilled water. Standard solutions of 5 ppm, 10 ppm and 15 ppm were prepared by pipetting 5 ml, 10 ml and 15 ml, respectively of the working solution into 100 ml volumetric flask then made to the mark using distilled water.

3.3.2 Preparation of Stock and Working Solution of Cadmium

Stock solution of Cd^{2+} was prepared by dissolving 1.0 g of Cd in 10 ml of 1:1 nitric acid to water mixture then diluted to 1 litre to give 1000 ppm of Cd. A working solution of 100 ppm was prepared by pipetting 10 ml from 1000 ppm stock solution into 100 ml volumetric flask then made to the mark using distilled water. Standard solutions of 1 ppm, 2 ppm and 3 ppm were prepared by pipetting 1 ml, 2 ml and 3 ml, respectively of the working solution into 100 ml volumetric flask then made to the mark using distilled water.

3.3.3 Preparation of Stock and Working Solution of Copper

Stock solution of Cu^{2+} was prepared by dissolving 1.0 g of Cu in 10 ml of 1:1 nitric acid to water mixture then diluted to 1 litre to give 1000 ppm of Cu. A working solution of 100 ppm was prepared by pipetting 10 ml from 1000 ppm stock solution into 100 ml volumetric flask then made to the mark using distilled water. Standard solutions of 2 ppm, 5 ppm and 10 ppm were prepared by pipetting 2 ml, 5 ml and 10 ml, respectively of the working solution into 100 ml volumetric flask then made to the mark using distilled water.

3.3.4 Preparation of Stock and Working Solution of Zinc

Stock solution of Zn^{2+} was prepared by dissolving 1.0 g of zinc in 40 ml of 1:1 hydrochloric acid to water mixture then diluted to 1 litre to give 1000 ppm of Zn. A working solution of 100 ppm was prepared by pipetting 10 ml from 1000 ppm stock solution into 100 ml volumetric flask then made to the mark using distilled water. Standard solutions of 0.5 ppm, 1.0 ppm and 1.5 ppm were prepared by pipetting 0.5 ml, 1.0 ml and 1.5 ml, respectively of the working solution into 100 ml volumetric flask then made to the mark using distilled water.

3.3.5 Preparation of Stock and Working Solution of Iron

Stock solution of Fe^{2+} was prepared by dissolving 1.0 g of iron in 20 ml of 1:1 hydrochloric acid to water mixture then diluted to 1 litre to give 1000 ppm of Fe. A working solution of 100 ppm was prepared by pipetting 10 ml from 1000 ppm stock solution into 100 ml volumetric flask then made to the mark using distilled water. Standard solutions of 5 ppm, 10 ppm and 15 ppm were prepared by pipetting 5 ml, 10 ml and 15 ml, respectively of the working solution into 100 ml volumetric flask then made to the mark using distilled water.

3.3.6 Preparation of Stock and Working Solution of Nickel

Stock solution of Ni^{2+} was prepared by dissolving 1.0 g of nickel in 10 ml of 1:1 nitric acid to water mixture then diluted to 1 litre to give 1000 ppm of Ni. A working solution of 100 ppm was prepared by pipetting 10 ml from 1000 ppm stock solution into 100 ml volumetric flask then made to the mark using distilled water. Standard solutions of 5 ppm, 10 ppm and 15 ppm were prepared by pipetting 5 ml, 10 ml and 15 ml, respectively of the working solution into 100 ml volumetric flask then made to the mark using distilled water.

3.4 Transfer Factors of Heavy Metals from Soil to Vegetables

In this study, transfer factors were calculated to understand the extent of risk and associated hazard due to ingestion of heavy metal consequent upon its accumulation in edible portion of vegetables. The heavy metal transfer factor from soil to the vegetables was calculated as follows:

Transfer factor = metal content in plant (mg/kg)/ metal content in soil (mg/kg)

3.5 Analysis of Coliform Bacteria

Analysis of coliform bacteria in bulb onions and soil samples was done using standard multiple tube fermentation technique according to Bartram & Pedley (1996); APHA (2001) with few modification.

In the presumptive phase, lactose broth was used as a culture medium. The medium was prepared by suspending 13 g of lactose broth in 1000 ml distilled water, mixed well then heated to dissolve completely. The medium was distributed into universal bottles containing inverted Durham tubes then sterilized by autoclaving at 121 ºC for

15 minutes after which they were allowed to cool. The universal bottles were then arranged in rows of three and each bottle was inoculated in a set of three replicate bottles in increasing sample dilution (10^{1}, 10^{-0} and 10^{-1}) after which they were inverted and swirled several times to thoroughly mix the sample with the nutrient medium and to ensure that the Durham tubes were full of liquid with no air bubbles then incubated at 35 ºC. After one hour, the bottles were inverted to remove trapped air in the Durham tubes and the caps were loosened slightly before being returned to the incubator. The inoculated bottles were incubated for 24 ± 2 hrs then swirled gently to examine for growth, gas and acidic reaction (shades of yellow colour). In some universal bottles where no gas production was evident, the universal bottles were reincubated and reexamined at the end of 48 ± 3 hrs. The presence or absence of growth, gas and acidic reaction was recorded. Presence of an acidic reaction, growth or gas in the Durham tubes within 48 ± 3 hrs constituted a positive presumptive test. Sample bottles showing positive response in presumptive test are provided in Appendix II.

Brilliant green lactose bile broth was used as a culture medium in the confirmed phase. The medium was prepared by suspending 40.01 g of brilliant green lactose bile broth in 1000 ml distilled water and mixed well to completely dissolve. The medium was dispensed into universal bottles containing inverted Durham tubes then sterilized by autoclaving at 121 ºC for 15 minutes after which they were allowed to cool. The universal bottles giving positive response in the presumptive phase were shaken gently to re-suspend the organisms after which three loopfuls of culture were transferred using a sterile loop of 3.5 mm in diameter to universal bottles containing brilliant green lactose bile broth. The inoculated brilliant green lactose bile broth bottles were inverted and swirled to remove trapped air in the Durham tubes then incubated at 35 ºC. After one hour, the bottles were inverted to remove trapped air in the Durham tubes and the caps were loosened slightly before being returned to the incubator. Formation of gas of any amount in the inverted Durham tubes of the brilliant green lactose bile broth fermentation bottles at any time within 48 ±3 hrs constituted a positive confirmed phase. Sample bottles showing positive response in confirmed phase are provided in Appendix III. Most probable number of total coliform was determined from MPN tables (APHA, 2001).

In the elevated-temperature test, *E. coli* broth was used as a culture medium. The medium was prepared by suspending 37.0 g of *E. coli* broth in 1000 ml distilled water and mixed well to dissolve. The medium was dispensed to universal bottles containing inverted Durham tubes, sterilized by autoclaving at 121 ºC for 15 minutes then allowed to cool. Elevated-temperature test for distinguishing organisms of the total coliform group that also belong to the faecal coliform group was used. All presumptive fermentation universal bottles showing any amount of gas, growth or acidity within 48 hrs of incubation were shaken gently then subjected to the faecal coliform test. A sterile loop with diameter of 3.5 mm was used to transfer culture to a universal bottle containing *E. coli* broth. The universal bottles were inverted and swirled several times to thoroughly mix the sample with the nutrient medium and ensure that the Durham tubes were full of liquid with no air bubbles then incubated at 44.5 ºC. After one hour, the bottles were inverted again to remove trapped air in the Durham tubes and the caps were loosened slightly before being returned to the incubator. Gas production with growth in an *E. coli* broth culture within 24 ± 2 hrs or less constituted a positive faecal coliform test. Sample bottles showing positive response in faecal coliform test are provided in Appendix IV. Most probable number of faecal coliform was determined from MPN tables (APHA, 2001).

Eosin methylene blue agar was used to determine the presence of *E. coli*. The agar was prepared by suspending 37.46 g of Eosin methylene blue agar in 1000 ml distilled water and mixed well to dissolve. Culture was transferred from all the positive presumptive tubes that also gave a positive response in faecal test and cultured by streaking on EMB agar plates then incubated at 35 °C for 24 hours. Positive plates contained typical colonies with green metallic sheen.

3.6 Data Analysis and Presentation

All data were analysed using descriptive methods. Statistical analysis was done using SPSS version 20.0. Comparison of mean concentration of heavy metal contaminants in soil and vegetables was done using t-test while comparison of mean concentration of heavy metal contaminants in vegetables during dry and wet seasons was done using paired t-test. In all the analysis, significance was considered at $p \leq 0.05$. All data were summarized and presented using tables and bar charts.

CHAPTER FOUR

RESULTS

4.1 Mean Concentrations of Heavy Metals in Soil

Levels of heavy metal contaminants were compared with the acceptable standards of WHO/FAO (2001) and SPCR (2001). Comparison of levels of heavy metals in soil with the acceptable standard of SPCR (2001) is provided in table 4.1 while comparison of mean concentration of the heavy metal contaminants in soil during wet and dry seasons is provided in Figure 4.1.

Table 4.1: Mean concentrations of heavy metals in soil for dry and wet seasons

Heavy metals in soil	No. of samples	Minimum	Maximum	Mean (mg/kg)	Std. Deviation	SPCR (2001)
Cd during dry season	7	0.0540	0.0850	0.0689	± 0.0110	1.0000
Cd during wet season	7	0.0530	0.0750	0.0646	± 0.0068	1.0000
Cu during dry season	7	0.0570	1.5790	0.4381	± 0.5280	50.0000
Cu during wet season	7	0.0410	1.2140	0.3267	± 0.4168	50.0000
Fe during dry season	7	27.6100	91.2200	58.5100	± 19.7196	150.0000
Fe during wet season	7	70.9000	232.0500	144.5571	± 56.9054	150.0000
Pb during dry season	7	1.1500	2.9000	1.7357	± 0.5659	50.0000
Pb during wet season	7	0.8700	2.8000	1.5257	± 0.6650	50.0000
Zn during dry season	7	1.2345	4.2156	2.6762	± 1.1229	150.0000
Zn during wet season	7	0.3991	9.3850	1.9392	± 3.2936	150.0000

The heavy metals analysed in this study were available in soil with mean concentration ranging from 0.06 mg/kg to 144.56 mg/kg. Levels of all the heavy metals in soil were found to be within accepted standard set by WHO/FAO (2001) and SPCR (2001). Mean concentration of iron in soil was the highest while that of cadmium was the lowest. Level of iron in the soil was significantly high during wet season than in dry season while concentrations of cadmium, copper, lead and zinc were higher during dry season than wet season as shown in Figure 4.1. The difference in levels of cadmium, copper, zinc and iron during dry and wet season were however not significant (Appendix V).

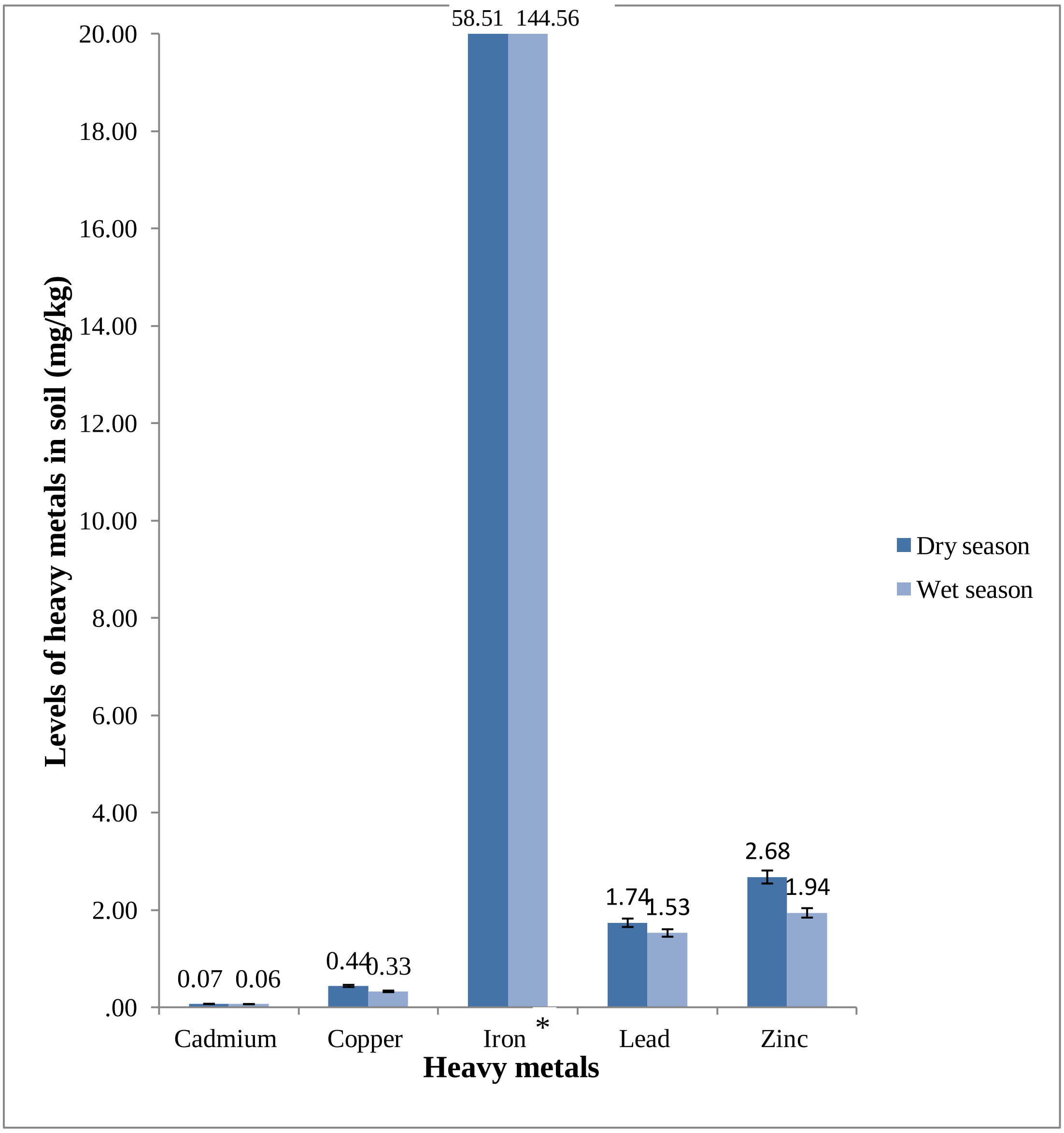

Figure 4.1: Levels of heavy metals in soil

* Concentration of iron was too high to be captured in the chart.

4.2 Mean Concentrations of Heavy Metals in Vegetables

Concentrations of heavy metal contaminants in vegetables were analysed using atomic absorption spectroscopy. The mean concentrations of heavy metal contaminants were compared with acceptable standard of WHO/FAO (2001).

4.2.1 Mean Concentrations of Lead in Kales, Spinach and Onions

Table 4.2: Mean concentrations of lead in kales, spinach and onions from different sites

Sample sites	Lead in kales (mg/kg)		Lead in spinach (mg/kg)		Lead in onion mg/kg
	Dry season	Wet season	Dry season	Wet season	
1	1.3600	2.0800	1.0600	1.4800	1.2400
2	1.3500	2.0000	1.0000	0.3900	1.3600
3	1.3800	2.2400	1.0200	2.7200	1.2200
4	1.1900	2.0400	0.9200	2.6000	1.3900
5	1.1900	2.1100	0.8000	1.4100	1.3700
6	1.1400	1.9900	1.3100	1.4000	1.3100
7	1.0900	2.0300	1.2900	2.0300	1.2000
8					1.4100
9					1.0500

Table 4.3: Mean concentrations of lead in kales, spinach and onions for dry and wet seasons

Lead in vegetables	No. of samples	Mean	Standard deviation
Pb in kales during dry season	7	1.2429	± 0.1180
Pb in kales during wet season	7	2.0700	± 0.0860
Pb in onions	9	0.7044	± 0.0566
Pb in spinach during dry season	7	1.0571	± 0.1861
Pb in spinach during wet season	7	1.7186	± 0.8058

Mean concentrations of lead in kales, spinach and onions for dry and wet seasons ranged from 0.7 mg/kg to 2.1 mg/kg. Mean concentration of lead was higher in kales followed by spinach then onions. Levels of lead in kales were significantly higher during wet season than dry season (Appendix VI).

Table 4.4: Comparison of levels of lead in kales, spinach and onions with acceptable standard of WHO/FAO

	WHO/FAO accepted value < 0.3 mg/kg					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Pb in Kales during dry season	21.1410	6	0.0000	0.9429	0.8337	1.0520
Pb in Kales during wet season	54.4390	6	0.0000	1.7700	1.6904	1.8496
Pb in onions	21.4400	8	0.0000	0.4044	0.3609	0.4479
Pb in spinach during dry season	10.7660	6	0.0000	0.7571	0.5850	0.9292
Pb in spinach during wet season	4.6580	6	0.0030	1.4186	0.6734	2.1638

Levels of lead in kales, spinach and onions during dry and wet seasons were significantly higher ($p<0.05$) than the accepted standard of 0.3 mg/kg (WHO/FAO, 2001) and standard of 0.2 mg/kg according to Luo *et al*. (2011).

4.2.2 Mean Concentrations of Cadmium in Kales, Spinach and Onions

Table 4.5: Mean concentrations of cadmium in kales, spinach and onions from different sites

Sample sites	Cadmium in kales (mg/kg)		Cadmium in spinach (mg/kg)		Cadmium in onion (mg/kg)
	Dry season	Wet season	Dry season	Wet season	
1	0.1070	0.1030	0.079	0.0680	0.3350
2	0.1030	0.0970	0.0720	0.0630	0.3710
3	0.0970	0.1100	0.0880	0.0790	0.3640
4	0.1010	0.1040	0.0890	0.0880	0.3650
5	0.1150	0.1150	0.0950	0.0900	0.3310
6	0.1170	0.1170	0.1190	0.0950	0.3250
7	0.1450	0.1150	0.1110	0.1190	0.3450
8					0.3360
9					0.3390

Table 4.6: Mean concentrations of cadmium in kales, spinach and onion for dry and wet seasons

Cadmium in vegetables	Number of samples	Mean conc.	Std. Deviation
Cd in kales during dry season	7	0.1121	± 0.0162
Cd in kales during wet season	7	0.1087	± 0.0075
Cd in onions	9	0.3457	± 0.0168
Cd in spinach during dry season	7	0.0933	± 0.0167
Cd in spinach during wet season	7	0.0860	± 0.0187

Mean concentrations of cadmium in kales, spinach and onions for dry and wet seasons ranged from 0.08 mg/kg to 0.35 mg/kg. The mean concentration of cadmium was higher in onions followed by kales then spinach.

Table 4.7: Comparison of levels of cadmium in kales, onions and spinach with WHO/FAO acceptable standard

	WHO/FAO (2001) of < 0.02 mg/kg					
	T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Cd in kales during dry season	15.0480	6	0.0000	0.0921	0.0772	0.1071
Cd in kales during wet season	31.1150	6	0.0000	0.0887	0.0817	0.0957
Cd in spinach during dry season	11.5830	6	0.0000	0.0733	0.0578	0.0888
Cd in spinach during wet season	9.3520	6	0.0000	0.0660	0.0487	0.0833

Levels of cadmium in kales, onions and spinach were significantly higher ($p<0.001$) than the accepted standard of 0.02 mg/kg (WHO/FAO, 2001) and standard of 0.05 mg/kg used by Luo *et al*. (2011).

4.2.3 Mean Concentrations of Copper in Kales, Spinach and Onions

Table 4.8: Mean concentrations of copper in kales, spinach and onions from different sites

	Copper in kales (mg/kg)		Copper in spinach (mg/kg)		Copper in onions (mg/kg)
Sample sites	Dry season	Wet season	Dry season	Wet season	
1	0.1330	0.1260	0.0820	0.0740	0.1320
2	0.1290	0.0870	0.0840	0.0820	0.1120
3	0.0900	0.0860	0.1190	0.1230	0.1080
4	0.0860	0.0800	0.1190	0.1140	0.1180
5	0.0850	0.0760	0.1180	0.1060	0.1000
6	0.0990	0.0940	0.1040	0.1040	0.1180
7	0.0850	0.0820	0.1120	0.0970	0.1070
8					0.1030
9					0.0840

Table 4.9: Mean concentrations of copper in kales, spinach and onions for dry and wet seasons

Copper in vegetables	Number of samples	Mean	Std. Deviation
Cu in kales during dry season	7	0.1010	± 0.0211
Cu in kales during wet season	7	0.0901	± 0.0168
Cu in onions	9	0.1091	± 0.0134
Cu in spinach during dry season	7	0.1054	± 0.0162
Cu in spinach during wet season	7	0.1000	± 0.0173

Mean concentrations of copper in kales, spinach and onions for both dry and wet seasons ranged from 0.09 mg/kg to 0.1 mg/kg. There was no significant difference in concentrations of copper in the vegetables for both dry and wet seasons (Appendix VI).

Table 4.10: Comparison of levels of copper in kales, onions and spinach with WHO/FAO acceptable standard

	WHO/FAO (2001) of < 40 mg/kg					
	T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Cu in kales during dry season	-1241.5390	6	0.0000	-9.8990	-9.9185	-9.8795
Cu in kales during wet season	-1559.0840	6	0.0000	-9.9099	-9.9254	-9.8943
Cu in onions	-2206.3990	8	0.0000	-9.8909	-9.9012	-9.8806
Cu in spinach during dry season	-1613.3640	6	0.0000	-9.8946	-9.9096	-9.8796
Cu in spinach during wet season	-1518.1650	6	0.0000	-9.9000	-9.9160	-9.8840

Levels of copper in kales, spinach and onions were significantly lower than the accepted limit of 40 mg/kg (WHO/FAO, 2001) and standard of 10 mg/kg used by Luo *et al*. (2011) with $p<0.05$.

4.2.4 Mean Concentrations of Zinc in Kales, Spinach and Onions

Table 4.11: Mean concentrations of zinc in kales, spinach and onions from different sites

	Zinc in kales (mg/kg)		Zinc in spinach (mg/kg)		Zinc in onion (mg/kg)
Sample sites	Dry season	Wet season	Dry season	Wet season	
1	1.4421	0.3213	1.2112	0.3398	1.1617
2	1.5747	0.2804	1.4769	0.5414	1.5336
3	2.8095	0.2700	1.1207	0.2613	1.2176
4	1.2896	0.2835	1.0028	0.4715	1.2116
5	0.8986	0.2278	1.0586	0.3039	1.3318
6	1.1868	0.2127	1.1636	0.6878	1.1136
7	1.2621	0.2651	0.9553	0.6324	1.3883
8					0.8915
9					1.1644

Table 4.12: Mean concentrations of zinc in kales, spinach and onions for dry and wet seasons

Zinc in vegetables	Number of samples	Mean	Std. Deviation
Zn in kales during dry season	7	1.4948	± 0.6170
Zn in kales during wet season	7	0.2658	± 0.0363
Zn in onions	9	1.2238	± 0.1819
Zn in spinach during dry season	7	1.1413	± 0.1727
Zn in spinach during wet season	7	0.4626	± 0.1666

Mean concentrations of zinc in kales, spinach and onions ranged from 0.26 mg/kg to 1.49 mg/kg. The mean concentrations of zinc were higher in onions followed by spinach then kales. Levels of zinc in spinach and kales were higher during dry season than in wet season. The difference was only significant in kales with p=0.002 (Appendix VI). The mean concentrations of zinc in all the vegetables were within the accepted level of 99.4 mg/kg as per the requirement of WHO/FAO (2001).

4.2.5 Mean Concentrations of Iron in Kales, Spinach and Onions

Table 4.13: Mean concentrations of iron in kales, spinach and onions from different sites

	Iron in kales (mg/kg)		Iron in spinach (mg/kg)		Iron in onions (mg/kg)
Sample sites	Dry season	Wet season	Dry season	Wet season	Wet season
1	5.2700	67.7000	3.5500	19.3500	3.2400
2	4.8200	66.2500	2.4000	19.3500	3.1200
3	2.3700	71.7500	3.1300	32.2500	2.3500
4	2.2200	99.3500	2.2400	35.4500	2.6500
5	1.9900	77.3000	3.5600	38.6500	3.1200
6	3.7300	70.3500	2.6900	45.1000	2.3100
7	2.8400	113.1500	11.6800	90.2500	2.2500
8					2.3500
9					2.4800

Table 4.14: Mean concentrations of iron in kales, spinach and onions for dry and wet seasons

Iron in vegetables	Number of samples	Mean	Std. Deviation
Fe in kales during dry season	7	3.3200	± 1.3123
Fe in kales during wet season	7	80.8357	± 18.1534
Fe in onions	9	2.6522	± 0.3991
Fe in spinach during dry season	7	4.1786	± 3.3488
Fe in spinach during wet season	7	40.0571	± 24.1056

The mean concentrations of iron in kales, spinach and onions ranged from 2.70 mg/kg to 80.80 mg/kg. Mean concentrations of iron in spinach and kales were significantly higher during wet season compared to dry season (Appendix VI; Appendix VII). Levels of iron were higher in kales followed by spinach then onions. Levels of iron in kales, spinach and onions during dry and wet seasons were within the accepted level of 425 mg/kg according to WHO/FAO (2001).

4.2.6 Mean Concentrations of Nickel in Kales, Spinach and Onions.

Table 4.15: Mean concentrations of nickel in kales and spinach from different sample sites

Sample sites	Nickel in kales during wet (mg/kg)	Nickel in spinach during wet season (mg/kg)
1	13.3650	13.4540
2	11.8810	10.0500
3	9.9800	11.3240
4	10.0510	9.2030
5	7.6770	8.2770
6	8.2010	7.9460
7	3.5460	4.0590

Table 4.16: Overall mean concentrations of nickel in kales and spinach for wet season

Nickel in vegetables	Number of samples	Mean	Std. Deviation
Ni in kales during wet season	7	9.2430	± 3.1922
Ni in spinach during wet season	7	9.1876	± 2.9491

Levels of nickel in spinach and kales ranged from 9.18 mg/kg to 9.24 mg/kg. The uptake of nickel was almost the same in spinach and kales.

Table 4.17: Comparison of levels of nickel in kales and spinach with WHO/FAO acceptable standard

	WHO/FAO accepted value < 67 mg/kg					
	T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Ni in kales during wet season	-47.8700	6	0.0000	-57.7570	-60.7093	-54.8047
Ni in spinach during wet season	-51.8660	6	0.0000	-57.8124	-60.5399	-55.0850

Levels of nickel in kales and spinach during dry and wet seasons were significantly lower than the accepted level of 67 mg/kg (WHO/FAO, 2001) although the value exceeded the world average value of nickel in vegetables which is in a range of 0.1-5 mg/kg.

4.3 Transfer Factors of Heavy Metals from Soil to Vegetables

Table 4.18 provides transfer factors of heavy metal contaminants from soil to vegetables for both dry and wet seasons. The transfer factors were calculated using data provided in Appendix VIII-XII.

Table 4.18: Transfer factors of heavy metals from soil to vegetables for dry and wet seasons

Vegetables	Lead	Cadmium	Copper	Zinc	Iron	Nickel
Kales (d)	0.7100	1.6200	0.2300	0.5600	0.0600	NA
Kales (w)	1.3500	1.6500	0.2700	0.1400	0.5600	0.8900
Spinach(d)	0.6100	1.3500	0.2500	0.4300	0.0700	NA
Spinach(w)	1.1200	1.3000	0.3000	0.2400	0.2800	0.8800
Onions (w)	0.5500	1.0600	0.2700	0.4200	0.1000	NA

The letters in the parenthesis (d and w) stand for dry and wet seasons respectively while (NA) stand for not analysed.

From the results provided in table 4.18, all the heavy metal contaminants had high transfer factors ranging from 0.06 to 1.65. Considering the three vegetables, the soil to plant transfer factors was in the order cadmium > lead > nickel > zinc > copper > iron. In general, iron had low transfer factor in spinach and kales during dry season and in onions. Transfer factors of lead in kales and spinach during wet season and that of cadmium for all the vegetables during dry and wet seasons were above 1.

4.4 Comparison of Levels of Heavy Metals during Dry and Wet Seasons

Figure 4.2 provides comparison of levels of lead in soil, spinach and kales during dry and wet seasons. Figure 4.2 was plotted using data provided in Appendix VIII. Levels of lead in soil was higher than its corresponding levels in kales and spinach during dry season but lower than its levels in kales and spinach during wet season. The uptake of lead by vegetables was extremely high; transfer factor values were greater than 1 for kales and spinach during wet season.

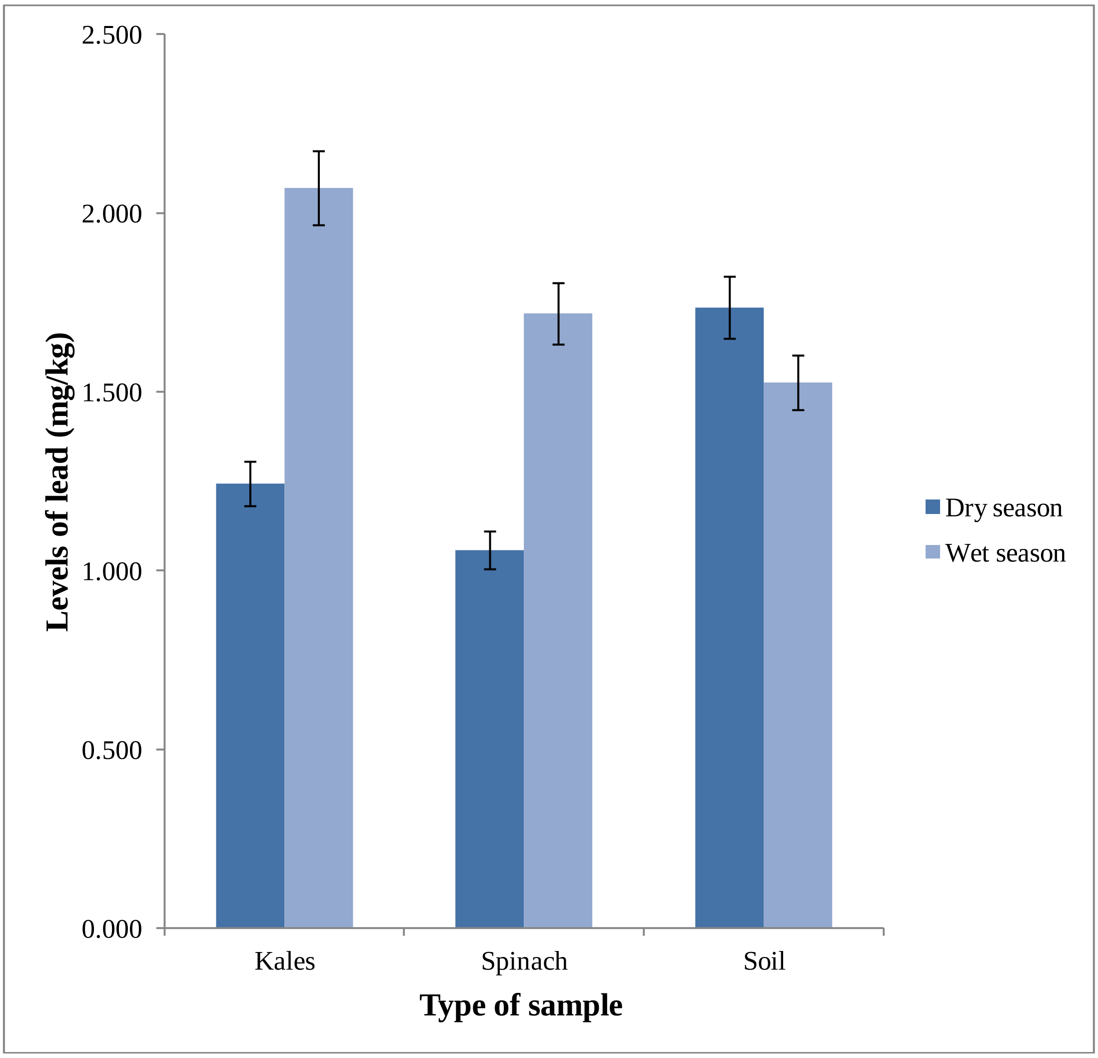

Figure 4.2: Levels of lead in kales, spinach and soil during dry and wet seasons

Comparison of levels of cadmium in soil, spinach and kales during dry and wet seasons is provided in figure 4.3. Figure 4.3 was plotted using data provided in Appendix IX. There was no significant difference in levels of cadmium in soil, kales and spinach during dry and wet seasons (Appendices V, VI and VII). Levels of cadmium in soil were however, lower than its corresponding levels in kales and spinach as shown in figure 4.3. The uptake of cadmium by vegetables was extremely high with transfer factor values were greater than 1.

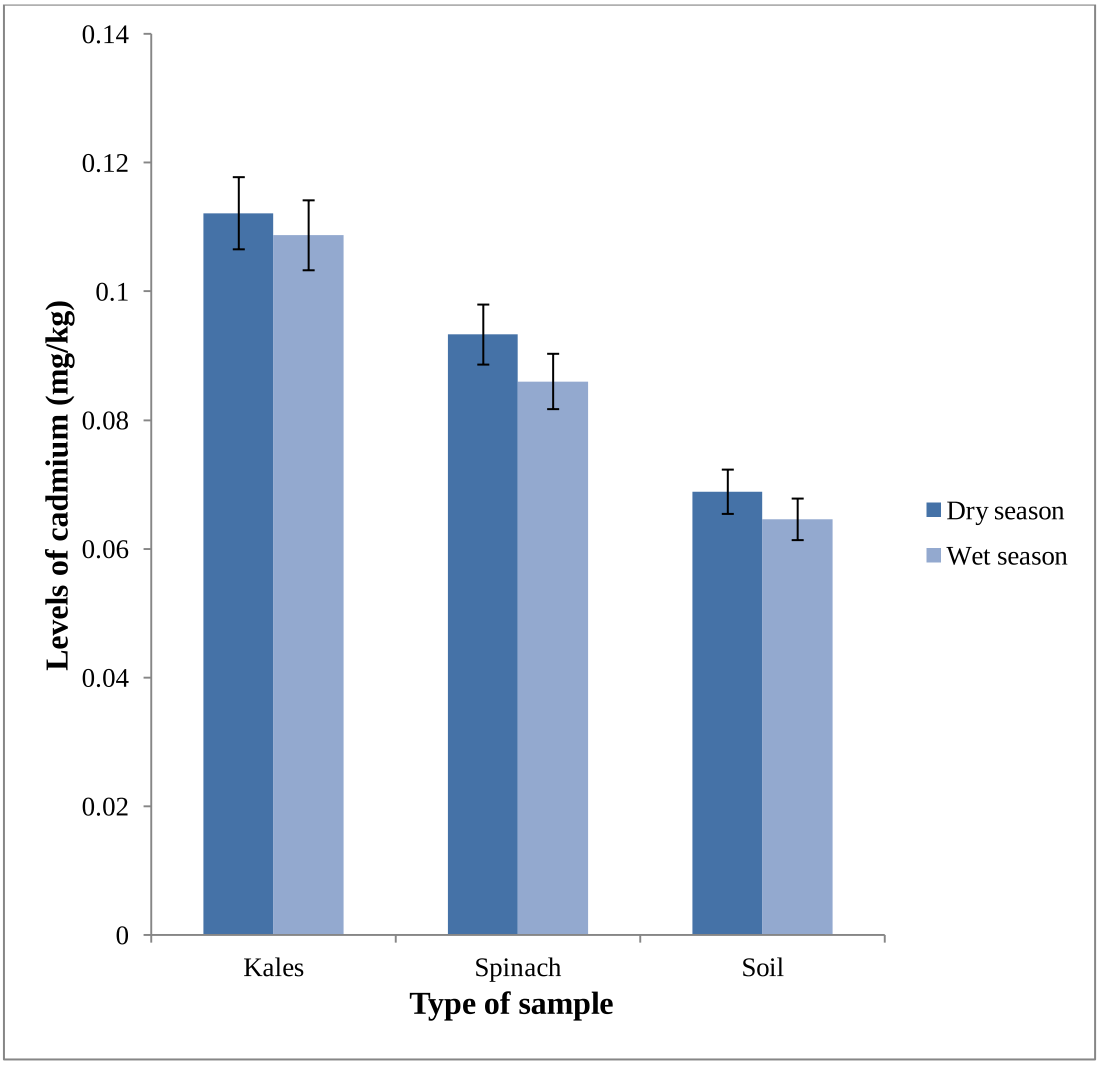

Figure 4.3: Levels of cadmium in vegetables and soil during dry and wet seasons

Figure 4.4 provides comparison of levels of copper in soil, spinach and kales during dry and wet seasons. Figure 4.4 was plotted using data provided in Appendix X. Levels of copper in soil were higher than the corresponding levels in kales and spinach for both dry and wet seasons. There was no significant difference in concentrations of copper in soil, kales and spinach during dry and wet seasons (Appendices V, VI and VII). The uptake of copper by the vegetables was fairly low compared to other metals with the transfer factor values being less than 0.3.

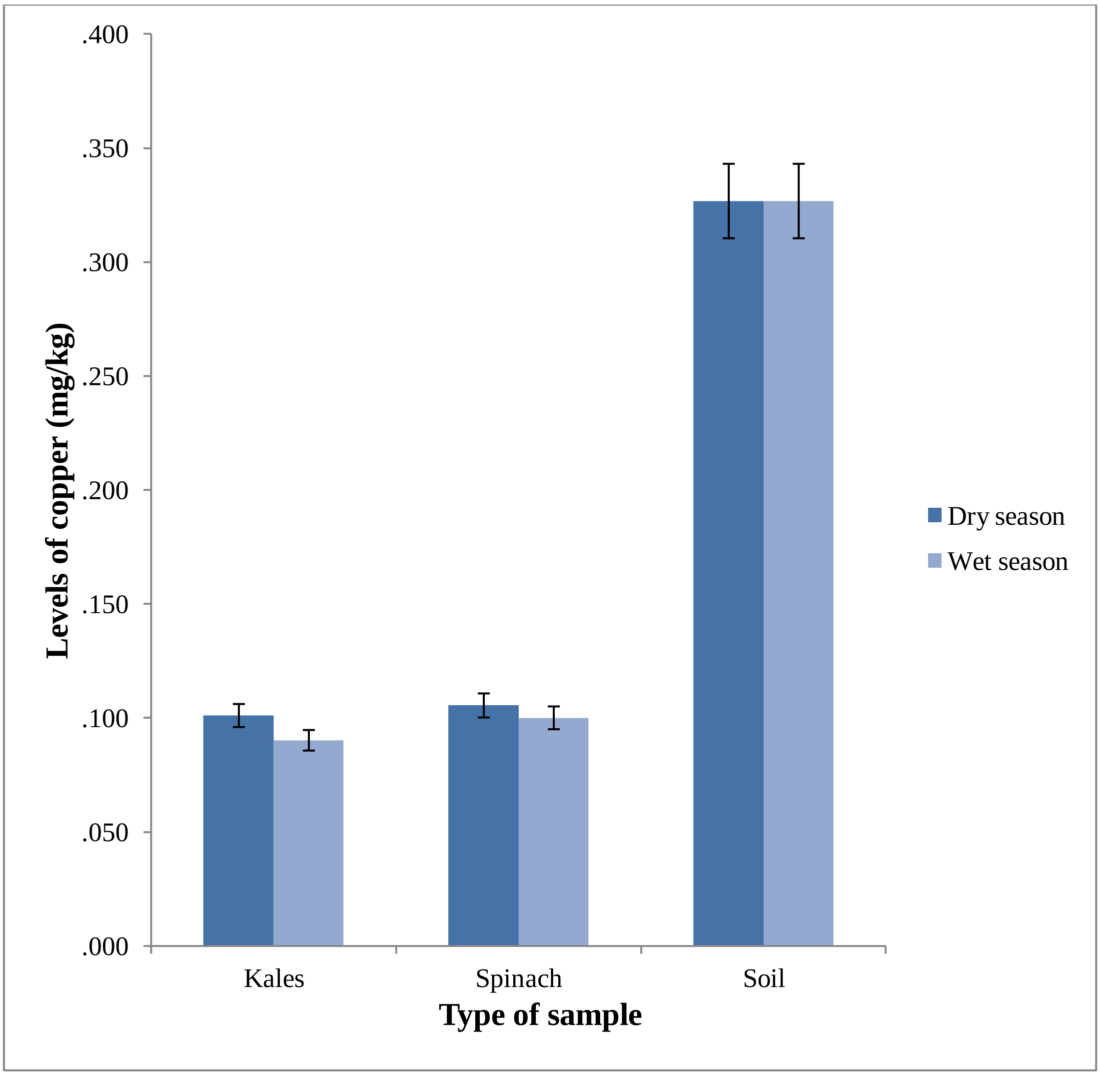

Figure 4.4: Levels of copper in vegetables and soil during dry and wet seasons

Comparison of levels of zinc in soil, spinach and kales during dry and wet seasons is provided in figure 4.5. Figure 4.5 was plotted using data provided in Appendix XI. Levels of zinc in soil were higher than the corresponding levels in kales and spinach for both dry and wet seasons. Levels of zinc in soil, kales and spinach were higher during dry season than wet season. However, the difference in levels of zinc during dry and wet seasons was not significant (Appendices V, VI and VII). The uptake of zinc by vegetables was fairly high compared to that of copper, however it was low in kales and spinach during wet season.

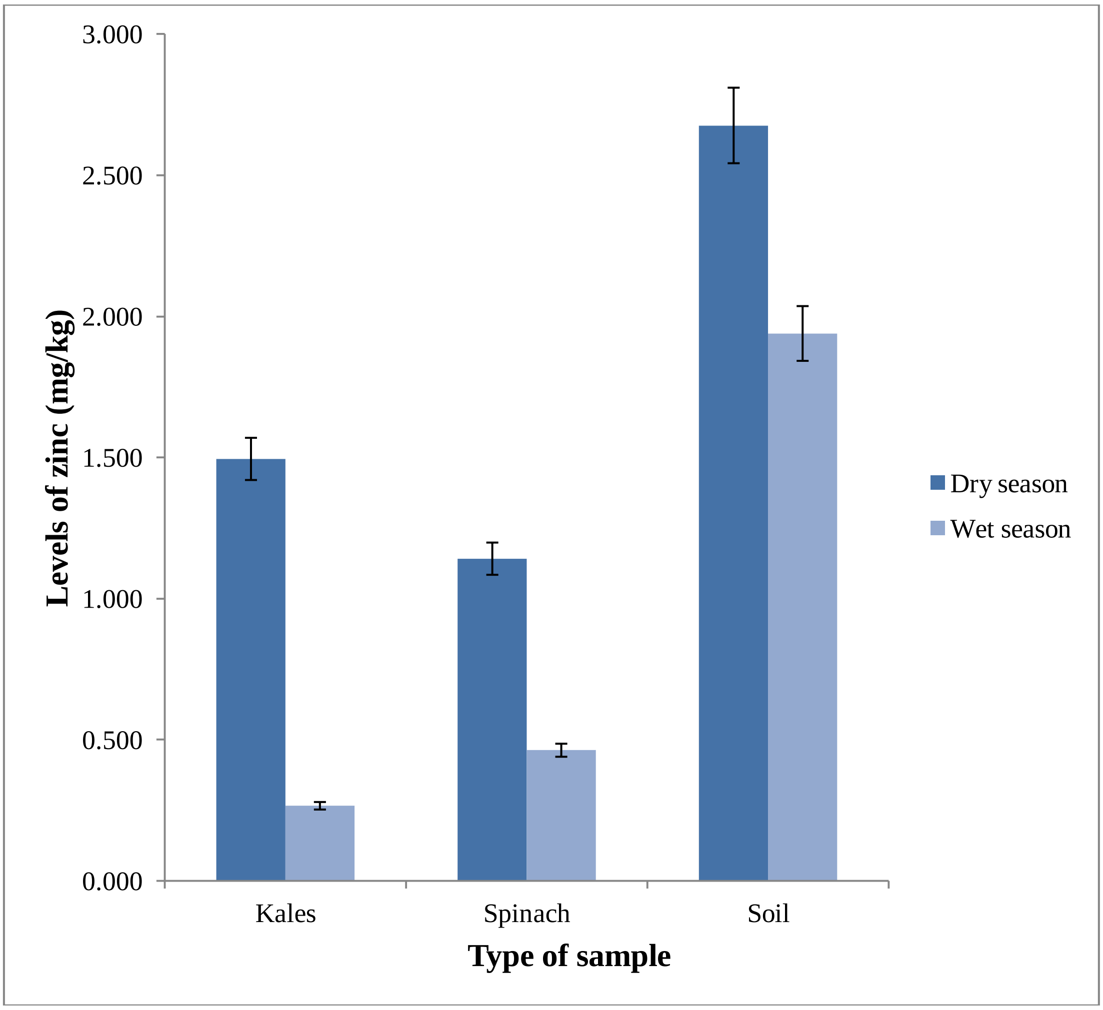

Figure 4.5: Levels of zinc in kales, spinach and soil during dry and wet seasons

Comparison of levels of iron in soil, spinach and kales during dry and wet seasons is provided in figure 4.6. Figure 4.6 was plotted using data presented in Appendix XII. Levels of iron in soil, kales and spinach were significantly higher during wet season than dry season (Appendices V, VI and VII). Levels of iron in soil were higher than its levels in kales and spinach for both dry and wet season; the uptake of iron by the vegetables was very low. However, the uptake of iron by spinach and kales during wet season was fairly high.

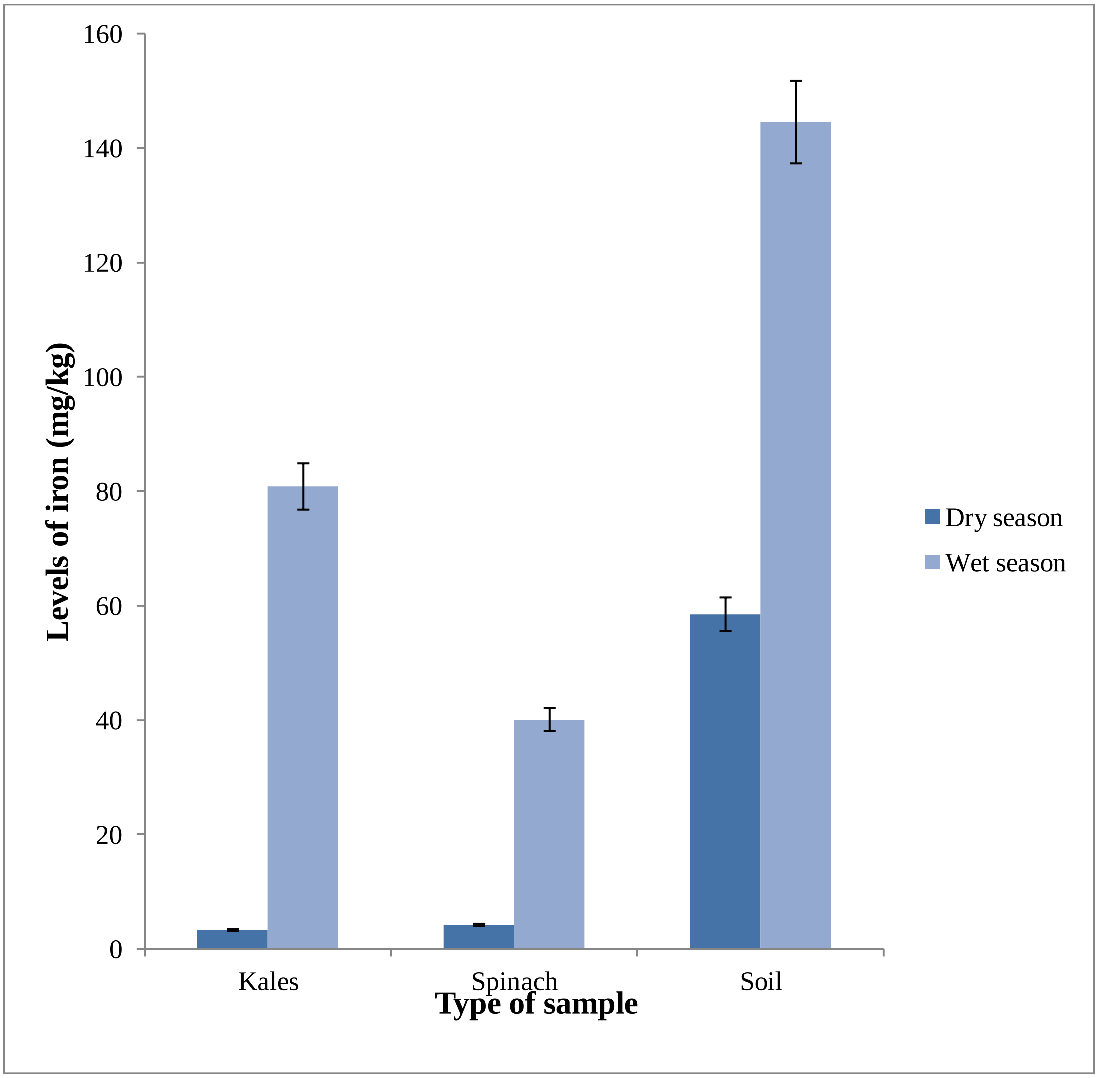

Figure 4.6: Levels of iron in kales, spinach and soil during dry and wet seasons

4.5 Comparison of Levels of Heavy Metals in Onions and Soil

Figure 4.7 provides comparison of mean concentrations of heavy metals in onions and soil. The bar graph was plotted using data provided in Appendix XIII.

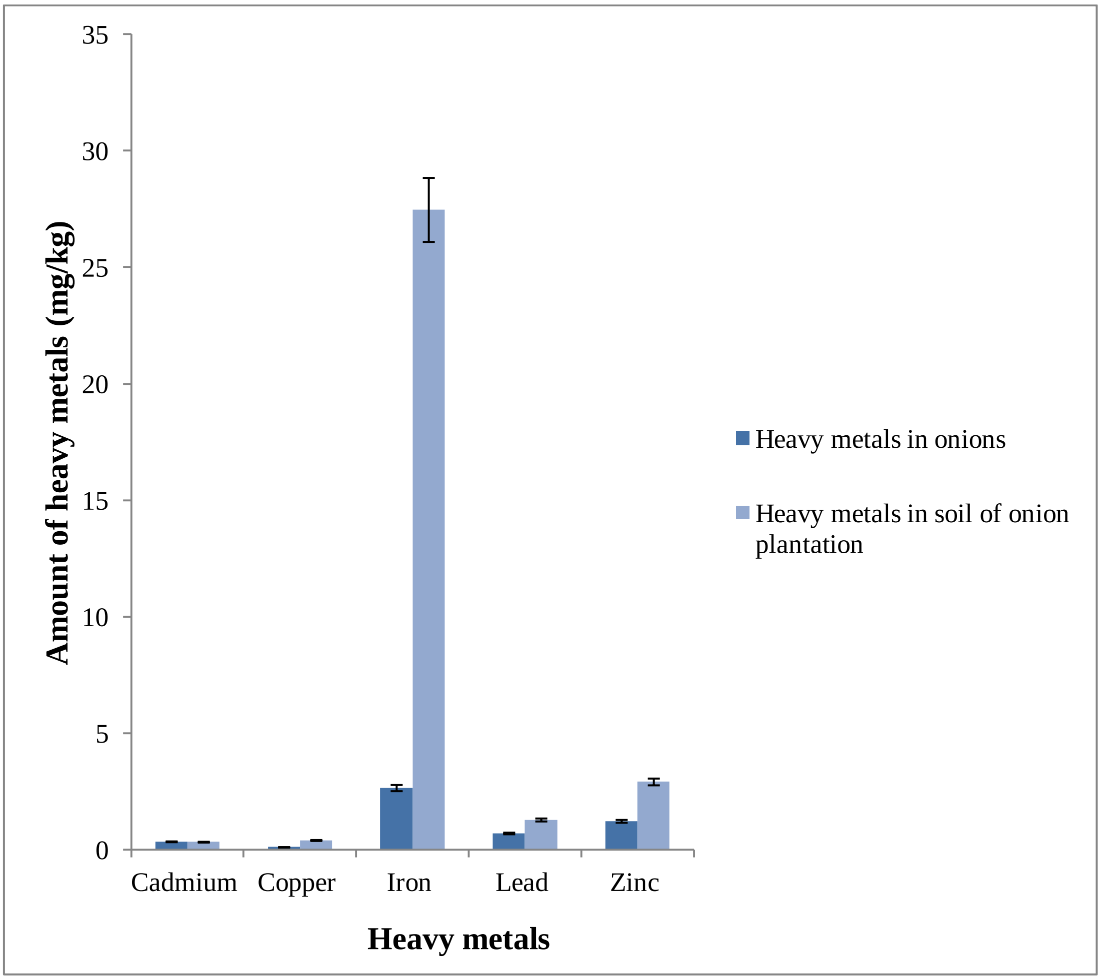

Figure 4.7: Levels of heavy metals in onions and soil

Mean concentrations of heavy metals in soil ranged from 0.33 mg/kg to 27.47 mg/kg while in onions the concentrations ranged from 0.11 mg/kg to 2.65 mg/kg. The mean concentrations of heavy metal contaminants in soil were in the order iron > zinc > lead > copper > cadmium while in onions the concentrations were in the order iron > zinc > lead > cadmium > copper.

Table 4.19: Paired t-test for levels of heavy metals in onions and soil

		Mean	No. of samples	Std. Deviation
Pair 1	Cd in onions	0.3457	9	± 0.0168
	Cd in soil	0.3307	9	± 0.0203
Pair 2	Cu in onions	0.1091	9	± 0.0134
	Cu in soil	0.4021	9	± 0.1284
Pair 3	Fe in onions	2.6522	9	± 0.3991
	Fe in soil	27.4733	9	± 11.2221
Pair 4	Pb in onions	0.7044	9	± 0.0566
	Pb in soil	1.2833	9	± 0.1166
Pair 5	Zn in onions	1.2238	9	± 0.1819
	Zn in soil	2.9160	9	± 0.8806

Table 4.20: Paired t-test for difference in levels of heavy metals in onions and soil

Paired samples test for heavy metals in onions and in soil									
Heavy metal		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Cd in onions - Cd in soil	0.0150	± 0.0174	0.0058	0.0016	0.0284	2.5860	8	0.0320
Pair 2	Cu in onions - Cu in soil	-0.2930	± 0.1209	0.0403	-0.3860	-0.2001	-7.2690	8	0.0000
Pair 3	Fe in onions - Fe in soil	-24.8211	± 10.9750	3.6583	-33.2573	-16.3850	-6.7850	8	0.0000
Pair 4	Pb in onions - Pb in soil	-0.5789	± 0.1147	0.0382	-0.6671	-0.4907	-15.1400	8	0.0000
Pair 5	Zn in onions - Zn in soil	-1.6922	± 0.9029	0.3010	-2.3862	-0.9982	-5.6230	8	0.0000

The mean concentrations of Pb, Cu, Zn and Fe were significantly higher in soil than in onion with $p<0.05$. Cd had a significantly higher concentrations in onions than in soil with $p=0.032$.

4.6 Levels of Total Coliform and Faecal Coliform in Onions and Soil

Levels of total coliform and faecal coliform in soil and onions are presented in Tables 4.21 and 4.22, respectively. The levels were compared with acceptable standard of WHO (2006).

Table 4.21: Levels of total coliform and faecal coliform in soil

Samples site	Total coliform MPN/100 ml	Faecal coliform MPN/100 ml
1	2.00×10^2	2.00×10^2
	2.80×10^2	2.80×10^2
2	2.40×10^4	1.10×10^4
	1.10×10^4	1.10×10^4
3	4.20×10^2	4.20×10^2
	4.40×10^2	4.40×10^2
4	5.30×10^2	5.30×10^2
	4.40×10^2	4.40×10^2
5	4.30×10^2	4.30×10^2
	7.50×10^2	7.50×10^2
6	9.30×10^2	9.30×10^2
	1.50×10^3	2.80×10^2
7	2.80×10^2	2.80×10^2
	3.50×10^2	2.80×10^2
8	9.30×10^2	9.30×10^2
	1.50×10^3	9.30×10^2
9	2.40×10^4	2.40×10^4
	2.10×10^3	2.10×10^3

Levels of both total coliform and faecal coliform in soil ranged from 2.00×10^2 to 2.40×10^4 MPN/100 ml.

Table 4.22: Levels of total coliform and faecal coliform in onions

Samples sites	Total coliform MPN/100 ml	Faecal coliform MPN/100 ml
1	2.90×10^3	1.10×10^4
	2.40×10^4	2.10×10^3
2	2.10×10^3	2.10×10^3
	1.50×10^3	1.50×10^3
3	2.40×10^4	2.40×10^4
	4.60×10^3	7.50×10^2
4	1.10×10^4	2.10×10^3
	2.40×10^4	2.10×10^3
5	2.90×10^3	7.50×10^2
	1.10×10^4	2.00×10^2
6	2.10×10^3	2.10×10^3
	4.20×10^2	2.60×10^2
7	2.40×10^4	2.40×10^4
	2.90×10^3	1.50×10^3
8	2.40×10^4	4.60×10^3
	2.40×10^4	2.40×10^4
9	4.60×10^3	2.10×10^3
	3.40×10^2	3.40×10^2

Levels of total coliform in onions ranged from 3.40×10^2 to 2.40×10^4 MPN/100 ml while faecal coliform ranged from 2.00×10^2 to 2.40×10^4 MPN/100 ml. The range was slightly higher in onions than in soil.

The bulb onions and soil were subjected to complete test of multiple tube fermentation technique to determine whether they were contaminated with *E. coli* strains. The results indicated that soil and onions from all the nine sample sites were contaminated with *E. coli* strains. Sample plates with (positive response) green metallic sheen in EMB agar for soil and onions are provided in plate 4.1.

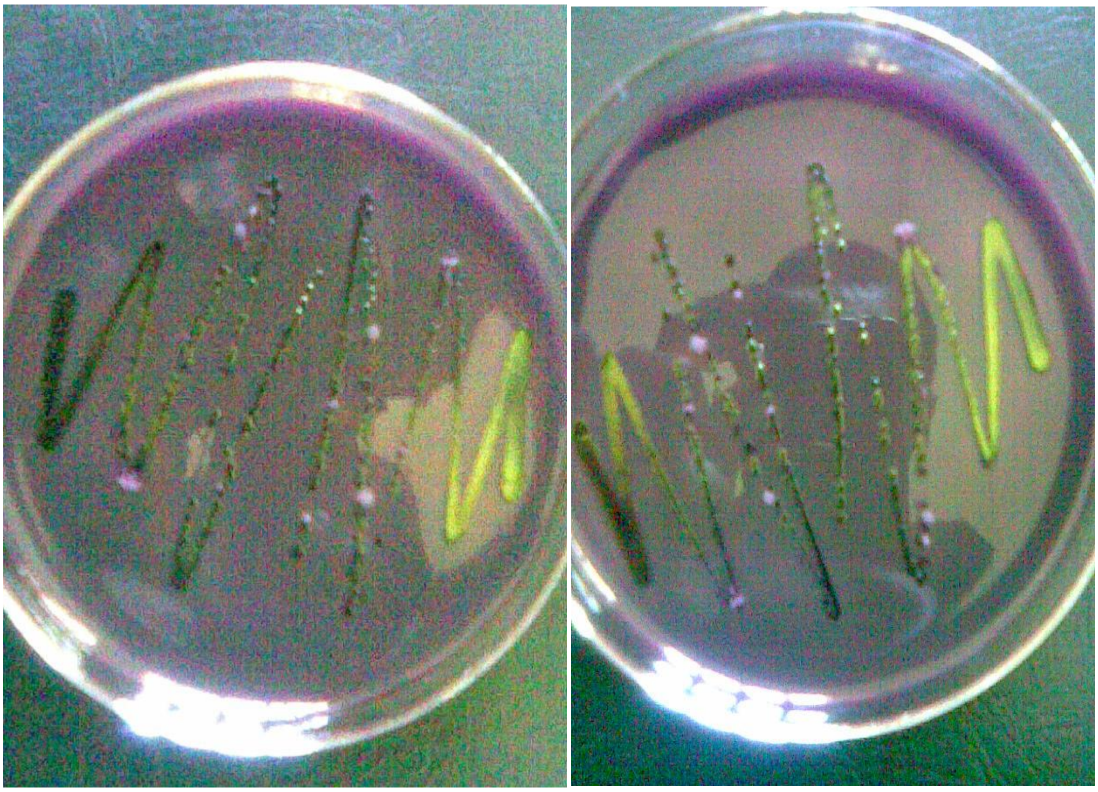

Plate 4.1: Plates showing positive response in complete test

(Source: Author 2015)

Tables 4.23 and 4.24 provide mean of levels of coliform bacteria in soil and in onions, respectively.

Table 4.23: Mean of total coliform and faecal coliform in soil

	Number of samples	Minimum	Maximum	Mean MPN/100 ml	Std. Deviation
Total coliform in soil	18	200.00	24000.00	3893.00	± 7718.22
Faecal coliform in soil	18	200.00	24000.00	3067.00	± 6219.27

Average total coliform in soil was 3.893×10^3 MPN/100 ml while faecal coliform in soil was 3.067×10^3 MPN/100 ml. The average value of faecal coliform in soil was higher than acceptable standard of <1000 MPN/100 ml (WHO, 2006).

Table 4.24: Mean of total coliform and faecal coliform in onion

	Number of samples	Minimum	Maximum	Mean MPN/100 ml	Std. Deviation
Faecal coliform	18	200.00	24000.00	5861.00	± 8691.18
Total coliform	18	340.00	24000.00	10576.00	± 10185.77

The average number of total coliform in onion was 1.0576 x 10^4 MPN/100 ml while that of faecal coliform was 5.861 x 10^3 MPN/100 ml. The average value of faecal coliform in onions was considerably high than the acceptable standard of <200 MPN/100 ml (WHO, 2006) and standard of 0 MPN/100 ml set by USEPA/USAID (1992).

CHAPTER FIVE

DISCUSSION

The results obtained in this study on concentration of heavy metal contaminants and coliform bacteria were compared with the recommended standards of WHO/FAO (2001); SPCR (2001 and WHO (2006) provided in Appendices XIV-XVI. All contaminants analysed in this study were present in soil and the vegetable samples. Mean concentration of lead in soil in this study ranged from 1.54 to 1.74 mg/kg. These concentrations were within the acceptable standards set by SPCR (2001). The concentrations were also low compared to those reported in literature. Njagi (2013) reported a range of 19.79 to 60.22 mg/kg while Premarathna *et al.* (2011) reported a range of 15 to 311 mg/kg. Similarly Kabata-Pendias & Pendias (1992); Haluschak *et al.* (1998); McGrath *et al.* (2001); Kimani (2007) reported high values of 189 mg/kg, 55 mg/Kg, 80 mg/kg and 34.5 mg/kg respectively. Mean concentrations of lead in the leafy vegetables analysed in this study ranged from 1.06 mg/kg to 2.07 mg/kg while in onions, the mean concentrations were 0.70 mg/kg. The mean concentrations of lead in vegetables compare well with those reported by Njagi (2013); Orisakwe *et al.* (2012); Naser *et al.* (2009); Akubugwo *et al.* (2012) who reported values of between 0.39±0.20 to 1.59±0.03 mg/kg, 0.35 to 3.89 mg/kg, 0.49 to 1.97 m/kg and 0.13 to 0.73 mg/kg, respectively. Muhammad *et al.* (2008) reported lead metal levels in spinach, coriander, lettuce, radish, cabbage and cauliflower with values of 2.251, 2.652, 2.411, 2.035, 1.921 and 1.331 mg/kg, respectively. The levels of lead in vegetables in the present study were significantly higher than the acceptable standard of 0.30 mg/kg set by WHO/FAO (2001). Therefore the vegetables grown in the dumpsite are not good for human consumption because of the high levels of lead. Gastrointestinal tract, kidneys and central nervous system among other organs are affected by high levels of lead. Children exposed to lead are at risk of impaired development, lower IQ, shortened attention span, hyperactivity and mental deterioration. Adults usually experience decreased reaction time, loss of memory, nausea, insomnia, anorexia and weakness of the joints when exposed to lead.

Although the values of lead in the dumpsite soil were within the permissible levels for agricultural soils, the transfer factor of this metal to the vegetables was significant and this could explain why the vegetables had higher levels than permissible limits. The high concentrations of lead recorded in vegetables may have been contributed by lead containing waste materials like batteries, discarded plumbing materials and solders which are commonly discarded from Eldoret town (Chaurasia & Dwivedi, 2008; Lawrence, 2011; Brevik & Burgess, 2013). Sewage wastewater is known to play a pivotal role in significantly increasing heavy metals in soil and crops (Devkota & Schmidt, 2000; Rattan *et al.*, 2001; Mapanda *et al*., 2005; Sharma *et al*., 2007; Khan *et al*., 2008). Municipal dumpsite soil is also known to transfer significant levels of toxic and persistent metals into plants (Cobb *et al*., 2000; Udosen *et al*., 2006). Levels of lead in kales and spinach recorded high values during wet season compared to dry season. In kales the level was significantly higher during wet season than in dry season. This can be attributed to water runoffs which carry wastes from different sources including sewage effluent from broken septic pipes. Sewage wastewater is known to increase levels of Pb in edible portion of vegetables causing health risk in the long run (Sharma *et al*., 2007). The transfer factor of lead was high; that of spinach and kales during wet season was greater than 1. This implies that there were other sources of lead to vegetables apart from the soil. Traces of lead from water run offs and the applied sewage sludge might have entered the vegetables through leaf surfaces.

Mean concentrations of cadmium in soil ranged from 0.065 to 0.069 mg/kg while in leafy vegetables, the values ranged from 0.09 mg/kg to 0.11 mg/kg. In onions, the mean concentration was 0.35 mg/kg. Levels of cadmium in soil were within the safe limit while in the vegetables the levels were significantly higher than the acceptable standard of 0.02 mg/kg set by WHO/FAO (2001). Therefore, the vegetables are not safe for human consumption because of high levels of cadmium. Cadmium in the body is known to affect several enzymes including those responsible for re-absorption of proteins in kidney tubules. The enhanced level of cadmium in vegetables may be attributed to application of sewage sludge to the vegetables and decay of abandoned electric batteries and other electronic components which are commonly disposed of in Eldoret. Sewage sludge and Ni-Cd electric batteries are known to be good sources of cadmium (IPCS, 1992; Jarup, 2003; Mull, 2005; Brevik & Burgess, 2013). Municipal dumpsite soil is known to transfer significant levels of toxic and persistent metals into plants (Cobb *et al.*, 2000; Udosen *et al.*, 2006). It is also known that application of agricultural inputs such as fertilizers, pesticides as well as the disposal of industrial wastes increases total concentrations of cadmium in soil and vegetables. Other studies carried out earlier are in agreement with the current study. A study of Odai *et al.* (2008) carried out on vegetables grown in a dumpsite in Kumasi showed that levels of lead and cadmium in vegetables were higher than recommended values of WHO/FAO. A study of Ebong *et al.* (2008) on heavy metal contents of municipal and rural dumpsite soils and rate of accumulation by *Carica papaya* and *Talinum* *triangulare* in Uyo, Nigeria revealed that cadmium and lead in vegetables were above the recommended standard.

The levels of cadmium in soil were significantly lower than its level in leafy vegetables; the transfer factor was more than 1. This implies that soil was not the only source of cadmium to the vegetables; cadmium may have entered into the vegetable tissues through deposits on leaf surfaces consequent to the applied raw sewage and polluted air. The mean concentrations of cadmium were higher in onions followed by kales then spinach. Onions had high levels of cadmium compared to the surface vegetables because they grow underground and as cadmium is leached it comes to contact with onions. Additionally, onions take long to mature hence have a long time of contact with the contaminants. Cadmium recorded the lowest concentration in soil in all the locations compared to other metals in this study. This is in agreement with the report provided by Udosen *et al*. (2006) in a research conducted from a municipal dumpsite in Nigeria. This may be attributed to the low levels of the metal in the earth's crust and as a non-essential element for plants (Amusan *et al*., 2005).

Mean concentration of copper in soil ranged from 0.35 to 0.44 mg/kg. The work of Njagi (2013) revealed copper levels that were much higher than those of this study with values ranging between 143.02 and 2089.61 mg/kg. Awokunmi *et al*. (2010) reported even higher levels of copper ranging from 95 to 6726 mg/kg in soil collected from several dumpsites in Nigeria. In the current study mean concentrations of copper in leafy vegetables ranged from 0.09 mg/kg to 0.11 mg/kg while in onions the mean concentration was 0.11 mg/Kg; these levels were within the acceptable standard of 40mg/kg (WHO/FAO, 2001). The low concentration of copper in vegetables of the current study may be explained by its low concentration in soil. Other studies have reported much higher values. Njagi (2013) reported levels ranging from the lowest value of 0.38±0.19 mg/kg to 1.72±0.11 mg/kg while Uwah *et al*. (2011) recorded copper values of between 0.81 mg/kg and 1.75 mg/kg in spinach and lettuce grown in Nigeria, respectively. Akubugwo *et al*. (2012); Muhammad *et al*. (2008) reported similarly high results in the range of 1.20 to 3.42 mg/kg and 0.25 mg/kg to 0.92 mg/kg, respectively while Sharma *et al*. (2006) reported copper concentration of (2.25-5.42 mg/kg) in vegetables grown in wastewater areas of Varanasi, India. Mean concentrations of copper in vegetables in this study were found to be much less than concentrations in its soil; uptake of copper by vegetables in this study was low as revealed by the low transfer factors. This could be explained by the fact that copper contents do not mobilize in plants and remain stagnant in roots (Bakere *et al*., 1994). There was no significant difference in concentrations of copper in soil and plants for both seasons. This implies that concentrations of copper in soil and vegetables were independent of seasonal variations. This can also support the fact that copper has low mobility in soil and plants.

Mean concentrations of zinc in soil ranged from 1.94 mg/kg to 2.68 mg/kg. These levels were much lower compared with those reported in some studies done earlier. Njagi (2013) reported a range of 128.11 mg/kg to 289.27 mg/kg. McGrath *et al*. (2001); Kimani (2007) reported the following values of zinc in different countries as 200 mg/kg and 133 mg/kg, respectively. Awokunmi *et al*. (2010) reported much higher zinc levels in soil ranging between 350-3052 mg/kg. The mean concentrations of zinc in leafy vegetables in this study ranged from 0.27 mg/kg to 1.49 mg/kg while in onions the concentration was 1.22 mg/kg. The concentrations of zinc in all the vegetables were however, within the acceptable standard of 99.4 mg/kg as per WHO/FAO (2001) requirements. The low concentrations of zinc in vegetables can be explained by its low concentrations in soil. Results of this study on levels of zinc were within the range reported by Njagi (2013) of 0.38±0.19 mg/kg to 2.43±0.15 mg/kg and Muhammad *et al*. (2008) who reported levels of zinc in leafy vegetable samples as 0.461(spinach), 0.705 (coriander), 0.743 (lettuce), 1.893 (radish), 0.777 (cabbage) and 0.678 (cauliflower) mg/kg, respectively. Akubugwo *et al*. (2012) reported higher values of zinc than those reported in this study with values ranging from 1.06 ± 0.02 to 2.82 ± 0.01 mg/kg in *Amaranthus hybridus*. Levels of zinc in spinach and kales were significantly higher during dry season than in wet season. This implies that zinc was soluble in the soil and hence easily washed away. Additionally, the mean concentrations of zinc were higher in onions followed by spinach then kales. Amount of zinc in onions which grow underground was the highest during wet season, this also supports the fact that zinc was soluble and easily leached away hence coming in contact with onions growing underground. The transfer factor of zinc was higher compared to that of copper. This implies that zinc was soluble in the soil hence high uptake and accumulation in plant tissues. Solubility of zinc can be attributed to high pH since municipal wastes increases soil pH (Ogunyemi *et al*., 2003). Zinc is relatively soluble in less acidic pH > 5.6 (Sherene, 2010).

The mean concentrations of iron in soil ranged from 58.50 mg/kg to 144.60 mg/kg. This was within the range reported by Akubugwo *et al*. (2012) and Njagi (2013) of between 73.62 mg/kg to 226.39 mg/kg and between 22.01 mg/kg to 525.50 mg/kg, respectively. Other studies have reported higher values than those in the current study. Tsafe *et al*. (2012) reported a value of 195.25 mg/kg in the soils studied while

Awokunmi *et al*. (2010) reported values between 1100 to 10,920 mg/kg. Mean concentrations of iron in leafy vegetables ranged from 2.65 mg/kg to 80.80 mg/kg. In onions, the concentration ranged from 2.25 mg/kg to 3.24 mg/kg. Mean concentrations of iron in kales, spinach and onions for both dry and wet seasons in this study were within the acceptable standard of 425 mg/kg (WHO/FAO, 2001). These levels are within the ranges reported by Tsafe *et al.* (2012) with mean content of 54.05 mg/kg and Uwah *et al*. (2011) who reported an iron content of 15.96 ± 0.18 mg/kg in *Amaranthus caudatus* and values of 42.84 ± 0.27 mg/kg in *Lactuca sativa*. Akubugwo *et al*. (2012) reported an even higher iron metal content of up to 147.41±0.01 mg/kg in the *Amaranthus hybridus*.

Although iron recorded the highest mean concentration in soil, its transfer factor was low compared to other metals. This implies that solubility of iron in the dumpsite soil was low. This is because the soil pH was high (Ogunyemi *et al*., 2003). Solubility of most heavy metals iron included decrease with increase in pH (Sherene, 2010). The low transfer factors of iron explain why mean concentrations of iron was within safe limits in vegetables yet high levels were recorded in soil. Mean concentrations of iron in spinach and kales were significantly higher during wet season compared to dry season. The high level of iron in spinach and kales during wet season may have come as result of water run offs. Levels of iron were higher in kales followed by spinach then onions. Thus onions which grow underground were not affected highly with iron contamination compared to kales and spinach which grow above the soil surface; this also supports the fact that iron might have originated from water run offs therefore affecting surface vegetables more. Solubility of iron was low as indicated by the low uptake by vegetables therefore iron was not leached and this also explains why its concentration in onions growing underground was low. The results revealed that iron recorded the highest mean metal concentrations in soil at all the locations compared to other metals. This is in agreement with the report of Amusan *et al*. (2005) during a research on plants from some rural and municipal dumpsites within Ife, Nigeria. This could be attributed to the availability of the metal in the earth's crust, at dumpsites and its high utilization by plants.

Soil in this study recorded concentrations of nickel that were lower than those reported in literature with values ranging from 4.6-13.6 mg/kg. Literature report values of 5250.62 –11968.76 mg/kg, 450 mg/kg, 98 mg/kg, 100 mg/kg, 1650 mg/kg and 2360 mg/kg recorded by Njagi (2013); Kabata-Pendias and Pendias (1992); Haluschak *et al*. (1998); McGrath *et al*. (2001); Awokunmi *et al*. (2010); Adefemi and Awokunmi (2009), respectively. Mean concentrations of nickel in kales and spinach were 9.24 mg/kg and 9.18 mg/kg, respectively. These levels were within accepted level of 67 mg/kg set by WHO/FAO (2001). The low levels of nickel in vegetables can be attributed to its low level in soil. The mean concentrations of nickel in leafy vegetables in this study were within the range reported by Premarathna *et al.* (2011) with values ranging from 2.3 to 37.80 mg/kg in various vegetables. Other studies have reported high values of nickel in vegetables. Njagi (2013) reported a range of 13.02±0.54 to 35.23±1.04 mg/kg. Okoronkwo *et al*. (2005) reported values of between 22.59 mg/kg and 24.47 mg/kg in the vegetables under study. On the other hand, Naser *et al.* (2009) in Bangladesh reported lower levels of nickel than those of this study (5.369 mg/kg) in the vegetables. In this study the transfer factor of nickel to the vegetables was high; approximately 0.9 (90%). This is attributed to the fact that nickel in plants is highly mobile and is likely to accumulate in both leaves and seeds (Sengar *et al*., 2008).

In general, the levels of all the heavy metals in soil were within the acceptable limits of SPRC (2001) and WHO/FAO (2001). This is in agreement with findings of Ebong *et al*. (2008) in a study to determine heavy metal contents of municipal and rural dumpsite soils and rate of accumulation by *Carica papaya* and *Talinum triangulare* in Uyo, Nigeria. Levels of lead and cadmium were above the recommended standards in vegetables. This is in agreement with a study of Sharma *et al*. (2007) who concluded that the use of wastewater for irrigation increased the contamination of Cd and Pb in the edible portion of vegetables causing health risk in the long run. Similar findings have been documented from a study conducted in Harare, Zimbabwe where farmers use wastewater to irrigate leafy vegetables (Mapanda *et al*., 2005). Nevertheless, results obtained in this study have shown that waste dumpsites contribute significant levels of toxic heavy metals to soil and finally to crops. Soil to plant transfer is one of the paths of human exposure to metals through food chain. In order to assess the health risks associated with contamination by heavy metals, it was necessary to determine the transfer factor of metals from soil to edible portions of the vegetables. In this study, the soil to plant transfer factor for various metals in three common vegetables consumed by local residents were calculated and provided in table 4.18. Considering the three vegetables, soil to plant transfer factors was in the order cadmium > lead > nickel > zinc > copper > iron. Cadmium had the highest transfer factor while iron had the lowest mobility although concentrations of iron in soil were the highest while that of cadmium were the lowest. The results indicate that uptake of heavy metals by vegetables does not increase linearly with increasing concentrations of heavy metals in soil. The apparent advantage of this phenomenon is that although long term polluted water and municipal wastes result in elevated levels of heavy metals in soil, the same will not be proportionately transferred to the food chain.

Average count of total coliform in soil was 3,893 MPN/100 ml while faecal coliform was 3,068 MPN/100 ml. The average count of faecal coliform in soil samples (3,068 MPN/100 ml) was higher than the accepted level of <1,000 MPN/100 ml as per WHO (2006) requirement. Thus, the soil of the old Eldoret municipal dumpsite may harbour higher levels of faecal coliform to food crops and should not be used for growing crops. Average total coliform in onions was 10576 MPN/100 ml while faecal coliform in onions was 5,861 MPN/100 ml. The level of faecal coliform in onions (5,861 MPN/100 ml) were higher than the accepted level of (<200 MPN/100 ml) as per WHO (2006). This was also higher compared to acceptable standard of 0 MPN/100 ml set by USEPA/USAID (1992). Therefore the onions were not safe for human consumption as far as level of faecal coliform is concerned. The high counts recorded for the total coliform and faecal coliform reflect the presence of human excreta at the waste dumpsite. This unsanitary activity is common in such a congested region like Huruma where adequate sewage systems are lacking. This can also be attributed to the poor sewage system in the area which allows effluent to flow to the vegetable farm, the direct application of raw sewage sludge to the vegetables and the fact that some residents defecate in the vegetable farms. The higher level can also be attributed to the fact that onions grow underground since the extent of microbial contamination decreases if the vegetable’s edible parts are above the ground while it increases if they are near the ground surface (Kwashie, 2009).

Comparison of levels of total coliform and faecal coliform in soil and onions showed that levels of total coliform and faecal coliform were higher in onions than in the soil. The coliform bacteria may have originated from the soil and applied sewage sludge but found a favourable environment in plant tissues. Pathogens find protection in plant tissues from various disinfection treatments, UV light and get ample amount of nutrients (Heaton & Jones, 2008). Therefore microorganisms occupy the plant tissues which offer good environment. Moreover, the coliform bacteria can get into the plant tissues through other paths aside from roots. According to Beuchat (1996) vegetables or plants can be exposed to pathogenic contamination through various routes which include soil, feaces, sewage, insects, animals and human beings. These routes of exposure to pathogenic contaminations are available in the old Eldoret municipal dumpsite and this might explain why the number of coliform bacteria was higher in bulb onions than in soil.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This research work has revealed that soil and vegetables grown at the old Eldoret municipal dumpsite and irrigated using raw sewage sludge are contaminated with heavy metals. The soil and vegetables were contaminated with toxic heavy metals which included lead, cadmium, copper, zinc, iron and nickel. In soil all the heavy metal contaminants were within safe limits. In vegetables copper, zinc, iron and nickel were within safe limits for human consumption while levels of lead and cadmium exceeded the acceptable standard of WHO/FAO (2001). The results have also indicated that vegetables can accumulate heavy metals to high levels beyond recommended standard even if the levels are within safe limits in soil. Thus vegetables should not be grown in contaminated soil and information about heavy metal content in soil alone cannot be used to draw conclusion on safety of food stuffs from the soil.

The research work has also revealed that soil and bulb onions grown at the old Eldoret municipal dumpsite and irrigated using raw sewage sludge are contaminated with pathogenic organisms. The soil and bulb onions grown at the old Eldoret municipal dumpsite were contaminated with total coliform, faecal coliform and *E. coli.* Levels of faecal coliform in soil and bulb onions were higher than the recommended standard of WHO (2006). Therefore the vegetables pose health risks to farmers who have a direct contact with the onions and soil and to unsuspecting consumers especially those who consume them when raw.

6.2 Recommendations

In order to safeguard health of the town's residents, intervention measures need to be undertaken. These measures include:

i. The ministry of Public Health and Sanitation and that of Agriculture should come up with health education programmes for the general population on dangers of consumption of crops grown in and around the waste disposal sites.
ii. Residents who grow crops in the old dumpsite should be equipped with knowledge on the need to shift from raising vegetables at the dumpsite. This may be a useful idea for reducing health risks to the farmers themselves and to consumers of the vegetables that are produced in the area.
iii. The government should put in place certain monitoring processes and empower NEMA together with other relevant institutions such as the ministry of local governments that deal with solid waste disposal management at the city council and municipal levels, to be able to assess solid waste disposal practices and impose penalties if good practices are not followed in disposal of solid waste. Moreover, modern wastes disposal facilities should be acquired by the authorities concerned and appropriate waste disposal sites chosen by experts to avoid exposure of food crops and underground water to contaminants through leachates from the wastes. Additionally, the local government should consider constructing a sewerage works for the rapidly expanding Eldoret town and repair the broken pipes that expose vegetables to contamination from septic tanks.
iv. Separation and recycling of wastes should be encouraged to help reduce the heavy metal load at the dumpsite. Likewise, generation of waste should be reduced by using less waste generating means in various human activities. The

less waste generating means may include use of more oral medication than injectables, using recyclable or reusable product wrappers or containers and discourage the use of non-biodegradable materials.

v. Since wastewater is known to be a good source of nutrients, it can be used to irrigate non edible crops like: fiber or oil crops where the oil extracted from these plants contain less or free from heavy metals.

vi. A medical examination on children residing in Huruma, frequently playing in areas flooded with wastewater and schooling near the dumpsite should be undertaken and proper medication be administered if the children have high metal content.

6.3 Suggestions for Further Research Work

i. Soil, air, vegetables and underground water around the dumpsite should be assessed to determine levels of heavy metal contaminants and coliform bacteria since the contamination may be extended through waste leachates.

ii. Other crops such as cereals and tubers grown in and around dumpsites should be analysed to determine heavy metal levels.

iii. Arsenic, chromium, mercury, manganese, cobalt, magnesium, PAH and other contaminants that are likely to be available in municipal dumpsite wastes and sewage wastewater and are harmful to human health to be analysed in soil and vegetables grown in the dumpsite.

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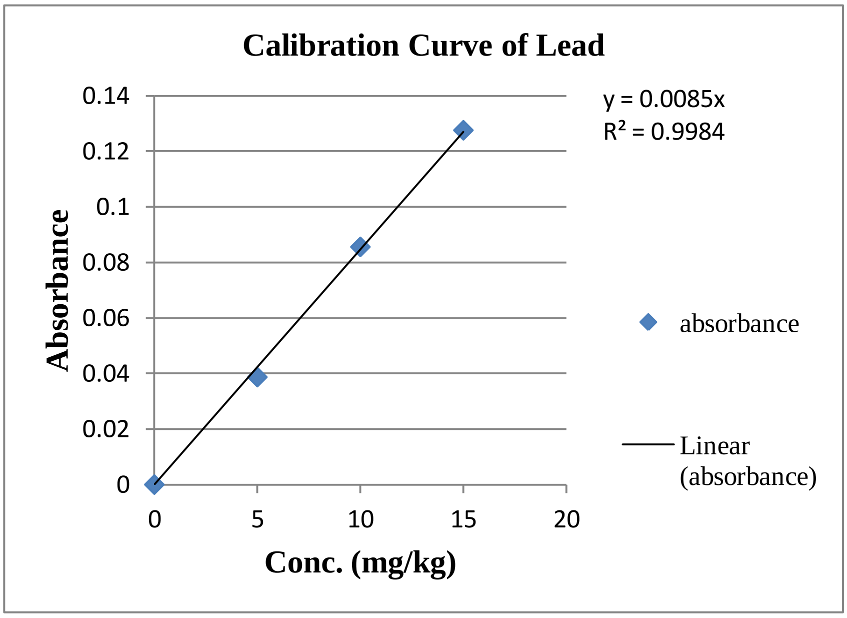
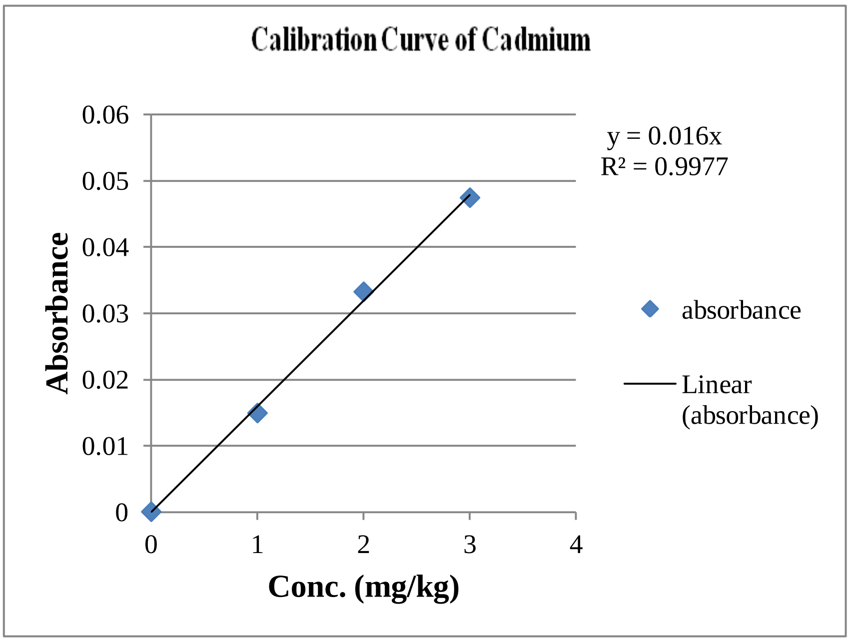
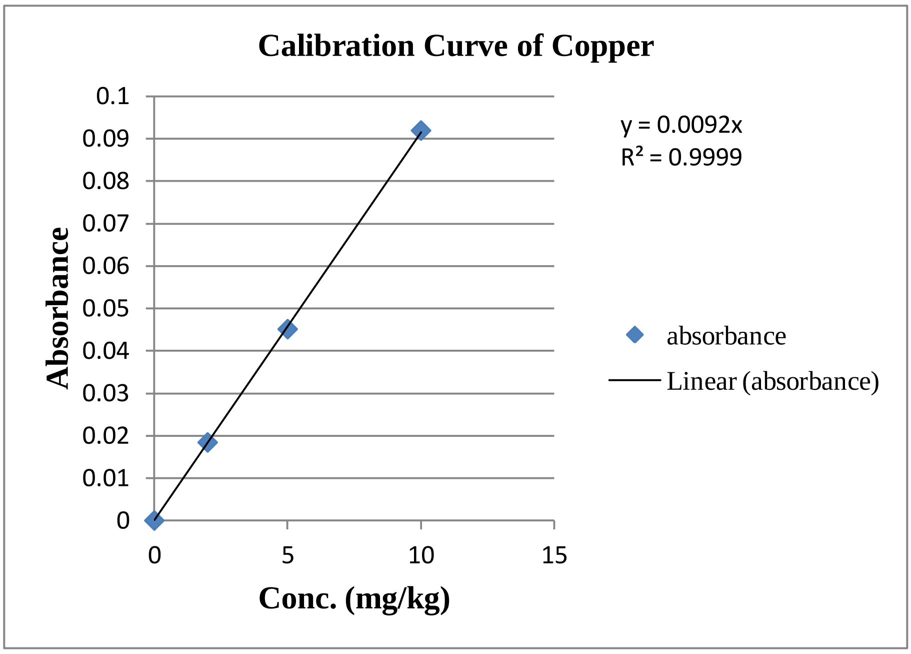
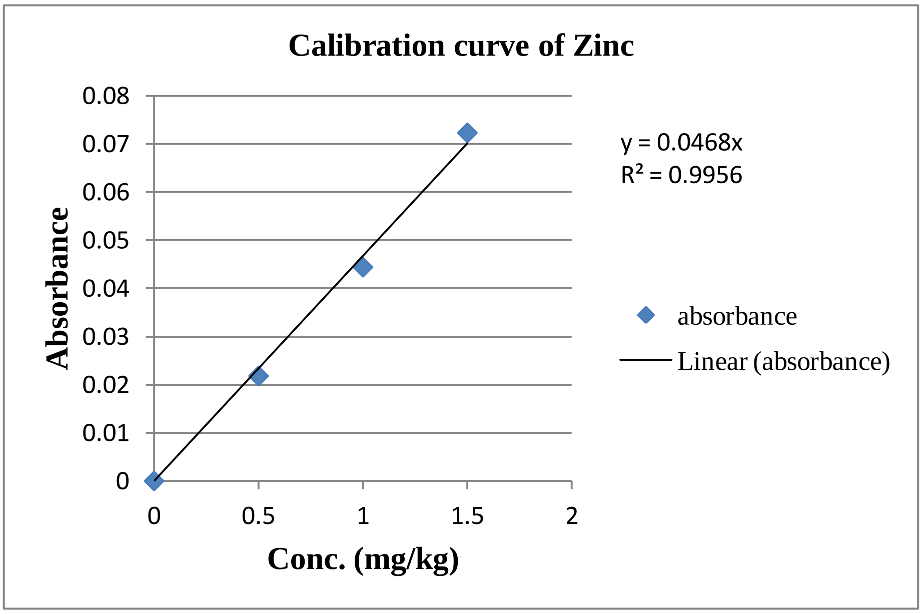
APPENDICES

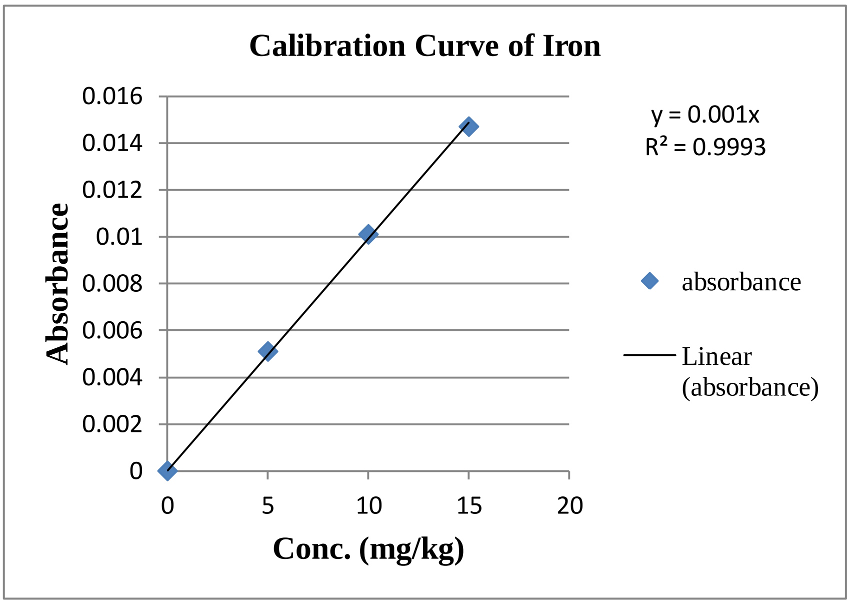
Appendix I: Calibration curves used in AAS analysis

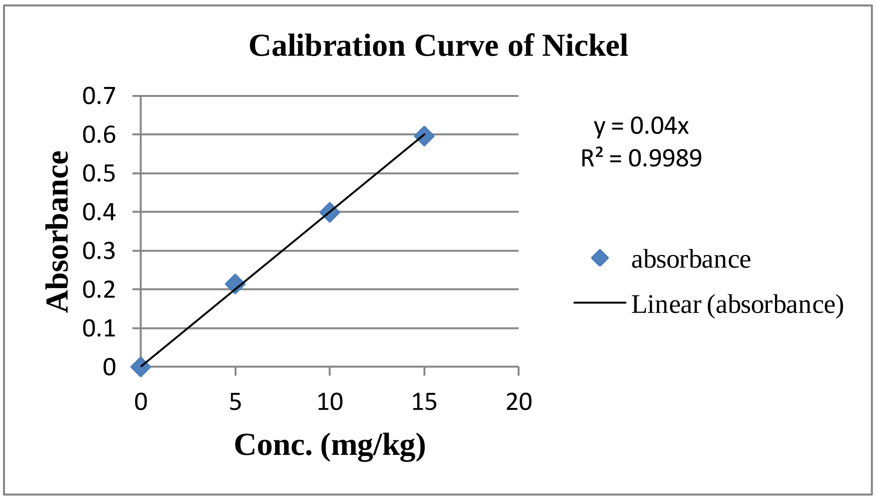





Calibration Curve of Copper
Absorbance
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
5
10
15
Conc. (mg/kg)
y = 0.0092x
R² = 0.9999
◆ absorbance
Linear (absorbance)


Calibration curve of Zinc
Absorbance
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
Conc. (mg/kg)
y = 0.0468x
R² = 0.9956
◆ absorbance
Linear (absorbance)


Calibration Curve of Iron
y = 0.001x
R² = 0.9993
Absorbance
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
5
10
15
20
Conc. (mg/kg)
absorbance
Linear (absorbance)


Calibration Curve of Nickel
y = 0.04x
R² = 0.9989
Absorbance
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
Conc. (mg/kg)
absorbance
Linear (absorbance)

Appendix II: Universal bottles showing positive response in presumptive phase

(Source: Author, 2015)

Appendix III: Universal bottles showing positive response in confirmed phase

(Source: Author, 2015)

Appendix IV: Universal bottles showing positive response in faecal test

(Source: Author, 2015)

Appendix V: Comparison of levels of heavy metals in soil during dry and wet seasons

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Cd in soil during dry season - Cd in soil during wet season	0.0043	± 0.0069	0.0026	-0.0021	0.0106	1.6500	6	0.1500
Pair 2	Cu in soil during dry season - Cu in soil during wet season	0.1114	± 0.6167	0.2331	-0.4589	0.6817	0.4780	6	0.6500
Pair 3	Fe in soil during dry season - Fe in soil during wet season	-86.0471	± 44.9499	16.9895	-127.6189	-44.4754	-5.0650	6	0.0020
Pair 4	Pb in soil during dry season - Pb in soil during wet season	0.2100	± 0.7361	0.2782	-0.4708	0.8908	0.7550	6	0.4790
Pair 5	Zn in soil during dry season – Zn in soil during wet season	0.7370	± 2.7362	1.0342	-1.7936	3.2675	0.7130	6	0.5030

Appendix VI: Comparison of levels of heavy metals in kales during dry and wet seasons

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Cd in Kales during dry season - Cd in Kales during wet season	0.0034	± 0.0132	0.0050	-0.0089	0.0156	0.6860	6	0.5180
Pair 2	Cu in Kales during dry season - Cu in Kales during wet season	0.0109	± 0.0139	0.0052	-0.0020	0.0237	2.0710	6	0.0840
Pair 3	Fe in Kales during dry season - Fe in Kales during wet season	-77.5157	± 18.8692	7.1319	-94.9668	-60.0646	-10.8690	6	0.0000
Pair 4	Pb in Kales during dry season - Pb in Kales during wet season	-0.8271	± 0.1051	0.0397	-0.9244	-0.7299	-20.8120	6	0.0000
Pair 5	Zn in Kales during dry season - Zn in Kales during wet season	1.2289	± 0.6074	0.2296	0.6672	1.7907	5.3530	6	0.0020

Appendix VII: Comparison of levels of heavy metals in spinach during dry and wet seasons

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Cd in spinach during dry season - Cd in spinach during wet season	0.0073	± 0.0098	0.0037	-0.0018	0.0164	1.9650	6	0.0970
Pair 2	Cu in spinach during dry season - Cu in spinach during wet season	0.0054	± 0.0067	0.0025	-0.0008	0.0117	2.1340	6	0.0770
Pair 3	Fe in spinach during dry season - Fe in spinach during wet season	-35.8786	± 21.1348	7.9882	-55.4250	-16.3321	-4.4910	6	0.0040
Pair 4	Pb in spinach during dry season - Pb in spinach during wet season	-0.6614	± 0.8293	0.3134	-1.4284	0.1055	-2.1100	6	0.0790
Pair 5	Zn in spinach during dry season - Zn in spinach during wet season	0.6787	± 0.2349	0.0888	0.4615	0.8959	7.6450	6	0.0000

Appendix VIII: Mean concentrations of lead in kales, spinach and soil

Lead in vegetables	Number of samples	Minimum	Maximum	Mean	Std. Deviation
Lead in kales during dry season	7	1.0900	1.3800	1.2429	± 0.1180
Lead in spinach during dry season	7	0.8000	1.3100	1.0571	± 0.1861
Lead in kales during wet season	7	1.9900	2.2400	2.0700	± 0.0860
Lead in spinach during wet season	7	0.3900	2.7200	1.7186	± 0.8058
Lead in soil during dry season	7	1.1500	2.9000	1.7357	± 0.5659
Lead in soil during wet season	7	0.8700	2.8000	1.5257	± 0.6650

Appendix IX: Mean concentrations of cadmium in kales, spinach and soil

Cadmium in vegetables	Number of samples	Minimum	Maximum	Mean	Std. Deviation
Cadmium in kales during dry season	7	0.0970	0.1450	0.1121	± 0.0162
Cadmium in kales during wet season	7	0.0970	0.1170	0.1087	± 0.0075
Cadmium in soil during dry season	7	0.0540	0.0850	0.0689	± 0.0110
Cadmium in soil during wet season	7	0.0530	0.0750	0.0646	± 0.0068
Cadmium in spinach during dry season	7	0.0720	0.1190	0.0933	± 0.0167
Cadmium in spinach during wet season	7	0.0630	0.1190	0.0860	± 0.0187

Appendix X: Mean concentrations of copper in kales, spinach and soil

Copper in vegetables	Number of samples	Minimum	Maximum	Mean	Std. Deviation
Copper in kales during dry season	7	0.0850	0.1330	0.1010	± 0.0211
Copper in kales during wet season	7	0.0760	0.1260	0.0901	± 0.0168
Copper in soil during dry season	7	0.0570	1.5790	0.4381	± 0.5280
Copper in soil during wet season	7	0.0410	1.2140	0.3267	± 0.4168
Copper in spinach during dry season	7	0.0820	0.1190	0.1054	± 0.0162
Copper in spinach during wet season	7	0.0740	0.1230	0.1000	± 0.0173

Appendix XI: Mean concentrations of zinc in kales, spinach and soil

Zinc in vegetables	Number of samples	Minimum	Maximum	Mean	Std. Deviation
Zinc in kales during dry season	7	0.8986	2.8095	1.4948	± 0.6170
Zinc in kales during wet season	7	0.2127	0.3213	0.2658	± 0.0363
Zinc in soil during dry season	7	1.2345	4.2156	2.6762	± 1.1229
Zinc in soil during wet season	7	0.3991	9.3850	1.9392	± 3.2936
Zinc in spinach during dry season	7	0.9553	1.4769	1.1413	± 0.1728
Zinc in spinach during wet season	7	0.2613	0.6878	0.4626	± 0.1666

Appendix XII: Mean concentrations of iron in kales, spinach and soil

Iron in vegetables	Number of samples	Minimum	Maximum	Mean	Std. Deviation
Iron in kales during dry season	7	1.9900	5.2700	3.3200	± 1.3123
Iron in kales during wet season	7	66.2500	113.1500	80.8357	± 18.1534
Iron in soil during dry season	7	27.6100	91.2200	58.5100	± 19.7196
Iron in soil during wet season	7	70.9000	232.0500	144.5571	± 56.9054
Iron in spinach during dry season	7	2.2400	11.6800	4.1786	± 3.3488
Iron in spinach during wet season	7	19.3500	90.2500	40.0571	± 24.1056

Appendix XIII: Mean concentrations of heavy metals in onions and soil

Cadmium	Number of samples	Minimum	Maximum	Mean	Std. Deviation
Cadmium in onions	9	0.3250	0.3710	0.3457	± 0.0168
Cadmium in soil	9	0.2930	0.3590	0.3307	± 0.0203
Copper in onions	9	0.0840	0.1320	0.1091	± 0.0134
Copper in soil	9	0.2560	0.5550	0.4021	± 0.1284
Iron in onions	9	2.2500	3.2400	2.6522	± 0.3991
Iron in soil	9	16.3500	51.1700	27.4733	± 11.2221
Lead in onions	9	0.6300	0.8200	0.7044	± 0.0566
Lead in soil	9	1.0500	1.4100	1.2833	± 0.1166
Zinc in onions	9	0.8915	1.5336	1.2238	± 0.1819
Zinc in soil	9	1.6483	4.3215	2.9160	± 0.8806

Appendix XIV: Acceptable standard of heavy metals in leafy vegetables (mg/kg)

Heavy metals	**Cadmium**	**Lead**	**Copper**	**Zinc**	**Iron**	**Nickel**
WHO/FAO (2001)	0.02	0.30	40.00	99.40	425.00	67.00
Luo *et al.* (2011)	0.05	0.20	10.00	20.00	NS	NS

KEY

NS- Not specified

Appendix XV: Acceptable standard of heavy metals in soil (mg/kg)

Heavy metals	**Cadmium**	**Lead**	**Copper**	**Zinc**	**Iron**	**Nickel**
WHO/FAO (2001)	NS	100.00	NS	600.00	NS	NS
SPCR (2001)	1.00	50.00	50.00	150.00	150.00	30.00
Netherlands	0.50	40.00	NS	NS	NS	15.00

KEY

NS- Not specified

Appendix XVI: Acceptable standard of faecal coliform in soil and food crops

	(WHO, 2006) and Blumenthal, 2002)	**(USEPA, 1992)**
Soil	Less than 1000	Less than 1000
Food crops	Less than 200	Less than 200
Food crops eaten raw	NS	0

KEY

NS- Not specified