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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

LEVELS OF HEAVY METALS IN *Capsicum annuum* AND *Lycopersicon esculentum* CULTIVATED IN TWO FARMING COMMUNITIES IN OBUASI

A DISSERTATION SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE

BY

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DECLARATION

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

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ABSTRACT

Vegetables have become an integral part of human's diet due to their nutritional values thus any form of contamination especially by heavy metals is of great concern. In Ghana agricultural lands are increasingly being used for Mining. As a result, the limited available agricultural lands are now found within or very close to Mining Concessions. In a bid to investigate the levels of heavy metals in vegetables grown in mining areas, the concentrations of six heavy metals (Arsenic, Cadmium, Lead, Copper, Iron and Zinc) in the fruits, shoots and roots of two commonly used vegetables *Capsicum annuum* (Pepper) and *Lycopersicon esculentum* (Tomato) in four farms in two farming communities in Obuasi (three farms from Apitikoko and one farm from Kwabenakwa) were determined using Atomic Absorption Spectrometer. All four farms are within 16 km from the Southern Tailings Storage Facility (STF) of Anglogold Ashanti Limited. The levels of the heavy metals in the soils were also determined. The levels of all six heavy metals determined in the fruits of both vegetables in all four farms exceeded the recommended standards. In the shoots and roots the levels of the heavy metals exceeded the recommended standards excepts for Cd in Tomato shoots in Farm 1, Cd in Pepper roots Farm 1 and Zn in Pepper roots in all four farms. Except for As the levels of heavy metals in the soils were below the recommended standards. The highest accumulated heavy metal in the fruits, shoots, roots and soils was Iron whilst the lowest accumulated metal was Cadmium. Farm 4 which is located outside the Anglogold Ashanti concessional area recorded the highest levels of heavy metals for both vegetables and soils than the other three farms which are located within the concessional area. In general the levels of heavy metals in the vegetative organs of the vegetables were higher than that of the reproductive organ; the fruit which is the edible part. In *Lycopersicon esculentum* heavy metals accumulation was highest in the roots whilst in *Capsicum annuum* accumulation was highest in the shoot. The levels of heavy metals in *Lycopersicon esculentum* fruits were higher than those of *Capsicum annuum* fruits. The general ranking of heavy metals levels in decreasing order in fruits, shoots and roots was Fe>Zn>As>Cu>Pb>Cd. Bioaccumulation ratio indicated that *Lycopersicon esculentum* plant accumulated more Pb, Fe and Zn whilst *Capsicum annuum* plant accumulated more As, Cd and Cu. Bioaccumulation ratio above one was recorded for all the heavy metals in both fruits except for As. The farm outside the concessional area tends to be more polluted than farms within the area and closer to the STF. Results indicate that there is a high level of atmospheric transport of heavy metals. It can be concluded that the soils in the two farming communities are polluted with Arsenic and the two vegetables cultivated have high levels of heavy metals, posing a health risk to humans and other livestock that consume them. Thus vegetables and possibly food crops cultivated within and around the Mining areas in Obuasi are unsuitable for human consumption.

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ABBREVIATIONS

Abbreviation	**Meaning**
AAS	Atomic Absorption Spectrometer
AGA	Anglogold Ashanti Mines Limited
As	Arsenic
Ca	*Capsicum annuum*
Cd	Cadmium
Conc	Concentrated
Cu	Copper
F1	Farm 1
F2	Farm 2
F3	Farm 3
F4	Farm 4
FAO	Food and Agriculture Organization
Fe	Iron
g	Gram
ha	Hectares
HCl	Hydrochloric Acid
HNO_3	Nitric Acid
Le	*Lycopersicon esculentum*
m	Metres
mg/kg	Milligram per Kilogram
ml	Millilitres
OMAMTDP	Obuasi Municipal Assembly Medium Term Development Plan
Pb	Lead
S	Soil
SD	Standard Deviation
STF	Southern Tailings Storage Facility
WHO	World Health Organisation
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Achieving rapid economic development is the goal of many countries that resort to various activities to exploit their natural resources. Mining which is one of such activities has the potential of contributing to the development of areas endowed with mineral resources. Mining provides both internal and external economic benefits to countries. Internally, there is the creation of employment and revenue generation and externally, a substantial foreign exchange is available to such countries (Yeboah, 2008).

Mining in Ghana makes a large portion of the Gross Domestic Product (GDP) and plays a significant role in the country's economic recovery programme. The main prospects of minerals in Ghana occur at Obuasi, Tarkwa, Prestea, Bibiani, Bogoso and Kenyasi (Asante and Ntow, 2009). Gold earns over US$600 million and accounts for almost 90% of the mineral output and has therefore replaced cocoa as the chief foreign exchange earner. As a result of this, the main focus of Ghana's mining and minerals development industry remains focused on gold (Yeboah, 2008).

Gold mining at Obuasi remains one of the oldest viable mines on the continent of Africa as it dates back to over a century. According to Yeboah (2008), mining activities are viewed as one of the major economic activities found within the Obuasi Municipality due to its geological location (Ashanti belt, where there are abundant mineral deposits) and most citizens and residents derive their economic livelihood from this activity. However, these gains are achieved at a great environmental cost as the exploitation of gold puts stress on water, soil, vegetation and poses human health hazards (Asante and Ntow, 2009).

Antwi-Agyei *et al.* (2009), also adds to this that the long history of mining at Obuasi has generated huge environmental legacy issues in the area and the most significant of the environmental challenges is that of trace elements contamination.

Agriculture in Ghana is one of the major economic sectors with about 40% share in the GDP. The livelihood of the average Ghanaian depends either on agriculture or agriculture related business (Asante and Ntow, 2009). In Ghana agricultural lands are increasingly being used for mining. As a result, the limited available agricultural lands are now found within or very close to Mining Concessions. In Obuasi, mining activities have deprived most farmers' access to fertile lands hence agricultural activities are not that widespread in the municipality and are predominantly on small scale basis. Major food crops grown are cassava, maize, yam, rice and cocoyam. Vegetables like pepper, tomatoes, egg plants, okra, cabbage, legumes, groundnut and cowpea are cultivated by farmers in the municipality.

Vegetables are consumed in almost every household in Ghana forming an important source of vitamins, protein, iron, calcium, minerals and other nutrients which are usually in short supply and required for human health (Maleki and Zarasvand, 2008) and also have beneficial antioxidant activities. Vegetables also act as buffering agents for acidic substances obtained during the digestion process. However, these plants may contain both essential and toxic elements, such as heavy metals, at a wide range of concentrations (Arora *et al.*, 2008). If these vegetables are not of good quality they can affect the organs of the body thus disrupting their normal functions. According to Mapanda *et al*. (2005), the perception of what is regarded as 'good or better quality' vegetable does not refer to good external morphology of the plant or vegetable as that alone cannot guarantee safety from contamination.

1.2 Problem Statement

Mine tailings which are crushed rocks that are left over after gold extraction are stored in special containment systems such as dams by some mining companies. These tailings contain heavy metals that find themselves in the environment when there is a leakage, flooding or when the wind blows (AGA Country Report, 2008). The heavy metals in tailing materials find themselves in soils, water bodies and plants. The plants absorb the heavy metals from contaminated soils through their roots and those that settle on the plants get into the plant organs through their leaves (Smical *et al.*, 2008). When these heavy metals get into the plant system they are stored in the roots, shoot and fruits. The Southern tailings storage facility (STF) of AGA in Obuasi has farms near and far from it where vegetables are cultivated. In cases where the soils and vegetables are contaminated with heavy metals, it would result in accumulation of these heavy metals in humans who eat them resulting in diseases like diarrhoea, dizziness, stomach cramps, nausea, anaemia, kidney damage and brain damage (Järup, 2003).

1.3 Justification

Food is essential for the upkeep and growth of living things especially humans. Due to the nutritional values of vegetables, people are encouraged to add vegetables to their meals. *Capsicum annuum* and *Lycopersicon esculentum* (pepper and tomato) are fruit vegetables that are consumed in almost every house in Obuasi and communities around and are usually consumed in their raw state. When these vegetables are contaminated with heavy metals, these metals accumulate and lead to the malfunctioning of some human organs. Bearing in mind the probable toxicity and persistent nature of heavy metals and the frequent consumption of vegetables, it is necessary to know these vegetables are safe for humans consumption.

1.4 Aims and Objectives

1.4.1 Main Objective

- To determine the levels of Arsenic, Cadmium, Lead, Copper, Iron and Zinc in two commonly consumed vegetables *Capsicum annuum* (Pepper) and *Lycopersicon esculentum* (Tomato) in two farming communities in Obuasi.

1.4.2 Specific Objectives

- To determine the concentrations of Arsenic, Cadmium, Lead, Copper, Iron and Zinc in the vegetables.
- To determine the concentrations of Arsenic, Cadmium, Lead, Copper, Iron and Zinc in shoots and roots system of the vegetable plants.
- To determine the concentrations of Arsenic, Cadmium, Lead, Copper, Iron and Zinc in cultivated soils.
- To determine the Bioaccumulation ratio of heavy metals in the vegetables.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Impact of mining on the environment

Mining activities contribute to environmental pollution and degradation by the release of particulate and gaseous materials such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (N_2O) and nitrous oxide (NO) and other toxic elements into the atmosphere. It also causes noise pollution, destruction of the eco-system and contamination of water bodies and land surfaces when there is acid drainage (Bitala, 2008).

Deforestation that results from surface mining has long-term effects even when the soil is replaced and trees are planted after mine decommissioning as tree species that might be introduced have the potential to influence the composition of the topsoil and subsequently determine soil fertility. Apart from erosion, when surface vegetation is destroyed, there is deterioration in the viability of the land for agricultural purposes and loss of habitat for birds and other animals (Akabzaa and Darimani, 2001).

From exploitation stage to actual mining, mine tailing, waste rocks, and wastewater are created, and dust is emitted. Mine tailings, waste rocks, and wastewater often contain contaminants such as acid generating sulfides, heavy metals, and mining chemicals. These materials are usually stored in ponds or containment but if improperly handled, can leach out into land surface and ground water causing serious pollution that can last for many generations (Ramasar *et al.*, 2003).

Tailings dam failure resulting in the spillage of toxic materials into the environment presents serious problems as reported in countries like China, Romania, Sweden, and USA in the year 2000 (Macklin *et al.,* 2003). According to the 2008 Country Report of Anglogold Ashanti Limited Obuasi, spillage of tailings materials at the Sansu Eastern wall, Boete slurry pipeline and hydra-fill pipeline from Sansu tailings pump to Kwesi Mensah shaft resulted in soil and water pollution, affecting nearby houses, land and vegetation.

2.2 Heavy metals

2.2.1 Heavy metals in the environment

Although there is no clear definition of what a heavy metal is, density, in most cases is taken to be the defining factor. Heavy metals are therefore defined as chemical elements having a specific density greater than 5 g/cm^3 (Järup, 2003). Examples of heavy metals include; arsenic, cadmium, chromium, cobalt, copper, mercury, nickel, lead, iron, selenium, uranium and zinc.

Small amounts of heavy metals are common in our environment and diet and are actually necessary for good health, but large amounts of any of them may cause acute or chronic toxicity (poisoning) (Anonymous, 2011).

Owing to the fact that heavy metals are harmful to humans and animals and have the potential of bioaccumulating in the food chain, they are currently of much environmental concern. Heavy metals can cause health problem to humans, as they have carcinogenic and teratogenic effect. Carcinogenic is concerning or containing carcinogen, the substance or agent that can cause cancer. Teratogenic is pertaining to the production of developmental deformities that is; can cause physical distortion, disfigurement and abnormality (Ismail, 2009).

2.2.2 Sources and route of exposure of heavy metals in the environment and humans

Weathering of rock and anthropogenic sources are the two main pathways of metal input into the environment. According to Turpeinen (2002), anthropogenic sources of metal contamination can be divided into five major groups: mining and smelting, industry, atmospheric deposition, agriculture and waste disposal.

Heavy metals may enter the human body through food, water, air, or absorption through the skin when they come in contact with humans in agricultural, manufacturing, pharmaceutical, industrial, or residential settings. Industrial exposure and injection account for a common route of exposure for adults and children respectively (Roberts, 1999). Children may develop toxic levels from their normal hand-to-mouth activity when they come in contact with contaminated soil or by actually eating objects that are not food such as dirt or paint chips (Dupler, 2001). Less common routes of exposure are during a radiological procedure, from inappropriate dosing or monitoring during intravenous (parenteral) nutrition, from a broken thermometer, or from a suicide or homicide attempt (Anonymous, 2011).

2.2.3 Beneficial heavy metals

Heavy metals such as iron, copper, manganese, and zinc are nutritionally essential for a healthy life when present in food in small quantities. These elements, or some form of them, are commonly found naturally in foodstuffs, in fruits and vegetables, and in commercially available multivitamin products (International Occupational Safety and Health Information Centre, 1999). Some heavy metals play essential roles in the body like helping in the functioning of critical enzymes in the body. Physiological roles are known for iron (haemmoeties of heamoglobin and cytochromes), copper (amine oxidases, dopamime hydrolase and collagen synthesis) and zinc (protein synthesis, stabilisation of DNA and

RNA) (Suruchi and Khana, 2011). Heavy metals are present in some of the products used in our homes as they are used in the manufacturing of pesticides, batteries, alloys, electroplated metal parts, textile dyes and steel thus they improve the quality of life when properly used (International Occupational Safety and Heath Information Centre (IOSHIC), 1999).

2.2.4 Toxic heavy metals

Toxic metals comprise a group of harmful minerals that have no known function in the body. Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues. Toxic heavy metals include; lead cadmium, arsenic, mercury, aluminium, antimony, bismuth, barium and uranium. Heavy metals needed in lesser quantities are usually toxic in greater amounts. Toxic heavy metals have the ability to replace vital minerals, for instance Cadmium, which is located just below zinc in the periodic table of the elements and has an atomic structure very similar to that of zinc almost fits perfectly in the zinc binding sites of critical enzymes such as RNA transferase, carboxypeptidase and alcohol dehydrogenase in the body (Wilson, 2011). Again, in diagnostic medical applications, direct injection of gallium during radiological procedures, dosing with chromium in parenteral nutrition mixtures, and the use of lead as a radiation shield around x-ray equipment (Roberts, 1999) proves that toxic metals are not completely harmful as they can extend life by keeping bodies functioning.

2.3 Bioavailability and Bioaccumulation of heavy metals in plants

2.3.1 Bioavailability and Bioaccumulation

Bioavailability is the proportions of total metals that are available for incorporation into biota (bioaccumulation). Total metal concentrations do not necessarily correspond with metal bioavailability. For example, sulfide minerals may be encapsulated in quartz or other chemically inert minerals, and despite high total concentrations of metals in sediment and soil containing these minerals, metals are not readily available for incorporation in the biota; associated environmental effects may be low (Davis *et al*., 2001).

Some living species have the capacity to accumulate in their organism heavy metals in concentrations much higher than these metal concentrations usually are in the environment. This process can be defined by using two basic notions: bioconcentration and bioaccumulation. Bioconcentration is the direct growth of a pollutant concentration while it passes from the environment to an organism. In the case of terrestrial organism, this process takes place by the pollutant passage from soil into the plant through the radicular system or from air into the animal organism by direct inhaling (Smical *et al.*, 2008). Bioaccumulation means an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment (Ismail, 2009).

These processes can be expressed by using the concentration factor (*Fc*). The concentration factor expresses the ratio between the pollutant concentration in an organism and its concentration in the biotope (Smical *et al.*, 2008):

Fc = Metal concentration in organism / Metal concentration in biotope

2.3.2 Factors affecting heavy metals mobility and bioavailability in plants

Plant uptake of trace elements is generally the first step of their entry into the agricultural food chain. Plant uptake is dependent on: movement of elements from the soil to the plant root, elements crossing the membrane of epidermal cells of the root, transport of elements from the epidermal cells to the xylem, in which a solution of elements is transported from roots to shoots, and possible mobilization, from leaves to storage tissues used as food (seeds, tubers, and fruit) in the phloem transport system. After plant uptake, metals are available to herbivores and humans both directly and through the food chain. The limiting step for elemental entry to the food chain is usually from the soil to the root (Amare, 2007).

Plant species, relative abundance and availability of necessary elements also control metal uptake rates. Abundant bio available amounts of essential nutrients can decrease plant uptake of non-essential but chemically similar elements. Bioavailability may also be related to the availability of other elements. For example, copper toxicity is related to low abundances of zinc, iron, molybdenum and (or) sulphate (Amare, 2007).

2.4 Vegetables

2.4.1 Definition of a vegetable

The noun vegetable means an edible plant or part of a plant, but usually excludes seeds and most sweet fruit. This typically means the leaf, stem, or root of a plant (http://en.wikipedia.org/wiki/Vegetable). Vegetables are among the major sources of human diet. Vegetables are eaten in a variety of ways, as part of meal and as snack food. They contain carbohydrate, little proteins or fats, dietary mineral, vitamins such as Vitamin A, Vitamin K and Vitamin B6, provitamin and metals important for life (http://en.wikipedia.org/wiki/Vegetable).

2.4.2 Importance of vegetables in food

The nutritional content of vegetables varies considerably, though generally they contain little protein or fat and varying proportions of vitamin, provitamin, dietary mineral and carbohydrates. Vegetables contain a great variety of other phytochemicals, some of which have been claimed to have antioxidant, antiseptic, antifungal, antiviral and anticarcinogenic properties. Some vegetables also contain fibres which are essential for growth, development and achieving optimal health now and for preventing chronic diseases later. Vegetables contain important nutrients necessary for proper growth of hair and skin as well. Diets containing recommended amounts of vegetables may help lower the risk of heart disease and type 2diabetes. These diets may also protect against some cancers and decrease bone loss. The potassium provided by vegetables may help prevent the formation of kidney stones (http://en.wikipedia.org/wiki/Vegetable). The consequences of not eating vegetable include; Health Risk, Weight Management Risk, Blood Pressure Risk, Cancer Risk, Gastrointestinal Health Risk and Vision Risk (DeVault, 2010).

2.5 Cultivation, harvest and nutritional values of *Capsicum annuum* and *Lycopersicon esculentum*

2.5.1.0 Cultivation, care and harvest of *Capsicum annuum*

Capsicum annuum is a fruit pod of small perennial shrub belonging to the nightshade or Solanaceae family. They are used worldwide as vegetables instead of spices. *Capsicum annuum* are native to Mexico and other Central American region from where they spread to the rest of the world by Spanish and Portuguese explorers during 16th and 17th centuries and now grown widely in many parts of the world as an important commercial crop (Mangajji, 2009).

Nursing of *Capsicum annuum* seeds are done eight to ten weeks before transplanting. For healthy and good yield, fertilizer or aged compost is added to the soil a week before transplanting. Transplanting of *Capsicum annuum* is when soils are warm as it thrives best in warm temperatures. Watering of *Capsicum annuum* seedlings is done once or twice a week in areas with cooler climates and everyday in warm climatic areas. Weeding is done carefully around the plants (http://www.almanac.com/plant).

Capsicum annuum fruits are said to be matured when they have reached full size and ripped when they have turned or is in the process of turning colour such as red or orange. Fully ripe *Capsicum annuum* are usually red in colour. First harvest of *Capsicum annuum* fruits are done 75 to 90 days after transplanting. Size and colour of the fruits also determine harvesting time. Earlier harvesting of fruits increases and extends yields. The longer *Capsicum annuum* fruits stay on the plant, the more sweet they become and the greater their Vitamin C content. Preservation of *Capsicum annuum* fruits is usually by refrigerating or oven drying (http://www.almanac.com/plant).

2.5.1.1 *Capsicum annuum* nutrition facts

Capsicum annuum contains small levels of health benefiting alkaloid compound capsaicin which has anti-bacterial, anti-carcinogenic, analgesic and anti-diabetic properties. It also contains vitamin-C which is required for collagen synthesis (Collagen is the main structural protein in the body required for maintaining the integrity of blood vessels, skin, organs, and bones), protects the body from scurvy, develop resistance against infectious agents (boosts immunity) and scavenge harmful, pro-inflammatory free radicals from the body.

It also contain good levels of vitamin-A, B-complex group of vitamins, anti-oxidant (that protect the body from injurious effects of free radicals generated during stress and diseases conditions) and adequate levels of essential minerals such as iron, copper, zinc, potassium, manganese, magnesium, and selenium (Mangajji, 2009).

2.5.2.0 Cultivation, care and harvest of *Lycopersicon esculentum*

Lycopersicon esculentum a nutritious fruit commonly known as tomato is used as a vegetable and has captured the attention of millions health seekers for its incredible phyto-chemical properties. Botanically, the vegetable belongs to Solanaceae or nightshade family. This exotic vegetable of all seasons is native to Central America and was cultivated by the Aztecs centuries before the Spanish explorers introduced it to all over the world (Mangajji, 2009).

Lycopersicon esculentum seeds are nursed six to eight weeks before transplanting. *Lycopersicon esculentum* grow well at sites with full sun and well-drained soil thus transplanting is done when soils are warm. For northern regions, it is very important that the site receives at least six hours of sun and for southern regions, light afternoon shade would ensure the survival and thriving of *Lycopersicon esculentum* plant. It is advisable to establish stakes at the time of planting as they keep developing fruit off the ground. Consistent watering is done throughout the growing season especially first four to six days after transplanting (http://www.almanac.com/plant).

Lycopersicon esculentum fruits are ready for harvest 75 to 90 days after transplanting. Pod size and colour are also used to determine harvesting time. Matured fruits are usually slightly soft and very red in colour. Earlier harvesting of fruits helps increases and extends yields. Preservation of fruits is usually by refrigerating (http://www.almanac.com/plant).

2.5.2.1 *Lycopersicon esculentum* nutrition facts

Lycopersicon esculentum is one of the low calorie vegetables with very low fat contents and has zero cholesterol levels. Nonetheless, they are excellent sources of antioxidants, dietary fibre, minerals, vitamin-C and vital B-complex vitamins and some essential minerals like iron, calcium, manganese, potassium, sodium and other trace elements. Their antioxidants are scientifically found to be protective against cancers including colon, prostate, breast, endometrial, lung, oral and pancreatic tumours, protect skin damage from ultra-violet (UV) rays thus offer protection from skin cancer, protect eyes from "age related macular disease"

(ARMD) in the elderly persons by filtering harmful ultra-violet rays, take part in vision, maintain healthy mucus membranes and skin, and bone health. Due to their all-round qualities, dieticians and nutritionists often recommend them to be included in cholesterol controlling and weight reduction programs (Mangajji, 2009).

2.6 Sources and Health effects of the heavy metals in the environment and organisms

2.6.1 Arsenic (As)

Arsenic is a metalloid element which normally occurs in mineral-bound form in the earth's crust and can easily become available by natural sources such as volcanic activity and weathering of minerals, and by anthropogenic activities causing emissions in the environment through man’s use of arsenic containing insecticides, herbicides, fungicides, pesticides, wood preservatives and veterinary or human medicinal drugs and through mining and burning of coal. Thus, anthropogenic use makes arsenic a common inorganic toxicant found at contaminated sites nationwide (Turpeinen, 2002), As a result of naturally occurring metabolic processes in the biosphere arsenic occurs as a large number of organic or inorganic chemical forms in food (species) (Codex, 2011).

It is reported that plants absorb only the soluble arsenic. Greater percentage (over 80%) of total arsenic is strongly associated with iron (Fe) and aluminium (Al), thus a limited fraction of total arsenic is readily available for plants uptake. Bioavailability of arsenic depends on various factors including plant species, the chemical form of arsenic, temperature and application of fertilizers - mainly phosphorous (Heidary-Monfared, 2011).

According to Järup (2003), the general population is exposed to arsenic through the intake of contaminated food and water with food being the main source and in some areas, drinking water being a significant source of exposure to inorganic arsenic. Contaminated soils such as mine-tailings are also a potential source of arsenic exposure. Inorganic arsenic is acutely toxic and intake of large quantities leads to gastrointestinal symptoms, severe disturbances of the cardiovascular and central nervous systems, and eventually death. In survivors, bone marrow depression, haemolysis, hepatomegaly, melanosis, polyneuropathy and encephalopathy may be observed. Ingestion of inorganic arsenic may induce peripheral vascular disease, which in its extreme form leads to gangrenous changes (black foot disease, reported in Taiwan) (Järup 2003).

2.6.2 Cadmium (Cd)

Cadmium is recovered as a by-product from the mining of sulfide ores of lead, zinc and copper. Cadmium compounds are used as stabilizers in PVC products, colour pigment, several alloys and now most commonly, in re-chargeable nickel– cadmium batteries. Metallic cadmium has mostly been used as an anticorrosion agent (cadmiation). Cadmium is also present as a pollutant in phosphate fertilizers (Järup, 2003).

Natural as well as anthropogenic sources of cadmium, including industrial emissions and the application of fertilizer and sewage sludge to farm land, may lead to contamination of soils, and increase cadmium uptake by crops and vegetables, grown for human consumption. The uptake process of soil cadmium by plants is enhanced at low pH (Järup, 2003).

Food is the most important source of cadmium exposure in the general non-smoking population in most countries. Cadmium is present in most foodstuffs, but concentrations vary greatly, and individual intake also varies considerably due to differences in dietary habits.

Women usually have lower daily cadmium intakes, because of lower energy consumption than men. Gastrointestinal absorption of cadmium may be influenced by nutritional factors, such as iron status (WHO, 1992).

Cadmium exposure may cause kidney damage. The first sign of the renal lesion is usually a tubular dysfunction, evidenced by an increased excretion of low molecular weight proteins such as β2-microglobulin and α1-microglobulin (protein HC) or enzymes such as N-Acetyl-β-D-glucosaminidase (NAG). Reports have shown that kidney damage and/or bone effects are likely to occur at lower kidney cadmium levels. Long-term high cadmium exposure may cause skeletal damage, first reported from Japan. The International Agency for Research on Cancer (IARC) has classified cadmium as a human carcinogen (group I) on the basis of sufficient evidence in both humans and experimental animals. Cadmium is also associated with prostate cancer (Järup, 2003).

2.6.3 Lead (Pb)

Lead is a ubiquitous element in nature but biologically non-essential. Lead and its compounds can enter the environment during mining, smelting, processing, use, recycling, and disposal of lead. However, the use of lead in batteries, bearing metals, cable covering, gasoline additives, explosives and ammunition as well as in manufacture of pesticides, antifouling paints and analytical reagents has caused widespread environmental contamination (Turpeinen, 2002).

According to Heidary-Monfared (2011), Lead is absorbed by root hairs and stored mainly in cell walls with concentration differing among the different organs of a plant. He reported that translocation of Pb from roots to tops is limited as only 3% of Pb absorbed via the root will accumulate in the shoot.

Non-smoking adults are exposed to lead through food and water while young children and infants are exposed through food, air, water and dust or soil. High Pb content in vegetables grown in contaminated areas can potentially pose a health risk to consumers. Food intake and age influence the rate of absorption of Pb. Much higher rates of absorption occurs after fasting than when Pb is ingested with a meal and the typical absorption rates in adults and infants are 10% and 50%, respectively. After Pb absorption and distribution in blood, it is initially distributed to soft tissues throughout the body. Eventually, bone accumulates Pb over much of the human life span and may serve as an endogenous source of Pb. The half-life for Pb in blood and other soft tissues is about 28-36 days, but it is much longer in the various bone compartments. The percentage retention of Pb in body stores is higher in children than adults. Lead that is not distributed is mainly excreted through the kidney (WHO, 2000).

Lead is a classical chronic or cumulative poison. In humans, Pb can result in a wide range of biological effects depending upon the level and duration of exposure. Health effects are generally not observed after a single exposure. Many of the effects that have been observed in laboratory animals have also been observed in humans, including hematological effects, neurological and behavioural effects, renal effects, cardiovascular effects, and effects on the reproductive system. Children are more vulnerable to the effects of lead than adults. Lead has been shown to be associated with impaired neurobehavioral functioning in children and has been considered to be the most critical effect (Codex, 2011).

2.6.4 Copper (Cu)

Copper occurs naturally in ores. It is mined as a primary ore product from copper sulfide and oxide ores. It is released into the environment through mining, agriculture and industrial activities. Copper is used extensively in the manufacture of textiles, antifouling paints, electrical conductors, plumbing fixtures, pipes, coins, cooking utensils, wood preservatives, pesticides and fungicides, and copper sulfate fertilizers (Heidary-Monfared, 2011).

The mobility of copper in soil depends on the soil pH and the content of organic compounds and other minerals with which copper might interact. In general, copper has low mobility in plants relative to other elements (Heidary-Monfared, 2011). Sensitivity to the toxic effects of excess dietary copper is influenced by its chemical form, species, and interaction with other dietary minerals. High levels can cause symptoms of acute toxicity, including nausea, abdominal discomfort, diarrhoea, haemoglobinuria and/or haematuria, jaundice, oliguria/anuria, hypotension, coma and death. Histopathological effects have been observed in the gastrointestinal tract, liver and kidney. There is limited information on chronic copper toxicity. However, copper does not appear to be a cumulative toxic hazard for man, except for individuals suffering from Wilson's disease. Copper is not considered to be mutagenic, carcinogenic or affect reproduction (Codex, 2011).

2.6.5 Iron (Fe)

Iron occurs as a natural constituent of all foods of plant and animal origin, and may also be present in drinking water. In food it occurs as iron oxides, inorganic and organic salts or organic complexes such as haem iron. Processing may affect the chemical form of iron. Levels of iron range from low for many fruits, vegetables and fats, to medium for red meats, chicken, eggs, whole wheat flower, to high for organ tissues, fish, green vegetables and tomatoes. Meat and grain contribute to a great part of diet-derived iron. Other important dietary sources include water, beverages and iron medication. Iron fortification of food, and also contamination of food during its preparation could increase the intake of iron. The rate of absorption of iron is affected by the chemical form of the dietary iron, the source of iron (plant or animal), its interaction with other food components and the body's need for iron (mucosal regulation) (Codex, 2011).

The effects of toxic doses of iron in animal studies are characterized by initial depression, coma, convulsion, respiratory failure and cardiac arrest. Post-mortem examination reveals adverse effects on the gastrointestinal tract. No long-term feeding studies are available, however, injection-site tumours have been observed in several animals' studies after injection with iron preparations. Some iron-forms were found positive in mutagenicity tests. No teratogenic effects were observed (Codex, 2011).

In human, acute toxicity of iron ingested from normal dietary sources has not been reported; the amount of iron absorbed in normal subjects is subject to mucosal regulation so that excessive iron is not stored in the body. However, subjects with impaired ability to regulate iron absorption (that is suffering from idiopathic haemochromatosis), will be at risk from excessive exposure to iron. Excess iron intake may result in siderosis (deposition of iron in tissue) in liver, pancreas, adrenals, thyroid, pituitary and heart depending on the chemical form (Codex, 2011).

2.6.6 Zinc (Zn)

Zinc is a ubiquitous metal present in the environment, most rocks and many minerals contain zinc which can be used for the zinc industry. Natural emissions results from erosion and forest fires. Anthropogenic sources are mining, zinc production facilities, iron and steel production, corrosion of galvanized structures, coal and fuel combustion, waste disposal and the use of zinc-containing fertilizers and pesticides. Zinc is utilized as protective coating of other metals, dye casting, construction industry, for alloys, dry cell batteries, dental, medical and household applications, fungicide, topical antibiotics and lubricants (Codex, 2011).

Zinc occurs as a natural constituent in all plant and animal tissues and functions as an integral part of several enzyme systems. Protein foods are important dietary sources of zinc. Levels range from high for oysters with lesser amounts in other seafood, muscle meats, nuts and whole cereals. Sugar, citrus fruits and non-leafy vegetables are poor sources of zinc. Unlike copper and lead, zinc is a relatively mobile element in the plant. Generally, in contaminated soils, roots contain higher concentration of zinc than shoots but in areas where zinc is an airborne pollutant, the opposite is true (Heidary-Monfared, 2011).

Among all heavy metals, zinc is the least toxic and an essential element in human diet as it is required to maintain the functioning of the immune system. Zinc deficiency in the diet may be highly detrimental to human health than too much Zinc in the diet (Kudirat and Funmilayo, 2011). In human, high levels of zinc cause acute effects such as vomiting and gastrointestinal irritation (nausea, cramps, diarrhoea), weakness, anorexia, anaemia, diminished growth, loss of hair, lowered food utilization, changes in the levels of liver and serum enzymes, morphological and enzymatic changes in the brain, and histological and functional changes in the kidney. However when bound to food components (that is meat, oysters) these effects are expected to be less. Impaired copper uptake in humans has been noted following the chronic elevated intake of zinc. Some effects of zinc therefore may be secondary to impaired copper utilization (that is anaemia) (Codex, 2011).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and Size

This study was carried out in the Obuasi Municipality. The Obuasi Municipality lies in the southern part of Ashanti Region of Ghana between latitudes 5º35'N and 5º65'N, and longitudes 6º35'W and 6º90'W. It is the second largest political authority in the region after Kumasi Metropolitan Assembly (KMA) and covers a land area of about 162.4 km^2 with Obuasi being its capital. It is bounded on the south by Upper Denkyira District of the Central Region, east by Adansi South, west by Amansie Central, and north by Adansi North. The municipal capital, Obuasi, is about 64 km drive from Kumasi, the regional capital (OMAMTDP, 2010-2013).

3.1.2 Population Size and Growth

The Obuasi Municipal Assembly's population in 2009 was about 148,200 based on the Municipal Annual Population Growth Rate of 4%. The projected population of the Municipality in 2005 was about 195,000. The projected population of the municipality is about 226,707 in 2010 consisting of 50.5% female and 49.5% male. According to the 2000 Population and Housing Census, the population distribution of the Municipality shows that about 48% of the population is in dependent age groups, that is between 0-14 years and 60 years and over and 52% constitute the potential labour force in the Municipality. This gives age-dependency ratio of about 1:1 implying that every person in the working age group takes care of himself/herself and an additional person (OMAMTDP, 2010-2013)

3.1.3 Climate and Vegetation

The Municipality experiences semi-equatorial climatic conditions with a double maximum rainfall regime. Mean annual rainfall ranges between 125 mm and 175 mm (OMAMTDP, 2010-2013). Temperatures are uniformly high all year with the hottest month being March when 30 ^oC is usually recorded. Mean average annual temperature is 25.5 ^oC. Relative humidity is highest (75% to 80%) in the wet season (OMAMTDP, 2010-2013).

The vegetation is predominantly a degraded semi-deciduous forest. The forest consists of limited species of hardwood, which are harvested as timber. The Municipality has nice scenery due to the hilly nature of the environment. AngloGold Ashanti has maintained large tracts of teak plantation as green belts covering 12.10 km^2 within its concession. Crops grown include citrus, oil palm, cocoa, plantain, maize, cassava and vegetables (OMAMTDP, 2010-2013).

3.1.4 Geology and Soil

Soils in the municipality are predominantly forest ochrosols developed under forest vegetation. They are rich in humus and suitable for both cash and food crops production (OMAMTDP, 2010-2013).

Rocks in the Municipality are mostly of Tarkwain (Pre-cambrian) and Upper Birimian formation which are noted for their rich mineral bearing potentials. Areas around the contacts of the Birimian and Tarkwain zones known as reefs are noted for gold deposits. AngloGold Ashanti Mines has been working on the steeply dipping quartz veins over a strike length of 8 km and has since 1898 produced over 600 tons (18 million ounces) of gold from ore averaging about 0.65 ounces per ton. The rocky hills and out crops in the municipality have immense potential for stone quarrying (OMAMTDP, 2010-2013).

3.1.5 Relief and Drainage

Generally, the Municipality has an undulating terrain with more of the hills rising above 500 meters above sea level. The highest point is located on the Pompo range at 634 metres near Obuasi. Highland ranges include Dampaia (the most extensive) in the east, Kusa in the north east, Pompo and Sanso near Obuasi. No area within the municipality falls below 100 metres above sea level (OMAMTDP, 2010-2013).

The Municipality is drained by streams and rivers which include; Pompo, Nyame, Akapori, and Kunka. Other perennial streams and rivers are Subin, Menson, Kwabrafo, Hweaseamo, Kyeabo, Ankafo, Gyimi and Nyam all of which depict dendritic pattern of flow. These rivers which can be harnessed for irrigation schemes to aid agricultural production are polluted by mining and other human activities. The municipality is endowed with springs which can be tapped as potable drinking water (OMAMTDP, 2010-2013).

3.1.6 Agriculture

Agriculture and its related activities, ranks third in the order of economic activities in the municipality, employing about 25% of the labour force (Service and Commerce sectors and Mining/Industry rank first and second respectively in order of economic activities) (OMAMTDP, 2010-2013). It can be emphasized that mining activities have deprived most farmers' access to fertile lands hence agricultural activities are not that widespread in the municipality. Agriculture is therefore, predominantly on small scale basis in the Municipality. About 90% of farm holdings are less than 2 hectares in size, although there are some large farms and plantations, particularly for citrus, oil palm and cocoa and to a lesser extent maize, cassava, vegetables (pepper, tomatoes, egg plants, okra, cabbage and legumes) and pineapple. Major tree cash crops cultivated are cocoa, citrus, oil palm and teak. Major food crops grown are cassava, maize, yam, rice and cocoyam. Vegetables like pepper, tomatoes, egg plants, okra, cabbage, legumes, groundnut and cowpea are cultivated by subsistence farmers in the municipality. It can be emphasized that labour in the sector has experienced a sharp decline as quite a good number have shifted to the mining sector, hence, reducing annual production levels of crops produced (OMAMTDP, 2010-2013).

3.2 Sampling Sites

Samples were taken from Apitikoko, a community 1 km to the active Southern Tailings Storage Facility (STF) of Anglogold Ashanti Limited and from Kwabenakwa, a community outside AGA concession, 16 km from Apitikoko and 15 km from STF (Fig. 1.). Samples were collected from three farms in Apitikoko and one farm from Kwabenakwa (Fig. 2.). Since Kwabenakwa community was outside AGA concession, far away from the prime-mining activities and free from the influence of surface runoff from the waste rock pile than Apitikoko, the samples collected were also taken to serve as control.

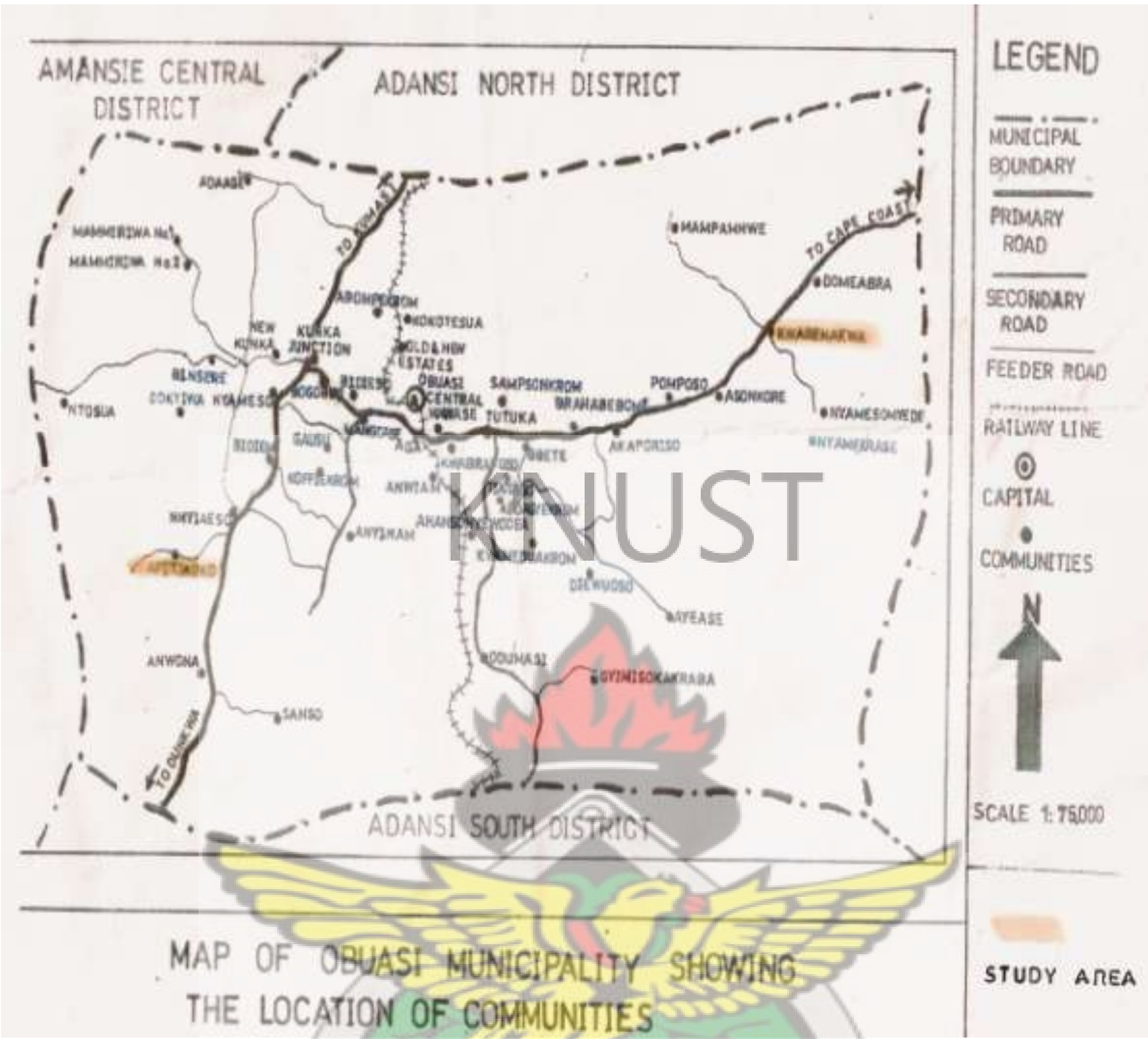

Fig. 1. Map of Obuasi Municipality showing the study areas

In all the four farms sampled, there was mixed cropping of mostly ephemerals and annual food crops like pepper, tomato, cassava, plantain, and cocoyam and in some cases orange trees. There has been continuous cropping of these lands with these same food crops over a period of eight years. Farmers who cultivate these four farms do not use any chemicals on their farms to kill weeds and spray their crops against pests and diseases but rather use the traditional method of weeding with cutlasses and hoes. Farming is greatly dependent on rainfall thus cultivation of the two sampled vegetables is mostly during the rainy season.

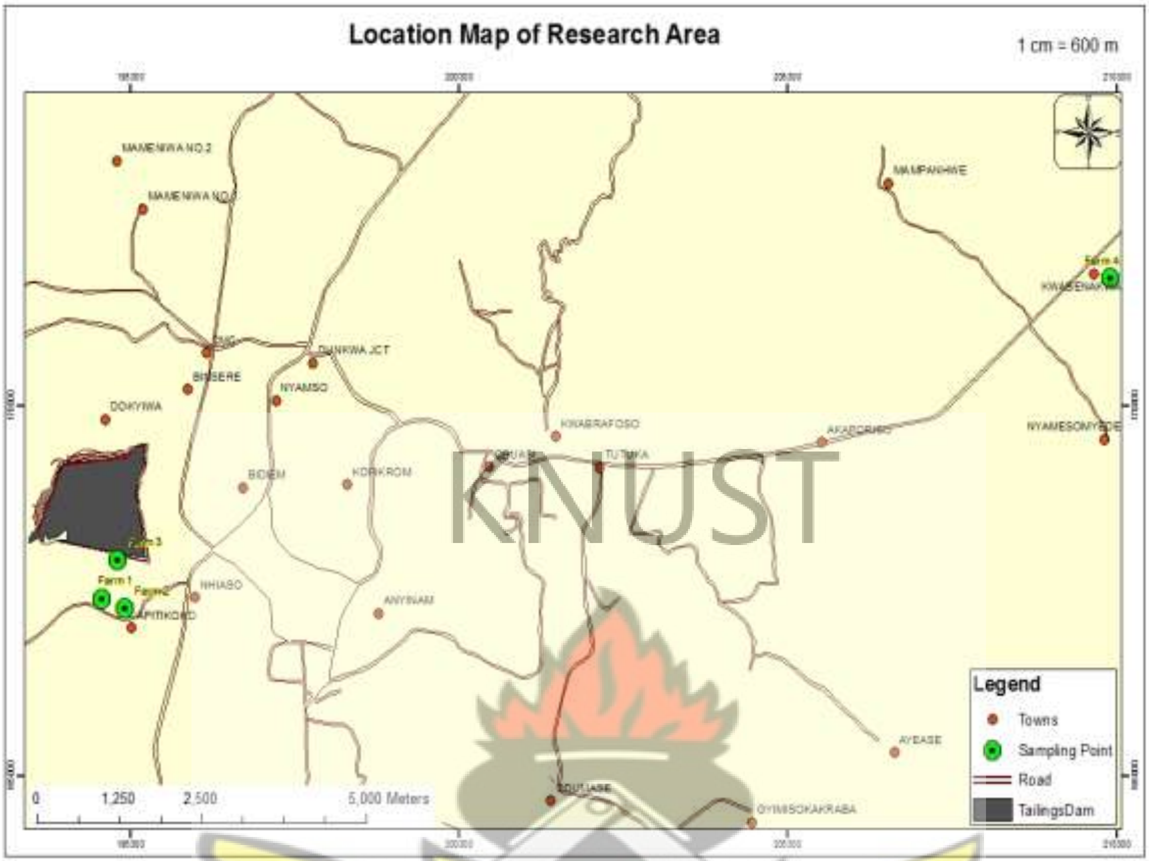

Fig. 2. Map showing the sampling sites

3.3 Sampling of Vegetables and Soil

3.3.1 Vegetable Sampling

The same varieties of the two species of vegetables (*Capsicum annuum* and *Lycopersicon esculentum*) were sampled in all four farms. The samples were collected from the farmlands during the second harvesting season 3 months after sowing. Three sampling plots of 9 m^2 were demarcated within each farmland. Each plot served as replicate. Within each plot samples of six plants of each vegetable (*Capsicum annuum* and *Lycopersicon esculentum*) were randomly collected or harvested. The samples of plants were then separated into fruits, shoots and roots and placed into separate polythene bags and labelled according to their plant type, part and farmland. They were then taken to the laboratory for preparation and analysis.

A total of 72 samples were collected. The 4 farms, each having 3 replicates of the two vegetables, separated into 3 parts.

3.3.2 Soil Sampling

Soil samples (5 g) around the roots (rhizosphere) of the plants harvested from each plot were collected when the plants were uprooted. These samples were mixed together (homogenize) to get a uniform sample. This was done for each of the three plots of each farmland. A total of 12 samples were collected from the four farms.

3.4 Preparation and Laboratory Analysis of Samples

3.4.1 Vegetables Preparation and Digestion

The collected samples were separately washed first with tap water then with distilled water to eliminate suspended particles. The calyx and pedicel were removed from all fruit samples and added to their respective shoots. Samples were cut into smaller pieces with a plastic knife. The samples were put in different crucibles and ash in a furnace at 650 ^{o}C for two hours. A quantity of the ash (0.4 g) from each plant sample was weighed separately into a beaker. To each, 3 ml of concentrated HCl and 1 ml of concentrated HNO_3 were added, and heated on a hot plate at 100 ^{o}C for 10 minutes to destroy any oxidizable materials and carbonates. The solutions were topped with deionised water to the 30 ml mark and filtered using a Whatman filter paper (Student grade). The filtrate were analysed for the presence of heavy metals.

3.4.2 Soil Preparation and Digestion

Unwanted materials were removed from the soil. Soil samples were air dried in a clean room to avoid contamination and ground to pass through 600 μm sieve and stored in polyethylene bags for analysis. 0.4 g of soil samples from each of the farm lands were weighed separately into a beaker, to each, 3 ml of concentrated HCl and 1 ml of concentrated HNO_3 were added and heated on a hot plate at 100 ^oC for 10 minutes to destroy any oxidizable materials and carbonates. The solutions were topped with deionised water to the 30 ml mark and filtered using a Whatman filter paper (Student grade). The filtrate were analysed for the presence of heavy metals.

Blank samples made from only reagents without sample were analyzed to get rid of any background concentration metals in the system.

3.5 How the Atomic Absorption Spectrometer (AAS) works

Atomic Absorption Spectrometer (AAS) was used for the analytical determination of the heavy metals. The instrument uses light to measure the concentration of gas phase atoms. The atoms absorb light and make transitions to higher energy levels. Since each element has a unique electronic structure, the wavelength of light at which the absorption would take place is a unique property of each individual element. The source of light is a hallow cathode lamp made of the same element as the metal of interest. The metal concentration is determined from the amount of light absorbed.

To determine the concentration of heavy metals of interest filtrates were aspirated into the excitation region of the AAS where they were desolvated, vaporised and atomised by a flame discharge. The monochromator was used to isolate the specific wavelength of light emitted by the hallow cathode lamp from the non-analytical ones. The hallow cathode lamp used depended on the metal being analysed. A light sensitive detector measured the absorbed light and a computer measured the response of the detector and translated this into concentration.

3.6 Data Analysis

Means and standard deviations of the concentrations of the heavy metals for the various samples were calculated with Microsoft Office Excel (2007) Spread Sheet. Concentrations of heavy metals were expressed as mean ± SDM (Standard Deviation of the Mean). Data obtained were subjected to Analysis of Variance (ANOVA) using SPSS version 16 with values for $p < 0.05$ considered significantly different. Least Significant Difference (LSD) was used to identify significant differences between the means. Results were presented in tables and graphs.

3.7 Quality Assurance

- Samples were refrigerated to prevent change in composition prior to analysis
- Plastic knives were used during homogenisation of the samples so as to eliminate possible contamination from the use of metal knives.
- To ensure accurate determination of concentration by the AAS, various standards of the heavy metals of interest were used.
- Blank samples made from only reagents without sample were analyzed to get rid of any background concentration metals in the system.

CHAPTER FOUR

4.0 RESULTS

4.1 Heavy metal concentrations in the fruits of *Capsicum annuum* and *Lycopersicon esculentum*

4.1.1 Comparison between the levels of heavy metals in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* and Codex and WHO standards

The results of the mean concentrations of heavy metals (As, Cd, Pb, Cu, Fe and Zn) in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* sampled in four farmlands in two farming communities in Obuasi are represented in Table 1. All the heavy metal levels determined in the two fruits in all four farms exceeded the standard maximum value for fruit vegetables set by Codex (2011) and maximum acceptable daily intake set by WHO (1996) (Table 1).

4.1.2 Levels of heavy metals in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

The Fe concentration in both vegetable fruits in all the farms was highest with mean concentration ranging from 163.58 to 442.01 mg/kg for *Capsicum annuum* fruits and 604.35 to 1120.33 mg/kg for *Lycopersicon esculentum* fruits. It was followed by Zn with mean concentration ranging from 81.54 to 340.31 mg/kg for *Capsicum annuum* fruist and 146.21 to 289.54 mg/kg for *Lycopersicon esculentum* fruits. Cadmium (Cd) recorded the lowest mean concentration, ranging from 1.37 to 2.63 mg/kg for *Capsicum annuum* fruits and 1.48 to 2.78 mg/kg for *Lycopersicon esculentum* fruits. The ranking of heavy metals concentrations in both vegetable fruits in decreasing order was as follows:- Fe>Zn>As>Cu>Pb>Cd (Table 1).

For *Capsicum annuum* fruits the highest concentration of heavy metal recorded by Fe was obtained in Farm 2. Farm 2 also recorded the highest mean concentration for Zn. The highest mean concentrations of Cd, Pb and Cu were recorded in Farm 3 whilst Farm 4 recorded the highest mean concentration for As. The lowest mean concentrations of Cd, Pb, Cu and Fe in the fruits of *Capsicum annuum* were obtained in Farm 4. Farm 3 recorded lowest mean concentration for As whilst Farm 1 recorded lowest concentration for Zn (Table 1).

For *Lycopersicon esculentum* fruits the highest mean concentration for Cd, Pb, Cu, Fe and Zn were recorded in Farm 1 whilst Farm 2 recorded the highest mean concentration for As. Lowest mean concentration of Cd, Pb, Cu and Zn for *Lycopersicon esculentum* fruits were obtained in Farm 4. Farm 3 recorded the lowest mean concentration for Fe whilst Farm 1 recorded the lowest mean concentration for As (Table 1).

Lycopersicon esculentum fruits in Farms 1, 2 and 4 recorded higher metal concentrations than *Capsicum annuum* fruits with the exception of As for Farms 1 and 4. At Farm 3, the closest to the STF, *Capsicum annuum* fruits recorded higher mean concentrations for As, Cd, Pb and Cu than *Lycopersicon esculentum* fruits. In general the concentration of the heavy metals in *Lycopersicon esculentum* fruits were higher than *Capsicum annuum* fruits (Table 1).

4.1.3 Levels of Arsenic in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In general the mean concentrations of As for both vegetable fruits among the four farms were significantly different. However, there were not significantly difference between *Lycopersicon esculentum* fruits in Farms 1 and 3, and *Lycopersicon esculentum* fruits in Farm 4 and *Capsicum annuum* fruits in Farm 2 ($p<0.05$) (Table 1).

The highest level of As in *Capsicum annuum* fruits was recorded in Farm 4 (90.58 mg/kg). It was 196% higher than the level of As in *Capsicum annuum* fruist in Farm 3 (30.56 mg/kg) and 97% higher than that of Farm 1 (45.98 mg/kg). The level of As in *Capsicum annuum* fruits in Farm 4 was 15% higher than that of Farm 2 (78.84 mg/kg) (Table 1).

The highest level of As in *Lycopersicon esculentum* fruits was recorded in Farm 2 (86.25 mg/kg). It was 2691% higher than the level of As in *Lycopersicon esculentum* fruits in Farm 1 (3.09 mg/kg) and 2257% higher than that of Farm 3 (3.66 mg/kg). The level of As in *Lycopersicon esculentum* fruits in Farm 2 was 7% higher than that of Farm 4 (80.78 mg/kg) (Table 1). The ranking of As concentrations in both vegetable fruits among the four farms in decreasing order was as follows:- F4*Ca*>F2*Le*>F4*Le*>F2*Ca*>F1*Ca*>F3*Ca*>F3*Le*=F1*Le* (Table 1).

4.1.4 Levels of Cadmium in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

Generally, the mean concentrations of Cd for both vegetable fruits in all four farms were significantly different. However, levels of Cd for *Capsicum annuum* fruits in Farms 1 and 4 and *Lycopersicon esculentum* fruits in Farm 4 were not significantly different. Similarly, Cd levels for *Capsicum annuum* fruits in Farms 1 and 2 and *Lycopersicon esculentum* fruits in Farm 4 were not significantly different. Also, Cd levels for *Lycopersicon esculentum* fruits in Farms 1 and 2 and *Capsicum annuum* fruits in Farm 3 were not significantly different. Again, there was no significant difference between Cd levels for *Capsicum annuum* fruits in Farm 2 and *Lycopersicon esculentum* fruits in Farm 3 (Table 1).

The highest level of Cd in *Capsicum annuum* fruits was recorded in Farm 3 (2.63 mg/kg). It was 92% higher than the Cd level in *Capsicum annuum* fruits in Farm 4 (1.37 mg/kg) and 56% higher than that of Farm 1 (1.69 mg/kg). The level of Cd in *Capsicum annuum* fruits in Farm 3 was 43% higher than that of Farm 2 (1.84 mg/kg) (Table 1).

The highest level of Cd in *Lycopersicon esculentum* fruits was recorded in Farm 1 (2.78 mg/kg). It was 88% higher than the Cd level in *Lycopersicon esculentum* fruits in Farm 4 (1.48 mg/kg) and 29% higher than that of Farm 3 (2.16 mg/kg). The level of Cd in *Lycopersicon esculentum* fruits in Farm 1 was 5% higher than that of Farm 2 (2.64 mg/kg). The ranking of Cd concentrations in both vegetable fruits among the four farms in decreasing order was as follows:-F1*Le*=F2*Le*=F3*Ca*>F3*Le*≥F2*Ca*≥F1*Ca*=F4*Le*≥F4*Ca* (Table 1).

4.1.5 Levels of Lead in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In general, the mean concentrations of Pb for both vegetable fruits in all four farms were significantly different. However, levels of Pb for *Lycopersicon esculentum* fruits in Farms 3 and 4 were not significantly different. Similarly, levels of Pb for *Capsicum annuum* fruits in Farm 3 and *Lycopersicon esculentum* fruits in Farm 1 were not significantly different. Also, levels of Pb for *Lycopersicon esculentum* fruits in Farms 1 and 2 were not significantly different (Table 1).

The highest level of Pb in *Capsicum annuum* fruits was recorded in Farm 3 (21.30 mg/kg). It was 107% higher than the Pb level in *Capsicum annuum* fruits in Farm 4 (10.28 mg/kg) and 65% higher than that of Farm 2 (12.92 mg/kg). The level of Pb in *Capsicum annuum* fruits in Farm 3 was 55% higher than that of Farm 1 (13.76 mg/kg) (Table 1).

The highest level of Pb in *Lycopersicon esculentum* fruit was recorded in Farm 1(20.98 mg/kg). It was 17% higher than the Pb levels in *Lycopersicon esculentum* fruits in Farms 3 and 4 (17.96 mg/kg and17.89 mg/kg respectively) and 3% higher than that of Farm 2 (20.40 mg/kg). The ranking of Pb concentrations in both vegetable fruits in the decreasing order was as follows:- F3*Ca*≥F1*Le*≥F2*Le*>F3*Le*=F4*Le*>F1*Ca*>F2*Ca*>F4*Ca* (Table 1).

4.1.6 Levels of Copper in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

Generally, the mean concentrations of Cu for both vegetable fruits in all four farms were significantly different. Nevertheless, levels of Cu for *Lycopersicon esculentum* fruits in Farm 1 and *Capsicum annuum* fruits in Farm 3 were not significantly different. Similarly, levels of Cu for *Capsicum annuum* fruits in Farm 1 and *Lycopersicon esculentum* fruits in Farm 3 were not significantly different (Table 1).

The highest level of Cu in *Capsicum annuum* fruits was recorded in Farm 3 (54.94 mg/kg). It was 107% higher than the Cu level in *Capsicum annuum* fruits in Farm 4 (20.55 mg/kg) and 71% higher than that of Farm 1 (32.06 mg/kg). The level of Cu in *Capsicum annuum* fruits in Farm 3 was 22% higher than that of Farm 2 (45.17 mg/kg) (Table 1).

The highest level of Cu in *Lycopersicon esculentum* fruits was recorded in Farm 1(55.28 mg/kg). It was 97% higher than the Cu level in *Lycopersicon esculentum* fruits in Farm 4 (28.07 mg/kg) and 74% higher than that of Farm 3 (31.86 mg/kg). The level of Cu in *Lycopersicon esculentum* fruits in Farm 1 was 20% higher than that of Farm 2 (45.90 mg/kg). The ranking of Cu concentrations in both vegetable fruits among the four farms in decreasing order was as follows:- F1*Le*=F3*Ca* >F2*Le*>F2*Ca*>F1*Ca*=F3*Le*>F4*Le*>F4*Ca* (Table 1).

4.1.7 Levels of Iron in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In generally, the mean concentrations of Fe for both vegetable fruits in all four farms were significantly different (Table 1). The highest level of Fe in *Capsicum annuum* fruits was recorded in Farm 2 (442.01 mg/kg). It was 170% higher than the Fe level in *Capsicum annuum* fruits in Farm 4 (163.58 mg/kg) and 134% higher than that of Farm 1 (189.02 mg/kg). The level of Fe in *Capsicum annuum* fruits in Farm 2 was 43% higher than that of Farm 3 (309.71 mg/kg) (Table 1).

The highest level of Fe in *Lycopersicon esculentum* fruits was recorded in Farm 1(1120.33 mg/kg). It was 85% higher than the Fe level in *Lycopersicon esculentum* fruits in Farm 3 (604.35 mg/kg) and 50% higher than that of Farm 4 (745.43 mg/kg). The level of Fe in *Lycopersicon esculentum* fruits in Farm 1 was 13% higher than that of Farm 2 (988.84 mg/kg). The ranking of Fe concentrations in both vegetable fruits among the four farms in decreasing order was as follows:-F1*Le*>F2*Le*>F4*Le*>F3*Le* >F2*Ca*>F3*Ca*>F1*Ca*>F4*Ca* (Table 1).

4.1.8 Levels of Zinc in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

Generally, the mean concentrations of Zn for both vegetable fruits in all four farms were significantly different (Table 1). The highest level of Zn in *Capsicum annuum* fruits was recorded in Farm 2 (340.31 mg/kg). It was 317% higher than the Zn level in *Capsicum annuum* fruits in Farm 1 (81.54 mg/kg) and 253% higher than that of Farm 4 (96.54 mg/kg). The level of Zn in *Capsicum annuum* fruits in Farm 2 was 93% higher than that of Farm 3 (176.04 mg/kg) (Table 1).

The highest level of Zn in *Lycopersicon esculentum* fruits was recorded in Farm 1(289.54 mg/kg). It was 98% higher than the Zn level in *Lycopersicon esculentum* fruits in Farm 4 (146.21 mg/kg) and 54% higher than that of Farm 3 (187.41 mg/kg). The level of Zn in *Lycopersicon esculentum* fruits in Farm 1 was 23% higher than that of Farm 2 (235.26 mg/kg). The ranking of Zn concentrations in both vegetable fruits among the four farms in decreasing order was as follows:- F2*Ca*>F1*Le*>F2*Le*>F3*Le*>F3*Ca*>F4*Le*>F4*Ca*>F1*Ca* (Table 1).

4.1.9 General ranking of the four farms in terms of heavy metals concentrations in the fruits of *Capsicum annuum* and *Lycopersicon esculentum*

Taking all the heavy metals into consideration for each vegetable within each farm, the decreasing order of levels of heavy metals in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* was as follows:- F1*Le*=F2*Le*>F3*Ca*>F2*Ca*>F3*Le*>F4*Le*>F1*Ca*> F4*Ca*. Taking all the heavy metals into consideration for both vegetables within each farm, the decreasing order of levels of heavy metals in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* was as follows:- F2>F3>F1>F4.

4.1.10 Mean difference in concentrations of the heavy metals in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

There were significant differences between the mean concentrations of all the heavy metals in *Capsicum annuum* fruits in all four farms (Table 2). Generally, there were significant differences between the mean levels of all the heavy metals in all four farms for *Lycopersicon esculentum* fruits. Nonetheless, levels of As and Cd in Farms 1 and 3 were not significantly different (Table 2).

Table 1. Mean concentration of heavy metals (mg/kg) in *Capsicum annuum* and *Lycopersicon esculentum* fruits cultivated in four farms in two farming communities in Obuasi

FARM	SAMPLE	As	Cd	Pb	Cu	Fe	Zn
Farm 1	*Capsicum annuum* fruit	45.98±2.50 ^{c}	1.69±0.16 $^{a b}$	13.76±0.91 ^{c}	32.06±0.50 ^{c}	189.02±3.87 ^{b}	81.54±1.29 ^{a}
	Lycopersicon esculentum fruit	3.09±0.63 ^{a}	2.78±0.36 ^{d}	20.98±0.51 $^{e f}$	55.28±0.62 ^{f}	1120.33±4.05 ^{h}	289.54±0.51 ^{g}
Farm 2	*Capsicum annuum* fruit	78.84±0.16 ^{d}	1.84±0.18 $^{b c}$	12.92±0.20 ^{b}	45.17±0.66 ^{d}	442.01±0.44 ^{d}	340.31±1.16 ^{h}
	Lycopersicon esculentum fruit	86.25±2.43 ^{e}	2.64±0.38 ^{d}	20.40±0.38 ^{e}	45.90±0.37 ^{e}	988.84±1.55 ^{g}	235.26±3.57 ^{f}
Farm 3	*Capsicum annuum* fruit	30.56±0.35 ^{b}	2.63±0.22 ^{d}	21.30±0.64 ^{f}	54.94±0.47 ^{f}	309.71±2.87 ^{c}	176.04±1.25 ^{d}
	Lycopersicon esculentum fruit	3.66±0.38 ^{a}	2.16±0.29 ^{c}	17.96±0.18 ^{d}	31.86±0.30 ^{c}	604.35±3.06 ^{e}	187.41±0.50 ^{e}
Farm 4	*Capsicum annuum* fruit	90.58±0.22 ^{f}	1.37±0.17 ^{a}	10.28±0.1 ^{a}	20.55±0.12 ^{a}	163.58±0.14 ^{a}	96.54±1.20 ^{b}
	Lycopersicon esculentum fruit	80.78±0.57 ^{d}	1.48±0.13 $^{a b}$	17.89±0.10 ^{d}	28.07±0.43 ^{b}	745.43±1.03 ^{f}	146.21±5.97 ^{c}
Standard	FV (Codex) (mg/kg)	0.1	0.05	0.1	0.5	0.8	1
	MADI (WHO) (mg/day)	0.2	0.5	0.36	12	45	45

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

Table 2. Differences in mean concentration of heavy metals (mg/kg) in *Capsicum annuum* and *Lycopersicon esculentum* fruits cultivated in four farms in two farming communities in Obuasi

	Farm 1		Farm 2		Farm 3		Farm 4	
Metal	*Capsicum annuum* fruit	*Lycopersicon esculentum* fruit	*Capsicum annuum* fruit	*Lycopersicon esculentum* fruit	*Capsicum annuum* fruit	*Lycopersicon esculentum* fruit	*Capsicum annuum* fruit	*Lycopersicon esculentum* fruit
As	45.98±2.50 [d]	3.09±0.63 [a]	78.84±0.16 [d]	86.25±2.43 [d]	30.56±0.35 [c]	3.66±0.38 [a]	90.58±0.22 [d]	80.78±0.57 [d]
Cd	1.69±0.16 [a]	2.78±0.36 [a]	1.84±0.18 [a]	2.64±0.38 [a]	2.63±0.22 [a]	2.16±0.29 [a]	1.37±0.17 [a]	1.48±0.13 [a]
Pb	13.76±0.91 [b]	20.98±0.51 [b]	12.92±0.20 [b]	20.40±0.38 [b]	21.30±0.64 [b]	17.96±0.18 [b]	10.28±0.10 [b]	17.89±0.10 [b]
Cu	32.06±0.50 [c]	55.28±0.62 [c]	45.17±0.66 [c]	45.90±0.37 [c]	54.94±0.47 [d]	31.86±0.30 [c]	20.55±0.12 [c]	28.07±0.43 [c]
Fe	189.02±3.87 [f]	1120.33±4.05 [e]	442.01±0.44 [f]	988.84±1.55 [f]	309.71±2.87 [f]	604.35±3.06 [e]	163.58±0.14 [f]	745.43±1.03 [f]
Zn	81.54±1.29 [e]	289.54±0.51 [d]	340.31±1.16 [e]	235.26±3.57 [e]	176.04±1.25 [e]	187.41±0.50 [d]	96.54±1.20 [e]	146.21±5.97 [e]

Means in same column with different letters in superscripts differ significantly ($p < 0.05$).

4.2 Heavy metal concentrations in the shoots of *Capsicum annuum* and *Lycopersicon esculentum*

4.2.1 Comparison between levels of heavy metals in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* and Normal Plant Values and Range of Critical Plant Concentration

The mean concentrations of heavy metals (As, Cd, Pb, Cu, Fe and Zn) in *Capsicum annuum* and *Lycopersicon esculentum* shoots sampled in four farmlands in two farming communities in Obuasi are represented in Table 3. All the heavy metals levels determined except As, in the two vegetable shoots exceeded the Normal Plant Values (NPV) of heavy metals stated by Sharma and Chettri (2005). However, Cd in *Lycopersicon esculentum* shoot in Farm 1 was below the standard. Again, all the heavy metals except As and Fe determined in the two vegetable shoots were below and within the Range of Critical Plant Concentration (CPC) as stated by Sharma and Chettri (2005). Nonetheless, Zn concentrations in the two vegetable shoots in all four farms were above the range. Similarly, Cu concentration in *Capsicum annuum* shoots in Farms 1, 3 and 4 were above the range. Arsenic (As) levels determined in the shoots of the two vegetables exceeded the Swiss tolerable level of As in food plants stated by Gulz (2005) (Table 3).

4.2.2 Levels of heavy metals in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

The Fe concentration in both vegetable shoots in all four farms was highest with mean range concentration of 929.53 to 1,127.93 mg/kg for *Capsicum annuum* shoots and 584.85 to 1,208.55 mg/kg for *Lycopersicon esculentum* shoots. It was followed by Zn with mean range concentration of 409.93 to 878.89 mg/kg for *Capsicum annuum* shoots and 411.26 to 857.19 mg/kg for *Lycopersicon esculentum* shoots. Cadmium (Cd) recorded the lowest mean concentration of 4.84 to 5.89 mg/kg for *Capsicum annuum* shoots and 1.80 to 3.69 mg/kg for *Lycopersicon esculentum* shoots. The ranking of heavy metals concentrations in both shoots among the four farms in decreasing order was as follows:- Fe>Zn>Cu>As>Pb>Cd (Table 3).

For *Capsicum annuum* shoots the highest mean concentrations of Pb and Fe were recorded in Farm 1. The highest mean concentration of Cd, Cu and Zn were recorded in Farm 3 whilst Farm 4 recorded the highest mean concentration for As. The lowest mean concentrations of As, Cu and Zn in the shoots of *Capsicum annuum* were obtained in Farm 2. The lowest mean concentrations for Cd, Fe and Pb were recorded in Farms 1, 3 and 4 respectively (Table 3).

For *Lycopersicon esculentum* shoots the highest mean concentrations of As, Pb, Cu and Zn were recorded in Farm 4 whilst Farm 2 recorded the highest mean concentration for Cd and Fe. The lowest concentrations of As, Cd, Pb and Cu in the shoots of *Lycopersicon esculentum* were obtained in Farm 1. Farm 2 recorded lowest concentrations of Zn whilst Farm 4 recorded lowest concentration of Fe (Table 3).

Capsicum annuum shoots recorded higher heavy metal concentrations than *Lycopersicon esculentum* shoots in all the Farms. However, in Farms 1 and 2 Fe level for *Lycopersicon esculentum* shoots was higher than *Capsicum annuum* shoots. Similarly, Zn levels for *Lycopersicon esculentum* shoots in Farms 1, 2 and 4 were higher than *Capsicum annuum* shoots. Also, Pb level for *Lycopersicon esculentum* shoots in Farm 4 was higher than *Capsicum annuum* shoots. Again, As level for *Lycopersicon esculentum* shoots in Farm 2 was higher than *Capsicum annuum* shoots (Table 3).

4.2.3 Levels of Arsenic in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In general the mean concentrations of As for both vegetable shoots in all four farms were significantly different ($p<0.05$) (Table 3). The highest level of As in *Capsicum annuum* shoots was recorded in Farm 4 (202.82 mg/kg). It was 496% higher than the level of As in *Capsicum annuum* shoots in Farm 2 (34.03 mg/kg) and 397% higher than that of Farm 1 (40.83 mg/kg). The level of As in *Capsicum annuum* shoots in Farm 4 was 33% higher than that of Farm 3 (152.12 mg/kg) (Table 3).

The highest level of As in *Lycopersicon esculentum* shoots was recorded in Farm 4 (133.74 mg/kg). It was 3294% higher than the level of As in *Lycopersicon esculentum* shoots in Farm 1 (3.94 mg/kg) and 1450% higher than that of Farm 3 (8.63 mg/kg). The level of As in *Lycopersicon esculentum* shoots in Farm 4 was 235% higher than that of Farm 2 (39.98 mg/kg) (Table 3). The ranking of As concentrations in both vegetable shoots among the four farms in decreasing order was as follows:-F4*Ca*>F3*Ca*>F4*Le*>F1*Ca*>F2*Le*>F2*Ca*>F3*Le*> F1*Le* (Table 3).

4.2.4 Levels of Cadmium in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In general the mean concentrations of Cd for both vegetable shoots in all four farms were significantly different. However, levels of Cd for *Lycopersicon esculentum* shoots in Farms 2, 3 and 4 were not significantly different, Similarly, Cd levels for *Capsicum annuum* shoots in Farms 1 and 4 were not significantly different. Also, Cd levels for *Capsicum annuum* shoots in Farms 2 and 4 were not significantly different (Table 3).

The highest level of Cd in *Capsicum annuum* shoots was recorded in Farm 3 (5.89 mg/kg). It was 22% higher than the level of Cd in *Capsicum annuum* shoots in Farm 1 (4.84 mg/kg) and 12% higher than that of Farm 4 (5.27 mg/kg). The level of Cd in *Capsicum annuum* shoots in Farm 3 was 9% higher than that of Farm 2 (5.40 mg/kg) (Table 3).

The highest level of Cd in *Lycopersicon esculentum* shoots was recorded in Farm 2 (3.92 mg/kg). It was 118% higher than the level of Cd in *Lycopersicon esculentum* shoots in Farm 1 (1.80 mg/kg) and 12% higher than that of Farm 4 (3.49 mg/kg). The level of Cd in *Lycopersicon esculentum* shoots in Farm 2 was 6% higher than that of Farm 3 (3.69 mg/kg) (Table 3). The ranking of Cd concentrations in both vegetable shoots among the four farms in decreasing order was as follows:- F3*Ca*>F2*Ca*≥F4*Ca*≥F1*Ca*>F2*Le*=F3*Le*=F4*Le*>F1*Le* (Table 3).

4.2.5 Levels of Lead in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

Generally, the mean concentrations of Pb for both vegetable shoots in all four farms were significantly different (Table 3). The highest level of Pb in *Capsicum annuum* shoots was recorded in Farm 1 (41.96 mg/kg). It was 23% higher than the level of Pb in *Capsicum annuum* shoots in Farm 4 (34.16 mg/kg) and 19% higher than that of Farm 2 (35.34 mg/kg). The level of Pb in *Capsicum annuum* shoots in Farm 1 was 13% higher than that of Farm 3 (37.03 mg/kg) (Table 3).

The highest level of Pb in *Lycopersicon esculentum* shoots was recorded in Farm 2 (29.16 mg/kg). It was 61% higher than the level of Pb in *Lycopersicon esculentum* shoots in Farm 1 (18.13 mg/kg) and 20% higher than that of Farm 3 (24.24 mg/kg). The level of Pb in

Lycopersicon esculentum shoots in Farm 2 was 15% higher than that of Farm 4 (25.33 mg/kg) (Table 3). The ranking of Pb concentrations in both vegetable shoots among the four farms in decreasing order was as follows:-F1*Ca*>F3*Ca*>F2*Ca*>F4*Ca*>F2*Le*>F4*Le*>F3*Le*> F1*Le* (Table 3).

4.2.6 Levels of Copper in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In general the mean concentrations of Cu for both vegetable shoots in all four farms were significantly different (Table 3). The highest level of Cu in *Capsicum annuum* shoots was recorded in Farm 3 (170.63 mg/kg). It was 212% higher than the level of Cu in *Capsicum annuum* shoots in Farm 2 (54.73 mg/kg) and 49% higher than that of Farm 1 (114.47 mg/kg). The level of Cu in *Capsicum annuum* shoots in Farm 3 was 41% higher than that of Farm 4 (121.44 mg/kg) (Table 3).

The highest level of Cu in *Lycopersicon esculentum* shoots was recorded in Farm 4 (97.11 mg/kg). It was 165% higher than the level of Cu in *Lycopersicon esculentum* shoots in Farm 1 (36.69 mg/kg) and 130% higher than that of Farm 2 (42.21 mg/kg). The level of Cu in *Lycopersicon esculentum* shoots in Farm 4 was 31% higher than that of Farm 3 (73.97 mg/kg) (Table 3). The ranking of Cu concentrations in both vegetable shoots among the four farms in decreasing order was as follows:- F3*Ca*>F4*Ca*>F1*Ca*>F4*Le*>F3*Le*>F2*Ca*>F2*Le*> F1*Le* (Table 3).

4.2.7 Levels of Iron in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

Generally, the mean concentrations of Fe for both vegetable shoots in all four farms were significantly different. However, levels of Fe for *Lycopersicon esculentum* shoots in Farms 1 and 2 were not significantly different. Similarly, Fe levels for *Lycopersicon esculentum* shoots in Farm 3 and 4 were not significantly different (Table 3).

The highest level of Fe in *Capsicum annuum* shoots was recorded in Farm 1 (1127.93 mg/kg). It was 21% higher than the level of Fe in *Capsicum annuum* shoots in Farm 3 (929.53 mg/kg) and 15% higher than that of Farm 2 (981.38 mg/kg). The level of Fe in *Capsicum annuum* shoots in Farm 1 was 7% higher than that of Farm 4 (1056.79 mg/kg) (Table 3).

The highest level of Fe in *Lycopersicon esculentum* shoots was recorded in Farm 2 (1208.55 mg/kg). It was 107% higher than the level of Fe in *Lycopersicon esculentum* shoots in Farm 4 (584.85 mg/kg) and 105% higher than that of Farm 3 (588.32 mg/kg). The level of Fe in *Lycopersicon esculentum* shoots in Farm 2 was 0.3% higher than that of Farm 1 (1205.03 mg/kg) (Table 3). The ranking of Fe concentrations in both vegetable shoots among the four farms in decreasing order was as follows:- F2*Le*=F1*Le*>F1*Ca*>F4*Ca*>F2*Ca*>F3*Ca*>F3*Le*= F4*Le* (Table 3).

4.2.8 Levels of Zinc in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In general, the mean concentrations of Zn for both vegetable shoots in all four farms were significantly different. However, levels of Zn for *Capsicum annuum* shoots and *Lycopersicon esculentum* shoots in Farm 2 were not significantly different (Table 3).

The highest level of Zn in *Capsicum annuum* shoots was recorded in Farm 3 (878.89 mg/kg). It was 114% higher than the level of Zn in *Capsicum annuum* shoots in Farm 2 (409.93 mg/kg) and 103% higher than that of Farm 1 (432.79 mg/kg). The level of Zn in *Capsicum annuum* shoots in Farm 3 was 82% higher than that of Farm 4 (483.26 mg/kg) (Table 3).

The highest level of Zn in *Lycopersicon esculentum* shoots was recorded in Farm 4 (857.19 mg/kg). It was 108% higher than the level of Zn in *Lycopersicon esculentum* shoots in Farm 2 (411.26 mg/kg) and 16% higher than that of Farm 1 (740.63 mg/kg). The level of Zn in *Lycopersicon esculentum* shoots in Farm 4 was 13% higher than that of Farm 3 (759.09 mg/kg) (Table 3). The ranking of Zn concentrations in both vegetable shoots among the four farms in decreasing order was as follows:- F3*Ca*>F4*Le*>F3*Le*>F1*Le*>F4*Ca*>F1*Ca*>F2*Le*= F2*Ca* (Table 3).

4.2.9 General ranking of the four farms in terms of heavy metals concentrations in the shoots of *Capsicum annuum* and *Lycopersicon esculentum*

Taking all the heavy metals into consideration for each vegetable within each farm, the decreasing order of levels of heavy metals in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* was as follows:- F3*Ca*>F4*Ca*>F1*Ca*>F4*Le*>F2*Ca*>F2*Le*>F3*Le*> F1*Le*. Taking all the heavy metals into consideration for both vegetables within each farm, the decreasing order of levels of heavy metals in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* was as follows:- F4>F3>F1>F2.

4.2.10 Mean difference in concentrations of the heavy metals in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

There were significant differences between the mean concentrations of all the heavy metals in *Capsicum annuum* shoots in all four farms. Nevertheless, levels of As and Pb in Farm 1 were not significantly different (Table 4). In general, there were significant differences between the mean levels of all the heavy metals in all four farms for *Lycopersicon esculentum* shoots. However, levels of As and Cd in Farm 1 were not significantly different. Similarly, levels of As and Cu in Farm 2 were not significantly different (Table 4).

Table 3. Mean concentration of heavy metals (mg/kg) in *Capsicum annuum* and *Lycopersicon esculentum* shoots cultivated in four farms in two farming communities in Obuasi

FARM	SAMPLE	As	Cd	Pb	Cu	Fe	Zn
Farm 1	*Capsicum annuum* shoot	40.83±1.25 ^{e}	4.84±0.23 ^{c}	41.96±0.32 ^{h}	114.47±0.11 ^{f}	1127.93±3.37 ^{e}	432.79±1.02 ^{b}
	Lycopersicon esculentum shoot	3.94±0.26 ^{a}	1.80±0.37 ^{a}	18.13±0.11 ^{a}	36.69±0.21 ^{a}	1205.03±4.60 ^{f}	740.63±0.70 ^{d}
Farm 2	*Capsicum annuum* shoot	34.03±1.07 ^{c}	5.40±0.18 ^{d}	35.34±0.44 ^{f}	54.73±0.34 ^{c}	981.38±1.09 ^{c}	409.93±1.17 ^{a}
	Lycopersicon esculentum shoot	39.98±0.28 ^{d}	3.92±0.36 ^{b}	29.16±0.19 ^{d}	42.21±0.38 ^{b}	1208.55±4.15 ^{f}	411.26±3.12 ^{a}
Farm 3	*Capsicum annuum* shoot	152.12±0.28 ^{g}	5.89±0.20 ^{e}	37.03±0.31 ^{g}	170.63± 0.21 ^{h}	929.53±0.28 ^{b}	878.89±6.72 ^{g}
	Lycopersicon esculentum shoot	8.63±0.25 ^{b}	3.69±0.42 ^{b}	24.24±0.24 ^{b}	73.97±0.26 ^{d}	588.32±0.62 ^{a}	759.09±0.64 ^{e}
Farm 4	*Capsicum annuum* shoot	202.82±0.16 ^{h}	5.27±0.17 $^{c\,d}$	34.16±0.18 ^{e}	121.44±0.22 ^{g}	1056.79±0.32 ^{d}	483.26±2.00 ^{c}
	Lycopersicon esculentum shoot	133.74±4.26 ^{f}	3.49±0.35 ^{b}	25.33±0.20 ^{c}	97.11±0.16 ^{e}	584.85±3.78 ^{a}	857.19±6.46 ^{f}
Standard	CPC (mg/kg)	0.2*	5.00 - 30.00	20.00 - 300.00	20.00 - 100.00		100.00 - 400.00
	NPV (mg/kg)		1.00 - 2.40	0.10 - 10.00	5.00 - 15.00	140	20.00 - 400.00

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

*Swiss tolerable level of heavy metals in food plants (mg/kg) (Gulz, 2005).
NPV= Normal Plant Value (Sharma and Chettri, 2005), CPC= Range of Critical Plant Concentration (Sharma and Chettri, 2005).

Table 4. Differences in mean concentration of heavy metals (mg/kg) in *Capsicum annuum* and *Lycopersicon esculentum* shoots cultivated in four farms in two farming communities in Obuasi

	Farm 1		Farm 2		Farm 3		Farm 4	
Metal	*Capsicum annuum* shoot	*Lycopersicon esculentum* shoot	*Capsicum annuum* shoot	*Lycopersicon esculentum* shoot	*Capsicum annuum* shoot	*Lycopersicon esculentum* shoot	*Capsicum annuum* shoot	*Lycopersicon esculentum* shoot
As	40.83±1.25 [b]	3.94±0.26 [a]	34.03±1.07 [b]	39.98±0.28 [c]	152.12±0.28 [c]	8.63±0.25 [b]	202.82±0.16 [d]	133.74±4.26 [d]
Cd	4.84±0.23 [a]	1.80±0.37 [a]	5.40±0.18 [a]	3.92±0.36 [a]	5.89±0.20 [a]	3.69±0.42 [a]	5.27±0.17 [a]	3.49±0.35 [a]
Pb	41.96±0.32 [b]	18.13±0.11 [b]	35.34±0.44 [c]	29.16±0.19 [b]	37.03±0.31 [b]	24.24±0.24 [c]	34.16±0.18 [b]	25.33±0.20 [b]
Cu	114.47±0.11 [c]	36.69±0.21 [c]	54.73±0.34 [d]	42.21±0.38 [c]	170.63± 0.21 [d]	73.97±0.26 [d]	121.44±0.22 [c]	97.11±0.16 [c]
Fe	1127.93±3.37 [e]	1205.03±4.60 [e]	981.38±1.09 [f]	1208.55±4.15 [e]	929.53±0.28 [f]	588.32±0.62 [e]	1056.79±0.32 [f]	584.85±3.78 [e]
Zn	432.79±1.02 [d]	740.63±0.70 [d]	409.93±1.17 [e]	411.26±3.12 [d]	878.89±6.72 [e]	759.09±0.64 [f]	483.26±2.00 [e]	857.19±6.46 [f]

Means in same column with different letters in superscripts differ significantly ($p<0.05$).

4.3 Heavy metal concentrations in the roots of *Capsicum annuum* and *Lycopersicon esculentum*

4.3.1 Comparison between levels of heavy metal in the roots of *Capsicum annuum* and *Lycopersicon esculentum* and Normal Plant Values and Range of Critical Plant Concentration

The mean concentrations of heavy metals (As, Cd, Pb, Cu, Fe and Zn) in *Capsicum annuum* and *Lycopersicon esculentum* roots sampled at four farms in two farming communities in Obuasi are represented in Table 5. All the heavy metals levels except As determined in the two vegetable roots exceeded the Normal Plant Values (NPV) of heavy metals stated by Sharma and Chettri (2005). However, Cd level in *Capsicum annuum* root in Farm 1 was below the standard. Similarly, Zn levels in *Capsicum annuum* root in all four farms was below the standard. Again, all the heavy metals except As and Fe determined in the two vegetable roots were below and within the Range of Critical Plant Concentration (CPC) as stated by Sharma and Chettri (2005). Nonetheless, Zn concentrations in *Lycopersicon esculentum* roots in all four farms were above the range. Similarly, Cu concentration in *Capsicum annuum* and *Lycopersicon esculentum* roots in Farm 4 were above the range. Arsenic (As) levels determined in the roots of the two vegetables exceeded the Swiss tolerable level of As in food plants stated by Gulz (2005) (Table 5).

4.3.2 Levels of heavy metals in the roots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

The Fe concentration in both vegetable roots in all the farms was the highest with mean range concentration of 1,228.86 to 1,582.35 mg/kg for *Capsicum annuum* roots and 1,325.01 to 1,579.95 mg/kg for *Lycopersicon esculentum* roots. It was followed by Zn with mean range concentration of 194.53 to 305.14 mg/kg for *Capsicum annuum* roots and 594.28 to 911.59

mg/kg for *Lycopersicon esculentum* roots. Cadmium (Cd) recorded the lowest mean concentration of 1.86 to 3.64 mg/kg for *Capsicum annuum* roots and 3.83 to 5.23 mg/kg for *Lycopersicon esculentum* roots. The ranking of heavy metals concentrations in both vegetable roots among the four farms in decreasing order was as follows:- Fe>Zn>As>Cu>Pb>Cd (Table 5).

For *Capsicum annuum* roots, the highest mean concentrations of As, Cu and Fe were recorded in Farm 4. The highest mean concentration of Cd, Pb and Zn were recorded in Farms 3, 2 and 1 respectively. The lowest mean concentration of Cd, Pb, Cu and Fe in the roots of *Capsicum annuum* were obtained in Farm 1 whilst, the lowest mean concentration of As and Zn were recorded in Farms 2 and 3 respectively (Table 5).

For *Lycopersicon esculentum* roots, the highest mean concentrations of As, Cd, Pb, Cu and Fe were recorded in Farm 4, whilst Farm 1 recorded the highest mean concentration for Zn. The lowest concentrations of Cd, Cu and Zn in the roots of *Lycopersicon esculentum* were obtained in Farm 2. Farm 3 recorded lowest concentrations for As and Fe whilst Farm 1 recorded lowest concentration for Pb (Table 5).

Lycopersicon esculentum roots recorded higher metal concentrations for Cd, Pb and Zn than *Capsicum annuum* roots in all the Farms. With the exception of Farms 2 and 1 *Capsicum annuum* roots recorded higher concentration of As and Cu respectively than *Lycopersicon esculentum* roots. *Capsicum annuum* roots recorded higher concentration of Fe than *Lycopersicon esculentum* roots in Farms 3 and 4 only. In general, *Lycopersicon esculentum* roots recorded higher metal concentrations than *Capsicum annuum* roots (Table 5).

4.3.3 Levels of Arsenic in the roots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In general the mean concentrations of As for both vegetable roots in all four farms were significantly different. However, levels of As for *Lycopersicon esculentum* roots in Farms 1 and 3 were not significantly different ($p<0.05$) (Table 5).

The highest level of As in *Capsicum annuum* roots was recorded in Farm 4 (264.41 mg/kg). It was 515% higher than the level of As in *Capsicum annuum* roots in Farm 2 (42.96 mg/kg) and 176% higher than that of Farm 1 (95.83 mg/kg). The level of As in *Capsicum annuum* roots in Farm 4 was 119% higher than that of Farm 3 (120.64 mg/kg) (Table 5).

The highest level of As in *Lycopersicon esculentum* roots was recorded in Farm 4 (99.21 mg/kg). It was 150% higher than the level of As in *Lycopersicon esculentum* roots in Farm 3 (39.71 mg/kg) and 148% higher than that of Farm 1 (40.05 mg/kg). The level of As in *Lycopersicon esculentum* roots in Farm 4 was 107% higher than that of Farm 2 (48.00 mg/kg) (Table 5). The ranking of As concentrations in both vegetable roots among the four farms in decreasing order was as follows:- F4*Ca*>F3*Ca*>F4*Le*>F1*Ca*>F2*Le*>F2*Ca*>F1*Le*=F3*Le* (Table 5).

4.3.4 Levels of Cadmium in the roots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

Generally, the mean concentrations of Cd for both vegetable roots in all four farms were significantly different. However, levels of Cd for *Capsicum annuum* roots in Farm 2 and 3 were not significantly different. Similarly, levels of Cd for *Lycopersicon esculentum* roots in Farm 2 and *Capsicum annuum* roots in Farm 3 were not significantly different. Also, levels of Cd for *Lycopersicon esculentum* roots in Farms 1 and 4 were not significantly different (Table 5).

The highest level of Cd in *Capsicum annuum* roots was recorded in Farm 3 (3.64 mg/kg). It was 96% higher than the level of Cd in *Capsicum annuum* roots in Farm 1 (1.86 mg/kg) and 39% higher than that of Farm 4 (2.61 mg/kg). The level of Cd in *Capsicum annuum* roots in Farm 3 was 11% higher than that of Farm 2 (3.28 mg/kg) (Table 5).

The highest level of Cd in *Lycopersicon esculentum* roots was recorded in Farm 4 (5.23 mg/kg). It was 37% higher than the level of Cd in *Lycopersicon esculentum* roots in Farm 2 (3.83 mg/kg) and 14% higher than that of Farm 3 (4.59 mg/kg). The level of Cd in *Lycopersicon esculentum* roots in Farm 4 was 2% higher than that of Farm 1 (5.14 mg/kg) (Table 5). The ranking of Cd concentrations in both vegetable roots among the four farms in decreasing order was as follows:- F4*Le*=F1*Le*>F3*Le*>F2*Le*≥F3*Ca*≥F2*Ca*>F4*Ca*>F1*Ca* (Table 5).

4.3.5 Levels of Lead in the roots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In generally, the mean concentrations of Pb for both vegetable roots in all four farms were significantly different (Table 5). Nonetheless, levels of Pb for *Lycopersicon esculentum* roots in Farms 1 and 2 were not significantly different (Table 5).

The highest level of Pb in *Capsicum annuum* roots was recorded in Farm 2 (26.57 mg/kg). It was 110% higher than the level of Pb in *Capsicum annuum* root in Farm 1 (12.64 mg/kg) and

40% higher than that of Farm 4 (18.94 mg/kg). The level of Pb in *Capsicum annuum* roots in Farm 2 was 23% higher than that of Farm 3 (21.54 mg/kg) (Table 5).

The highest level of Pb in *Lycopersicon esculentum* roots was recorded in Farm 4 (35.98 mg/kg). It was 32% higher than the level of Pb in *Lycopersicon esculentum* roots in Farm 1 (27.19 mg/kg) and 30% higher than that of Farm 2 (27.58 mg/kg). The level of Pb in *Lycopersicon esculentum* roots in Farm 4 was 12% higher than that of Farm 3 (32.08 mg/kg) (Table 5). The ranking of Pb concentrations in both vegetable roots among the four farms in decreasing order was as follows:- F4*Le*>F3*Le*>F2*Le*=F1*Le*>F2*Ca*>F3*Ca*>F4*Ca*>F1*Ca* (Table 5).

4.3.6 Levels of Copper in the roots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

Generally, the mean concentrations of Cu for both vegetable roots in all four farms were significantly different (Table 5). The highest level of Cu in *Capsicum annuum* roots was recorded in Farm 4 (126.69 mg/kg). It was 112% higher than the level of Cu in *Capsicum annuum* roots in Farm 1 (59.72 mg/kg) and 64% higher than that of Farm 2 (77.18 mg/kg). The level of Cu in *Capsicum annuum* roots in Farm 4 was 32% higher than that of Farm 3 (95.96 mg/kg) (Table 5).

The highest level of Cu in *Lycopersicon esculentum* roots was recorded in Farm 4 (103.63 mg/kg). It was 214% higher than the level of Cu in *Lycopersicon esculentum* roots in Farm 2 (32.96 mg/kg) and 66% higher than that of Farm 1 (62.33 mg/kg). The level of Cu in *Lycopersicon esculentum* roots in Farm 4 was 13% higher than that of Farm 3 (91.54 mg/kg) (Table 5). The ranking of Cu concentrations in both vegetable roots among the four farms in decreasing order is as follows:- F4*Ca*>F4*Le*>F3*Ca*>F3*Le*>F2*Ca*>F1*Le*>F1*Ca*>F2*Le* (Table 5).

4.3.7 Levels of Iron in the roots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In general, the mean concentrations of Fe for both vegetable roots in all four farms were significantly different. Nevertheless, levels of Fe for *Lycopersicon esculentum* roots in Farm 1 and *Capsicum annuum* roots in Farm 3 were not significantly different. Similarly, levels of Fe for *Capsicum annuum* roots in Farm 4 and *Lycopersicon esculentum* roots in Farm 4 were not significantly different (Table 5).

The highest level of Fe in *Capsicum annuum* roots was recorded in Farm 4 (1582.35 mg/kg). It was 29% higher than the level of Fe in *Capsicum annuum* roots in Farm 1 (1228.86 mg/kg) and 24% higher than that of Farm 2 (1274.25 mg/kg). The level of Fe in *Capsicum annuum* roots in Farm 4 was 7% higher than that of Farm 3 (1483.82 mg/kg) (Table 5).

The highest level of Fe in *Lycopersicon esculentum* roots was recorded in Farm 4 (1579.95 mg/kg). It was 19% higher than the level of Fe in *Lycopersicon esculentum* roots in Farm 3 (1325.01 mg/kg) and 6% higher than that of Farm 1 (1484.27 mg/kg). The level of Fe in *Lycopersicon esculentum* roots in Farm 4 was 1% higher than that of Farm 2 (1565.29 mg/kg) (Table 5). The ranking of Fe concentrations in both vegetable roots among the four farms in decreasing order was as follows:- F4*Ca*=F4*Le*>F2*Le*>F1*Le*=F3*Ca*>F3*Le*>F2*Ca*>F1*Ca* (Table 5).

4.3.8 Levels of Zinc in the roots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

In general, the mean concentrations of Zn for both vegetable roots in all four farms were significantly different (Table 5). The highest level of Zn in *Capsicum annuum* roots was recorded in Farm 1 (305.14 mg/kg). It was 57% higher than the level of Zn in *Capsicum annuum* roots in Farm 3 (194.53 mg/kg) and 25% higher than that of Farm 2 (244.88 mg/kg). The level of Zn in *Capsicum annuum* roots in Farm 1 was 20% higher than that of Farm 4 (254.61 mg/kg) (Table 5).

The highest level of Zn in *Lycopersicon esculentum* roots was recorded in Farm 1 (911.59 mg/kg). It was 53% higher than the level of Zn in *Lycopersicon esculentum* roots in Farm 2 (594.28 mg/kg) and 34% higher than that of Farm 4 (681.79 mg/kg). The level of Zn in *Lycopersicon esculentum* roots in Farm 1 was 24% higher than that of Farm 3 (733.07 mg/kg) (Table 5). The ranking of Zn concentrations in both vegetable roots among the four farms in decreasing order was as follows:- F1*Le*>F3*Le*>F4*Le*>F2*Le*>F1*Ca*>F4*Ca*>F2*Ca*>F3*Ca* (Table 5).

4.3.9 General ranking of the four farms in terms of heavy metals concentrations in the roots of *Capsicum annuum* and *Lycopersicon esculentum*

Taking all the heavy metals into consideration for each vegetable within each farm, the decreasing order of contamination in the roots of *Capsicum annuum* and *Lycopersicon esculentum* was as follows:-F4*Le*>F1*Le*>F4*Ca*>F3*Le*>F2*Le*>F3*Ca*>F2*Ca*>F1*Ca*. Taking all the heavy metals into consideration for both vegetables within each farm, the decreasing order of levels of heavy metals in the roots of *Capsicum annuum* and *Lycopersicon esculentum* was as follows:- F4>F3>F1>F2

4.3.10 Mean difference in concentrations of the heavy metals in the roots of *Capsicum annuum* and *Lycopersicon esculentum* in the four farms

There was significant difference between the mean levels of all the heavy metals in *Capsicum annuum* roots in all four farms (Table 6). Generally, there were significant differences between the mean levels of all the heavy metals in all four farms for *Lycopersicon esculentum* shoots (Table 6).

Table 5. Mean Concentration of heavy metals (mg/kg) in *Capsicum annuum* and *Lycopersicon esculentum* roots cultivated in four farms in two farming communities in Obuasi

FARM	SAMPLE	As	Cd	Pb	Cu	Fe	Zn
Farm 1	*Capsicum annuum* root	95.83±0.51 ^{d}	1.86±0.16 ^{a}	12.64±0.60 ^{a}	59.72±0.65 ^{b}	1228.86±1.16 ^{a}	305.14±1.08 ^{d}
	Lycopersicon esculentum root	40.05±0.49 ^{a}	5.14±0.35 ^{f}	27.19±0.10 ^{e}	62.33±0.32 ^{c}	1484.27±2.72 ^{d}	911.59±0.75 ^{h}
Farm 2	*Capsicum annuum* root	42.96±0.51 ^{b}	3.28±0.18 ^{c}	26.57±0.50 ^{d}	77.18±0.37 ^{d}	1274.25±1.95 ^{b}	244.88±1.14 ^{b}
	Lycopersicon esculentum root	48.00±0.92 ^{c}	3.83±0.37 ^{d}	27.58±0.22 ^{e}	32.96±0.36 ^{a}	1565.29±2.91 ^{e}	594.28±0.50 ^{e}
Farm 3	*Capsicum annuum* root	120.64±0.35 ^{f}	3.64±0.16 $^{c\,d}$	21.54±0.13 ^{c}	95.96±0.31 ^{f}	1483.82±0.38 ^{d}	194.53±1.79 ^{a}
	Lycopersicon esculentum root	39.71±0.86 ^{a}	4.59±0.38 ^{e}	32.08±0.07 ^{f}	91.54±0.70 ^{e}	1325.01±0.94 ^{c}	733.07±3.81 ^{g}
Farm 4	*Capsicum annuum* root	264.41±0.16 ^{g}	2.61±0.17 ^{b}	18.94±0.33 ^{b}	126.69± 0.20 ^{h}	1582.35±1.41 ^{f}	254.61±2.33 ^{c}
	Lycopersicon esculentum root	99.21±4.95 ^{e}	5.23±0.27 ^{f}	35.98±0.20 ^{g}	103.63±0.17 ^{g}	1579.95±2.56 ^{f}	681.79±0.55 ^{f}
Standard	CPC (mg/kg)	0.2*	5.00 - 30.00	20.00 - 300.00	20.00 - 100.00		100.00 - 400.00
	NPV (mg/kg)		1.00 - 2.40	0.10 - 10.00	5.00 - 15.00	140	20.00 - 400.00

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

*Swiss tolerable level of heavy metals in food plants (mg/kg) (Gulz, 2005).
NPV= Normal Plant Value (Sharma and Chettri, 2005), CPC= Range of Critical Plant Concentration (Sharma and Chettri, 2005).

Table 6. Differences in mean concentration of heavy metals (mg/kg) in *Capsicum annuum* and *Lycopersicon esculentum* roots cultivated in four farms in two farming communities in Obuasi

Metal	Farm 1 *Capsicum annuum* root	Farm 1 *Lycopersicon esculentum* root	Farm 2 *Capsicum annuum* root	Farm 2 *Lycopersicon esculentum* root	Farm 3 *Capsicum annuum* root	Farm 3 *Lycopersicon esculentum* root	Farm 4 *Capsicum annuum* root	Farm 4 *Lycopersicon esculentum* root
As	95.83±0.51 ^{d}	40.05±0.49 ^{c}	42.96±0.51^{c}	48.00±0.92 ^{d}	120.64±0.35 ^{d}	39.71±0.86 ^{c}	264.41±0.16 ^{e}	99.21±4.95 ^{c}
Cd	1.86±0.16 ^{a}	5.14±0.35 ^{a}	3.28±0.18 ^{a}	3.83±0.37 ^{a}	3.64±0.16 ^{a}	4.59±0.38 ^{a}	2.61±0.17 ^{a}	5.23±0.27 ^{a}
Pb	12.64±0.60 ^{b}	27.19±0.10 ^{b}	26.57±0.50^{b}	27.58±0.22 ^{b}	21.54±0.13 ^{b}	32.08±0.07 ^{b}	18.94±0.33 ^{b}	35.98±0.20 ^{b}
Cu	59.72±0.65 ^{c}	62.33±0.32 ^{d}	77.18±0.37 ^{d}	32.96±0.36 ^{c}	95.96±0.31 ^{c}	91.54±0.70 ^{d}	126.69± 0.20 ^{c}	103.63±0.17 ^{d}
Fe	1228.86±1.16 ^{f}	1484.27±2.72 ^{f}	1274.25±1.95 ^{f}	1565.29±2.91 ^{f}	1483.82±0.38 ^{f}	1325.01±0.94 ^{f}	1582.35±1.41 ^{f}	1579.95±2.56 ^{f}
Zn	305.14±1.08 ^{e}	911.59±0.75 ^{e}	244.88±1.14 ^{e}	594.28±0.50 ^{e}	194.53±1.79 ^{e}	733.07±3.81 ^{e}	254.61±2.33 ^{d}	681.79±0.55 ^{e}

Means in same column with different letters in superscripts differ significantly ($p < 0.05$).

4.4. Heavy metal concentrations in soil

4.4.1 Comparison between levels of heavy metals in the soils of the four farmlands and USEPA and WHO standards

The results of the mean concentrations of heavy metals (As, Cd, Pb, Cu, Fe and Zn) in the soils sampled in four farmlands in Obuasi are represented in Table 7. All the heavy metals levels (except Fe) determined in the soil samples were within the pollutant concentration limits in soils set by USEPA and maximum acceptable concentration of metals in soils set by WHO. However, levels of As in the soils in all four farms exceeded these two standards. Also, Cd levels in the soils of Farms 2, 3 and 4 exceeded the WHO standard. Iron (Fe) levels exceeded the normal soil value of Iron stated by Agyarko (2010) (Table 7).

4.4.2 Levels of heavy metals in the soils of the four farmlands

The Fe concentration in the soils in all the farms was the highest with a mean range concentration of 1,109.60 to 1, 177.50 mg/kg. It was followed by As with mean range concentration of 85.35 to 182.58 mg/kg. Cadmium (Cd) recorded the lowest mean concentration with mean range concentration of 1.18 to 2.43 mg/kg. The ranking of heavy metals concentrations in the soils of the four farms in the decreasing order was as follows:- Fe>As>Zn>Cu>Pb>Cd (Table 7).

Soil in Farm 4 recorded the highest mean concentrations of As, Cd and Fe. Soil in Farm 3 recorded the highest mean concentration for Cu and Pb whilst soil in Farm 2 recorded the highest mean concentration of Zn. The lowest mean concentrations of all the heavy metals were recorded in the soil in Farm 1(Table 7).

4.4.3 Levels of Arsenic in the soils of the four farmlands

In general, the mean concentrations of As in the soils in all four farms were significantly different. Nonetheless, levels of As in Farms 1 and 2 were not significantly different ($p<0.05$) (Table 7).

The highest level of As in the soils was recorded in Farm 4 (182.58 mg/kg). It was 114% higher than the level of As in the soil of in Farm 1 (85.35 mg/kg) and 75% higher than that of Farm 2 (104.45 mg/kg). The level of As in the soil of Farm 4 was 57% higher than that of Farm 3 (116.15 mg/kg) (Table 7). The ranking of As concentrations in the soils of the four farms in decreasing order was as follows:- F4S>F3S≥F2S≥F1S (Table 7).

4.4.4 Levels of Cadmium in the soils of the four farmlands

Generally, the mean concentrations of Cd in the soils in all four farms were significantly different. However, levels of Cd in Farms 2 and 3 were not significantly different (Table 7).

The highest level of Cd in the soils was recorded in Farm 4 (2.43 mg/kg). It was 106% higher than the level of Cd in the soils of in Farm 1 (1.18 mg/kg) and 28% higher than that of Farm 3 (1.90 mg/kg). The level of Cd in the soils of Farm 4 was 25% higher than that of Farm 2 (1.95 mg/kg) (Table 7). The ranking of Cd concentrations in the soils of the four farms in decreasing order was as follows:- F4S>F2S≥F3S>F1S (Table 7).

4.4.5 Levels of Lead in the soils of the four farmlands

Generally, the mean concentrations of Pb in the soils in all four farms were not significantly different. However, levels of Pb in Farms 1 and the other three farms were significantly different (Table 7).

The highest level of Pb in the soils was recorded in Farm 3 (15.05 mg/kg). It was 105% higher than the level of Pb in the soils of Farm 1 (7.35 mg/kg) and 17% higher than that of Farm 2 (12.85 mg/kg). The level of Pb in the soils of Farm 3 was 14% higher than that of Farm 4 (13.20 mg/kg) (Table 7). The ranking of Pb concentrations in the soils of the four farms in decreasing order was as follows:- F3S=F4S=F2S>F1S (Table 7).

4.4.6 Levels of Copper in the soils of the four farmlands

In general, the mean concentrations of Cu in the soils in all four farms were significantly different (Table 7). The highest level of Cu in the soils was recorded in Farm 3 (23.56 mg/kg). It was 74% higher than the level of Cu in the soils of in Farm 1 (13.58 mg/kg) and 43% higher than that of Farm 4 (16.43 mg/kg). The level of Cu in the soils of Farm 4 was 17% higher than that of Farm 2 (20.13 mg/kg) (Table 7). The ranking of Cu concentrations in the soils of the four farms in decreasing order was as follows:- F3S>F2S>F4S>F1S (Table 7).

4.4.7 Levels of Iron in the soils of the four farmlands

In generally, the mean concentrations of Fe in the soils in all four farms were significantly different (Table 7). The highest level of Fe in the soils was recorded in Farm 4 (1177.50 mg/kg). It was 6% higher than the level of Fe in the soils of in Farm 1 (1109.60 mg/kg) and 5% higher than that of Farm 2 (1121.55 mg/kg). The level of Fe in the soils of Farm 4 was 2% higher than that of Farm 3 (1153.15 mg/kg) (Table 7). The ranking of Fe concentrations in the soils of the four farms in decreasing order was as follows:- F4S>F3S>F2S>F1S (Table 7).

4.4.8 Levels of Zinc in the soils of the four farmlands

The mean concentrations of Zn in the soils in all four farms were significantly different. Nonetheless, levels of Zn in Farms 2 and 3 were not significantly different (Table 7).

The highest level of Zn in the soils was recorded in Farm 2 (36.8 mg/kg). It was 185% higher than the level of Zn in the soils of Farm 1 (12.93 mg/kg) and 49% higher than that of Farm 4 (24.73 mg/kg). The level of Zn in the soils of Farm 2 was 1% higher than that of Farm 3 (136.38 mg/kg) (Table 7). The ranking of Zn concentrations in the soils of the four farms in decreasing order was as follows:- F2S=F3S>F4S>F1S (Table 7).

4.4.9 General levels of heavy metals in the soils of the four farmlands

Taking the total sum of concentrations of all the heavy metals in the soils within each farmland, the ranking of heavy metals levels in the decreasing order of contamination in the soils was as follows:- F4>F3>F2>F1.

4.3.10 Mean difference in concentrations of the heavy metals in the soils of the four farmlands

There was significant difference between the mean values of all the heavy metals in Farm 1 except Pb and Zn and Cu and Zn. In Farms 2 and 3 there was significant difference between the mean values of all the heavy metals except Pb and Cu whilst in Farm 4 there was significant difference between the mean values of all the heavy metals except Pb, Cu and Zn and Cd and Pb (Table 8).

Table 7. Mean concentration of heavy metals (mg/kg) in soil samples in four farms in two farming communities in Obuasi

FARM	SAMPLE	As	Cd	Pb	Cu	Fe	Zn
Farm 1	Soil	85.35±4.39 [a]	1.18±0.04 [a]	7.35±0.59 [a]	13.58±1.32 [a]	1109.60±4.94 [a]	12.93±4.62 [a]
Farm 2	Soil	104.45±10.28 [a b]	1.95±0.27 [b]	12.85±0.88 [b]	20.13±1.04 [c]	1121.55±1.51 [b]	36.80±3.99 [c]
Farm 3	Soil	116.15±14.36 [b]	1.90±0.16 [b]	15.05±3.90 [b]	23.56±0.62 [d]	1153.15±6.72 [c]	36.38±5.08 [c]
Farm 4	Soil	182.58±15.91 [c]	2.43±0.04 [c]	13.20±0.91 [b]	16.43±0.53 [b]	1177.50±0.67 [d]	24.73±4.83 [b]
Standard	WHO (mg/kg)	12	1.4	70	63	_	200
	USEPA (mg/kg)	41	39	300	1500	5000-10000*	2800

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

*Normal Soil Value (mg/kg) (Agyarko *et al*., 2010)

Table 8. Differences in mean concentration of heavy metals (mg/kg) in soil samples in four farms in two farming communities in Obuasi

Metal	Farm 1 Soil	Farm 2 Soil	Farm 3 Soil	Farm 4 Soil
As	85.35±4.39 [d]	104.45±10.28 [d]	116.15±14.36 [d]	182.58±15.91 [c]
Cd	1.18±0.04 [a]	1.95±0.27 [a]	1.90±0.16 [a]	2.43±0.04 [a]
Pb	7.35±0.59 [b]	12.85±0.88 [b]	15.0503.90 [b]	13.20±0.91 [a b]
Cu	13.58±1.32 [c]	20.13±1.04 [b]	23.56±0.62 [b]	16.43±0.53 [b]
Fe	1109.60±4.94 [e]	1121.55±1.51 [e]	1153.15±6.72 [e]	1177.50±0.67 [d]
Zn	12.93±4.62 [b c]	36.80±3.99 [c]	36.38±5.08 [c]	24.73±4.83 [b]

Means in same column with different letters in superscript differ significantly ($p<0.05$)

4.5 Bioaccumulation Ratio

The bioaccumulation ratios (i.e. the ratio of the concentration of a heavy metal in the plant to that of the same heavy metal in the soil) of *Capsicum annuum* and *Lycopersicon esculentum* plants are represented in Table 9.

4.5.1 Concentration of heavy metals accumulated in the whole plants of *Capsicum annuum* and *Lycopersicon esculentum* in relation to concentration in soil

Generally, the bioaccumulation ratios of all the heavy metals in the whole plant of both vegetables were greater than 1. Zinc (Zn) recorded the highest bioaccumulation ratios for *Lycopersicon esculentum* (150.23) and *Capsicum annuum* (63.40) whilst Arsenic (As) had the least bioaccumulation ratios for *Capsicum annuum* (1.50) and *Lycopersicon esculentum* (0.45). The trend of heavy metals bioaccumulation in both vegetables in the decreasing order was as follows:- Zn>Cu>Pb>Cd>Fe>As (Table 9).

In general, Farm 1 obtained the highest heavy metals bioaccumulation ratio for *Capsicum annuum* plant whilst Farm 2 obtained the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Capsicum annuum* plant in the four farms in the decreasing order was as follows:- F1>F3>F4>F2 (Table 9). The highest heavy metals bioaccumulation ratio for *Lycopersicon esculentum* plant was obtained in Farm 1 whilst the least bioaccumulation ratio was obtained in Farm 2 (Table 9). The trend of heavy metals bioaccumulation in *Lycopersicon esculentum* plant in the four farms in the decreasing order was as follows:- F1>F4>F3>F2 (Table 9). Taking both vegetable plants into consideration, Farm 1 obtained the highest bioaccumulation ratio whilst Farm 2 obtained the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in both vegetable plants in the four farms in the decreasing order was as follows:- F1>F4>F3>F2 (Table 9).

4.5.2 Concentration of heavy metals accumulated in fruits of *Capsicum annuum* and *Lycopersicon esculentum* in relation to concentration in soil

Generally, bioaccumulation ratio in the two vegetable fruits was higher in *Lycopersicon esculentum* than *Capsicum annuum* (Table 9). Zinc (Zn) recorded the highest bioaccumulation ratio for *Capsicum annuum* fruit whilst Fe recorded the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Capsicum annuum* fruits in the four farms in the decreasing order was as follows:- Zn>Cu>Pb>Cd>As>Fe (Table 9). For *Lycopersicon esculentum* fruit, Zn recorded the highest bioaccumulation ratio whilst As recorded the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Lycopersicon esculentum* fruits in the four farms in the decreasing order was as follows:-Zn>Cu>Pb>Cd>Fe>As (Table 9).

In general, Farm 2 obtained the highest bioaccumulation ratio for *Capsicum annuum* fruit whilst Farm 4 obtained the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Capsicum annuum* fruit in the four farms in the decreasing order was as follows:- F2>F1>F3>F4 (Table 9). The highest bioaccumulation ratio for *Lycopersicon esculentum* fruit was obtained in Farm 1 whilst the least bioaccumulation ratio was obtained in Farm 3 (Table 9). The trend of heavy metals bioaccumulation in *Lycopersicon esculentum* fruit in the four farms in the decreasing order was as follows:- F1>F2>F4>F3 (Table 9). Taking both vegetable fruits into consideration, Farm 1 obtained the highest bioaccumulation ratio whilst Farm 4 obtained the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in both vegetable fruits in the four farms in the decreasing order was as follows:- F1>F2>F3>F4 (Table 9).

4.5.3 Concentration of heavy metals accumulated in shoots of *Capsicum annuum* and *Lycopersicon esculentum* in relation to concentration in soil

Generally, bioaccumulation ratio in the two vegetable shoots was higher in *Lycopersicon esculentum* than *Capsicum annuum* (Table 9). Zinc (Zn) recorded the highest bioaccumulation ratio for *Capsicum annuum* shoot whilst As recorded the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Capsicum annuum* shoots in the four farms in the decreasing order was as follows:- Zn>Cu>Pb>Cd>Fe>As (Table 9). For *Lycopersicon esculentum* shoot, Zn recorded the highest bioaccumulation ratio whilst As recorded the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Lycopersicon esculentum* shoots in the four farms in the decreasing order was as follows:-Zn>Cu>Pb>Cd>Fe>As (Table 9).

In general, Farm 1 obtained the highest bioaccumulation ratio for *Capsicum annuum* shoot whilst Farm 2 obtained the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Capsicum annuum* shoot in the four farms in the decreasing order was as follows:- F1>F3>F4>F2 (Table 9). The highest bioaccumulation ratio for *Lycopersicon esculentum* shoot was obtained in Farm 1 whilst the least bioaccumulation ratio was obtained in Farm 2 (Table 9). The trend of heavy metals bioaccumulation in *Lycopersicon esculentum* shoot in the four farms in the decreasing order was as follows:- F1>F4>F3>F2 (Table 9). Taking both vegetable shoots into consideration, Farm 1 obtained the highest bioaccumulation ratio whilst Farm 2 obtained the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in both vegetable shoots in the four farms in the decreasing order was as follows:- F1>F4>F3>F2 (Table 9).

4.5.4 Concentration of heavy metals accumulated in roots of *Capsicum annuum* and *Lycopersicon esculentum* in relation to concentration in soil

Generally, bioaccumulation ratio in the two vegetable roots was higher in *Lycopersicon esculentum* than *Capsicum annuum* (Table 9). Zinc (Zn) recorded the highest bioaccumulation ratio for *Capsicum annuum* root whilst As recorded the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Capsicum annuum* roots in the four farms in the decreasing order was as follows:- Zn>Cu>Pb>Cd>Fe>As (Table 9). For *Lycopersicon esculentum* root, Zn recorded the highest bioaccumulation ratio whilst As recorded the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Lycopersicon esculentum* roots in the four farms in the decreasing order was as follows:-Zn>Cu>Cd>Pb>Fe>As (Table 9).

In general, Farm 1 obtained the highest bioaccumulation ratio for *Capsicum annuum* root whilst Farm 3 obtained the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in *Capsicum annuum* root in the four farms in the decreasing order was as follows:- F1>F4>F2>F3 (Table 9). The highest bioaccumulation ratio for *Lycopersicon esculentum* root was obtained in Farm 1 whilst the least bioaccumulation ratio was obtained in Farm 2 (Table 9). The trend of heavy metals bioaccumulation in *Lycopersicon esculentum* root in the four farms in the decreasing order was as follows:- F1>F4>F3>F2 (Table 9).

Taking both vegetable roots into consideration, Farm 1 obtained the highest bioaccumulation ratio whilst Farm 2 obtained the least bioaccumulation ratio (Table 9). The trend of heavy metals bioaccumulation in both vegetable roots in the four farms in the decreasing order was as follows:- F1>F4>F3>F2 (Table 9).

Table 9. Bioaccumulation Ratio - Concentration of heavy metals accumulated in vegetables in relation to concentration in soil

	Plant	Plant part	As	Cd	Pb	Cu	Fe	Zn
Farm 1	*Capsicum annuum*	Fruit	0.54	1.44	1.87	2.36	0.17	6.31
		Shoot	0.48	4.12	5.71	8.43	1.02	33.48
		Root	1.12	1.58	1.72	4.40	1.11	23.61
		Whole plant	2.14	7.13	9.30	15.19	2.29	63.40
	Lycopersicon esculentum	Fruit	0.04	2.36	2.85	4.07	1.01	22.40
		Shoot	0.05	1.53	2.47	2.70	1.09	57.30
		Root	0.47	4.37	3.70	4.59	1.34	70.53
		Whole plant	0.55	8.27	9.02	11.37	3.43	150.23
Farm 2	*Capsicum annuum*	Fruit	0.76	0.94	1.01	2.24	0.39	9.25
		Shoot	0.33	2.77	2.75	2.72	0.88	11.14
		Root	0.41	1.68	2.07	3.83	1.14	6.65
		Whole plant	1.50	5.39	5.82	8.80	2.41	27.04
	Lycopersicon esculentum	Fruit	0.83	1.36	1.59	2.28	0.88	6.39
		Shoot	0.38	2.01	2.27	2.10	1.08	11.18
		Root	0.46	1.96	2.15	1.64	1.40	16.15
		Whole plant	1.67	5.33	6.00	6.02	3.35	33.72
Farm 3	*Capsicum annuum*	Fruit	0.26	1.38	1.42	2.33	0.27	4.84
		Shoot	1.31	3.10	2.46	7.24	0.81	24.16
		Root	1.04	1.91	1.43	4.07	1.29	5.35
		Whole plant	2.61	6.40	5.31	13.64	2.36	34.35
	Lycopersicon esculentum	Fruit	0.03	1.13	1.19	1.35	0.52	5.15
		Shoot	0.07	1.94	1.61	3.14	0.51	20.87
		Root	0.34	2.42	2.13	3.88	1.15	20.15
		Whole plant	0.45	5.50	4.94	8.37	2.18	46.17
Farm 4	*Capsicum annuum*	Fruit	0.50	0.56	0.78	1.25	0.14	3.90
		Shoot	1.11	2.17	2.59	7.39	0.90	19.55
		Root	1.45	1.07	1.43	7.71	1.34	10.30
		Whole plant	3.06	3.81	4.80	16.36	2.38	33.75
	Lycopersicon esculentum	Fruit	0.44	0.61	1.36	1.71	0.63	5.91
		Shoot	0.73	1.44	1.92	5.91	0.50	34.67
		Root	0.54	2.16	2.73	6.31	1.34	27.57
		Whole plant	1.72	4.21	6.00	13.93	2.47	68.16

4.6 Mean concentrations of heavy metals compared in fruits, shoots and roots of *Capsicum annuum* and *Lycopersicon esculentum*

4.6.1 Mean concentrations of Arsenic compared in fruits, shoots and roots of *Capsicum annuum* and *Lycopersicon esculentum*

Generally, *Capsicum annuum* plant recorded higher As concentration than *Lycopersicon esculentum* plant (Figure 3). The ranking of As concentration in the parts of *Capsicum annuum* plant in the decreasing order was as follows:- Root>Shoot>Fruit (Figure 3). The ranking of As concentration in the parts of *Lycopersicon esculentum* plant in the decreasing order was as follows:- Root>Shoot>Fruit (Figure 3).

The highest As concentration in the vegetables was obtained in Farm 4 whilst the least concentration was obtained in Farm 1 (Figure 3). The ranking of As concentration in the vegetables in the four farms in decreasing order was as follows:- F4>F3>F2>F1(Figure 3).

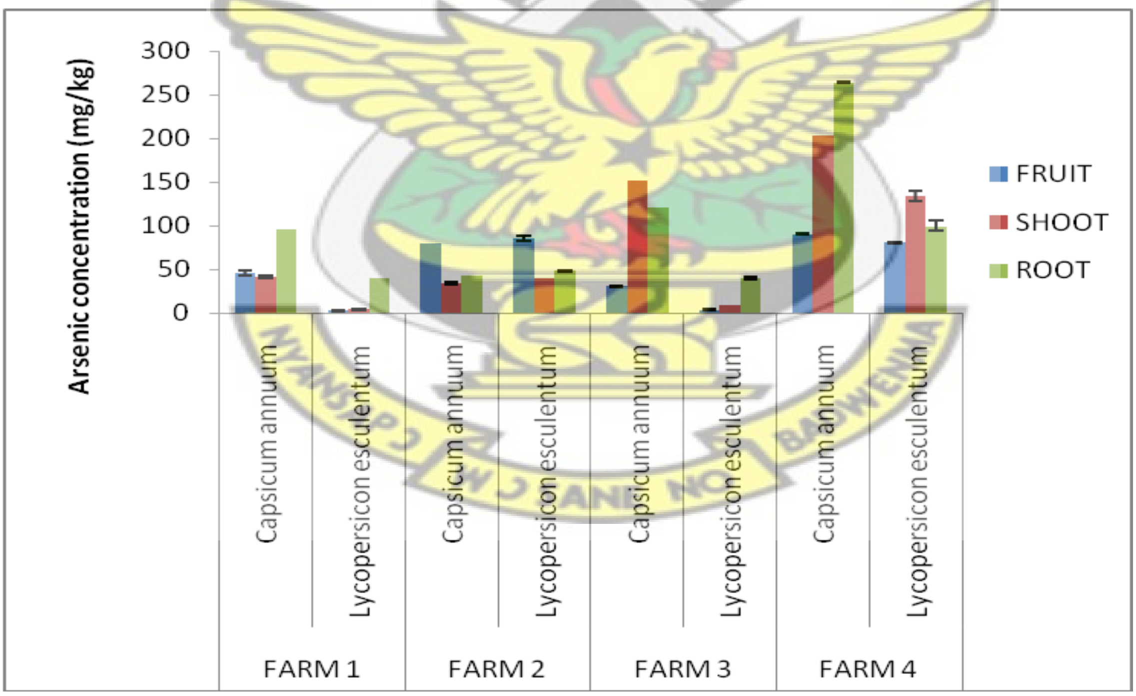

Fig. 3. Mean Concentrations of Arsenic in *Capsicum annuum* and *Lycopersicon esculentum* plants in four farms in two farming communities in Obuasi

4.6.2 Mean concentrations of Cadmium compared in fruits, shoots and roots of *Capsicum annuum* and *Lycopersicon esculentum*

Generally, *Lycopersicon esculentum* plant recorded higher Cd concentration than *Capsicum annuum* plant (Figure 4). The ranking of Cd concentration in the parts of *Capsicum annuum* plant in the decreasing order was as follows:- Shoot> Root>Fruit (Figure 4). The ranking of Cd concentration in the parts of *Lycopersicon esculentum* plant in the decreasing order was as follows:- Root>Shoot>Fruit (Figure 4).

The highest Cd concentration in the vegetables was obtained in Farm 3 whilst the least concentration was obtained in Farm 1 (Figure 4). The ranking of Cd concentration in the vegetables in the four farms in decreasing order was as follows:- F3>F2>F4>F1(Figure 4).

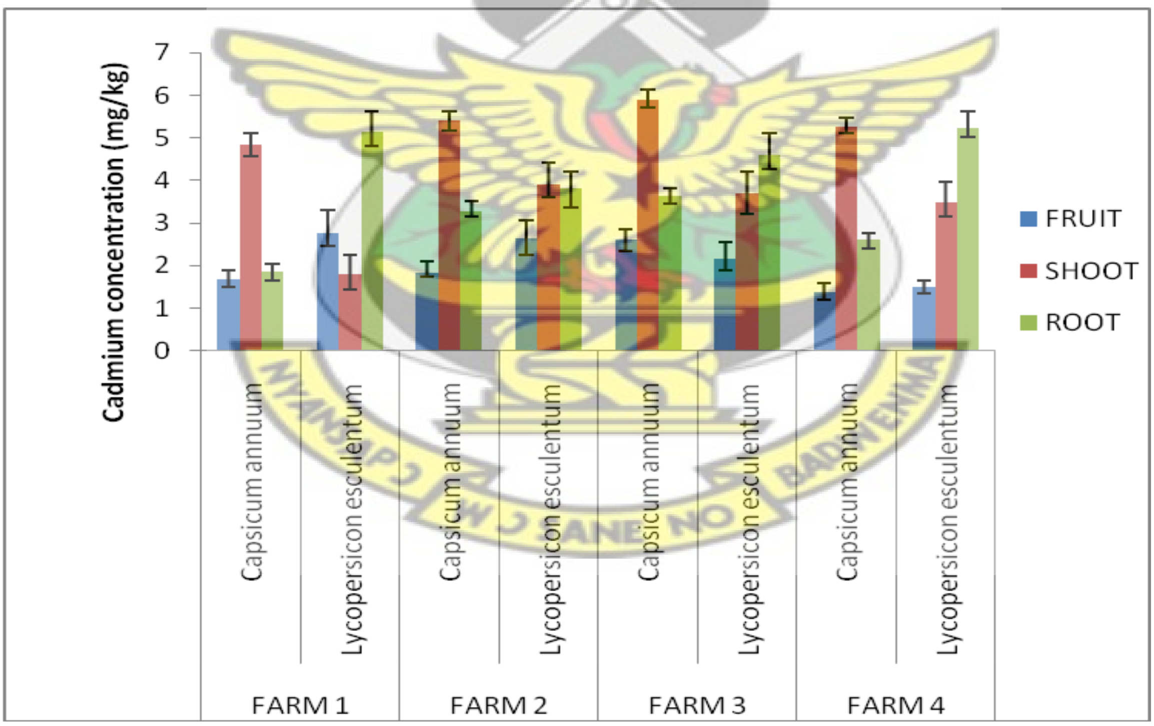

Fig. 4. Mean concentration of Cadmium in *Capsicum annuum* and *Lycopersicon esculentum* plants in four farms in two farming communities in Obuasi

4.6.3 Mean concentrations of Lead compared in fruits, shoots and roots of *Capsicum annuum* and *Lycopersicon esculentum*

Generally, *Lycopersicon esculentum* plant recorded higher Pb concentration than *Capsicum annuum* plant (Figure 5). The ranking of Pb concentration in the parts of *Capsicum annuum* plant in the decreasing order was as follows:- Shoot> Root>Fruit (Figure 5). The ranking of Pb concentration in the parts of *Lycopersicon esculentum* plant in the decreasing order was as follows:- Root>Shoot>Fruit (Figure 5).

The highest Pb concentration in the vegetables was obtained in Farm 3 whilst the least concentration was obtained in Farm 1 (Figure 5). The ranking of Pb concentration in the vegetables in the four farms in decreasing order was as follows:- F3>F2>F4>F1(Figure 5).

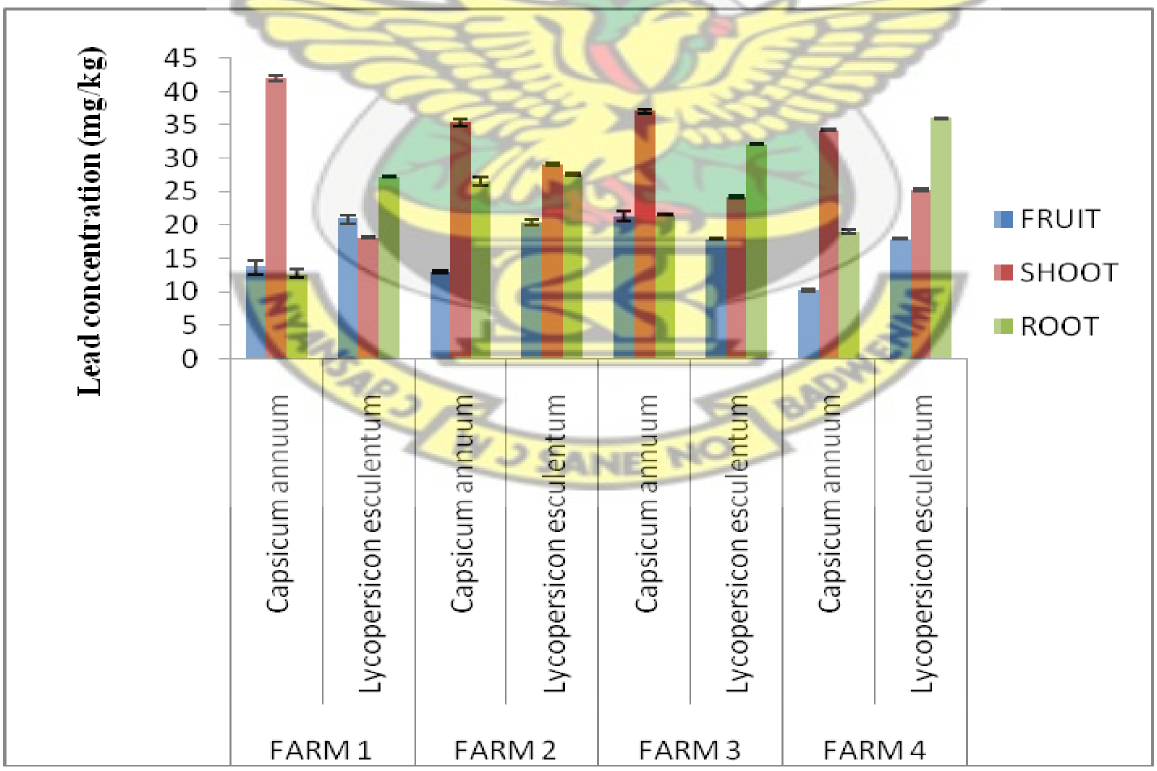

Fig. 5. Mean concentration of Lead in *Capsicum annuum* and *Lycopersicon esculentum* plants in four farms in two farming communities in Obuasi

4.6.4 Mean concentrations of Copper compared in fruits, shoots and roots of *Capsicum annuum* and *Lycopersicon esculentum*

Generally, *Capsicum annuum* plant recorded higher Cu concentration than *Lycopersicon esculentum* plant (Figure 6). The ranking of Cu concentration in the parts of *Capsicum annuum* plant in the decreasing order was as follows:- Shoot> Root>Fruit (Figure 6). The ranking of Cu concentration in the parts of *Lycopersicon esculentum* plant in the decreasing order was as follows:- Root>Shoot>Fruit (Figure 6).

The highest Cu concentration in the vegetables was obtained in Farm 3 whilst the least concentration was obtained in Farm 2 (Figure 6). The ranking of Cu concentration in the vegetables in the four farms in decreasing order was as follows:- F3>F4>F1>F2(Figure 6).

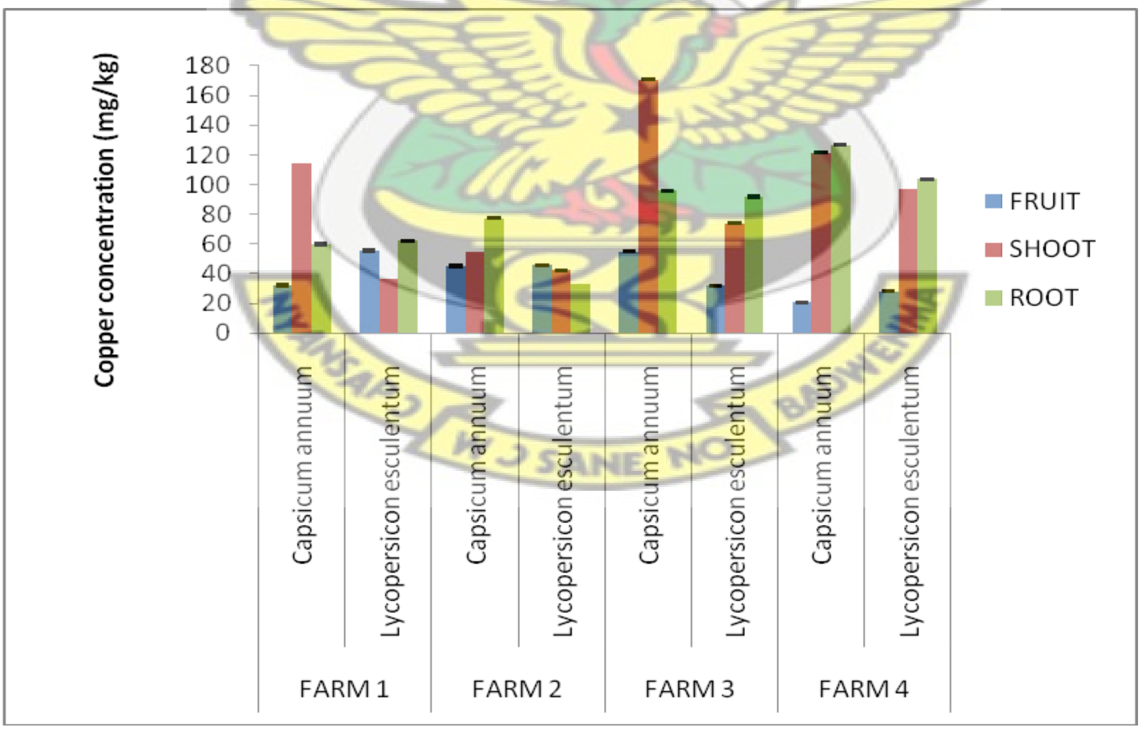

Fig. 6. Mean concentration of Copper in *Capsicum annuum* and *Lycopersicon esculentum* plants in four farms in two farming communities in Obuasi

4.6.5 Mean concentrations of Iron compared in fruits, shoots and roots of *Capsicum annuum* and *Lycopersicon esculentum*

Generally, *Lycopersicon esculentum* plant recorded higher Fe concentration than *Capsicum annuum* plant (Figure 7). The ranking of Fe concentration in the parts of *Capsicum annuum* plant in the decreasing order was as follows:- Root> Shoot>Fruit (Figure 7). The ranking of Fe concentration in the parts of *Lycopersicon esculentum* plant in the decreasing order was as follows:- Root>Shoot>Fruit (Figure 7).

The highest Fe concentration in the vegetables was obtained in Farm 2 whilst the least concentration was obtained in Farm 3 (Figure 7). The ranking of Fe concentration in the vegetables in the four farms in decreasing order was as follows:- F2>F1>F4>F3(Figure 7).

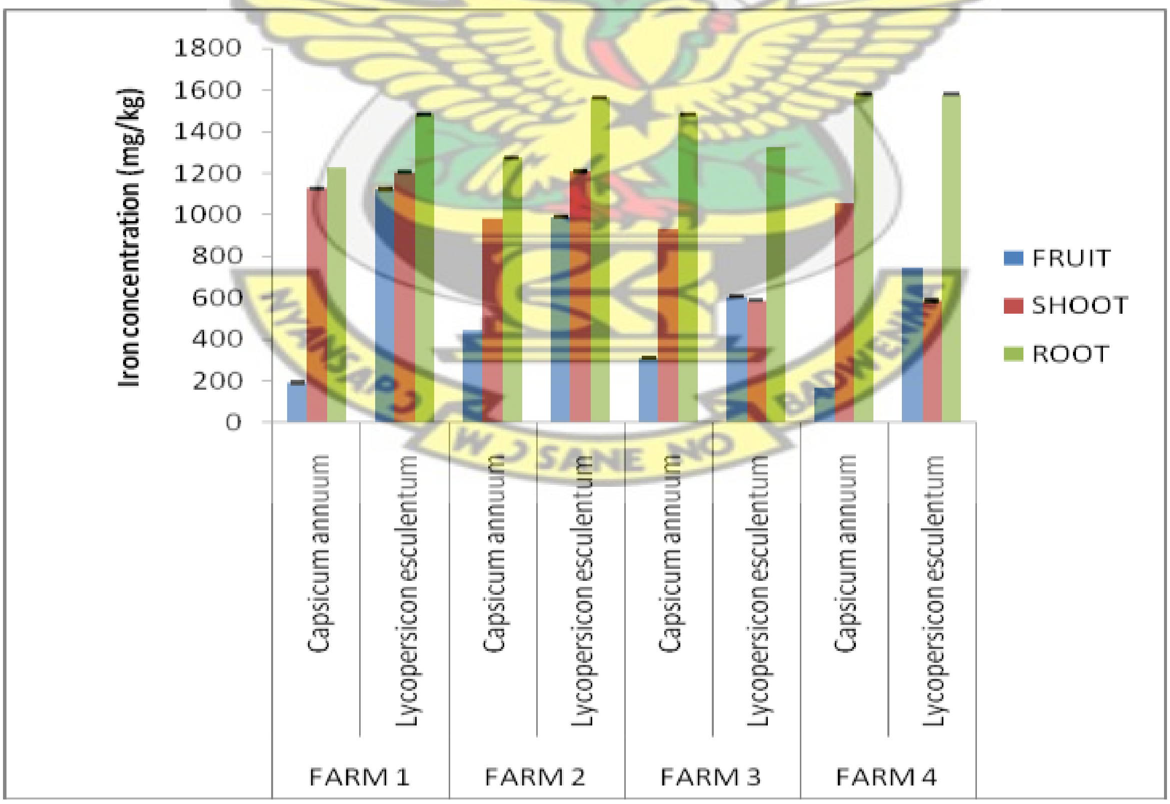

Fig. 7. Mean concentration of Iron in *Capsicum annuum* and *Lycopersicon esculentum* plants in four farms in two farming communities in Obuasi

4.6.6 Mean concentrations of Zinc compared in fruits, shoots and roots of *Capsicum annuum* and *Lycopersicon esculentum*

Generally, *Lycopersicon esculentum* plant recorded higher Zn concentration than *Capsicum annuum* plant (Figure 8). The ranking of Zn concentration in the parts of *Capsicum annuum* plant in the decreasing order was as follows:- Shoot> Root>Fruit (Figure 8). The ranking of Zn concentration in the parts of *Lycopersicon esculentum* plant in the decreasing order was as follows:- Root>Shoot>Fruit (Figure 8).

The highest Zn concentration in the vegetables was obtained in Farm 3 whilst the least concentration was obtained in Farm 2 (Figure 8). The ranking of Zn concentration in the vegetables in the four farms in decreasing order was as follows:- F3>F1>F4>F2(Figure 8).

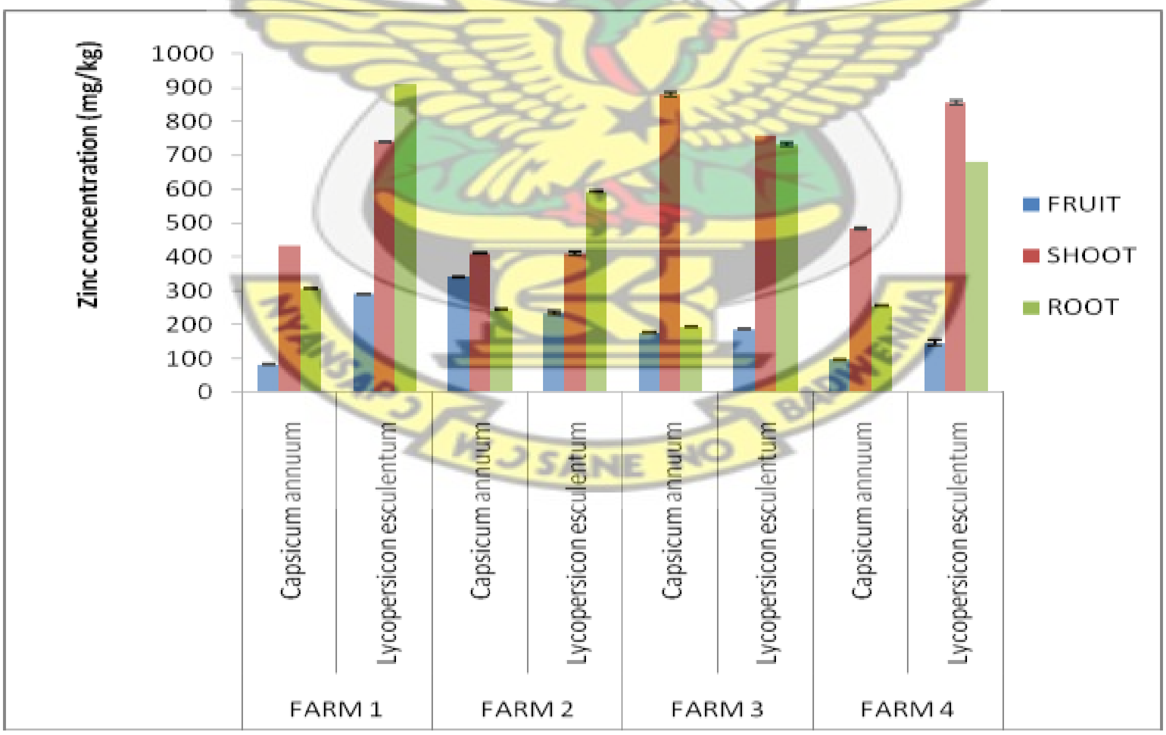

Fig. 8. Mean concentration of Zinc in *Capsicum annuum* and *Lycopersicon esculentum* plants in four farms in two farming communities in Obuasi

In general, the ranking of heavy metal concentrations in the various plant parts of *Capsicum annuum* in the decreasing order was as follows:- Shoot>Root>Fruits whilst that of *Lycopersicon esculentum* in the decreasing order was as follows:- Root>Shoot>Fruits (Fig. 3 – Fig. 8).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Heavy metal concentrations in the fruits of *Capsicum annuum* and *Lycopersicon esculentum*

Food being an important part of human existence has to be free from contaminants, toxic substances and harmful trace elements so as to be fit for human and livestock consumption. However, foodstuffs completely free of contaminant would be difficult to obtain as toxic substances and harmful trace elements are sometimes naturally present in soils and are also released from human activities all in the name of development. In view of this WHO, FAO and other countries have set standards and guidelines indicating tolerable or maximum permissible amount of trace elements that should be present in foodstuffs, plants and soils. When these elements exceed these standards, then the material (foodstuff, plant and soil) are polluted and hence unfit for consumption.

According to Radwan and Salama (2006), International and National regulations on food quality have lowered the maximum permissible levels of toxic metals in food items due to an increased awareness of risk these metals pose to food chain contamination.

Capsicum annuum (pepper) and *Lycopersicon esculentum* (tomato) fruits are universally commonly used vegetables by humans in their daily consumption thus their level of heavy metals should be very minimal if not absent. However, findings from this study indicated that *Capsicum annuum* and *Lycopersicon esculentum* fruits in the study area had higher concentrations of heavy metals than the recommended standards (maximum value for fruit vegetables set by Codex (2011) and maximum acceptable daily intake set by WHO (1996)). Similar findings of higher levels of heavy metals in vegetables have been recorded by Shilev and Babrikov (2005), (*Capsicum annuum* and *Lycopersicon esculentum*), Elbagermi *et al*. (2012), (*Lycopersicon esculentum*) and Miclean *et al*. (2000), (*Lycopersicon esculentum*).

Nonetheless, this work recorded lower levels of heavy metals for Cd (1.37 to 2.63 mg/kg), Pb (10.28 to 21.30 mg/kg) and Cu (20.55 to 54.94 mg/kg) in *Capsicum annuum* fruits when compared to findings of Shilev and Babrikov (2005), Cd (11.54 mg/kg), Pb (115.38 mg/kg) and Cu (75.00 mg/kg), working in a non ferrous metal smelting polluted area of Plovdiv region in Bulgaria. This difference in concentration can be attributed to the difference in geological location and the source of pollution which in this study was mining and their work was non ferrous metal pollution.

Levels of heavy metals of Cd (1.48 to 2.78 mg/kg), Pb (17.89 to 20.98 mg/kg), Cu (28.07 to 55.28 mg/kg) and Zn (146.21 to 289.54 mg/kg) in *Lycopersicon esculentum* fruits were higher than those recorded by Elbagermi *et al*. (2012) from fruits obtained in the markets of Misurata City in Libya Cd (0.25 mg/kg), Pb(0.51 mg/kg), Cu (2.25 mg/kg) and Zn (8.43 mg/kg). Shilev and Babrikov (2005) recorded higher levels of heavy metals for Cd (7.09 mg/kg), Pb (81.82 mg/kg), and Cu (49.09 mg/kg) compared to this study. However, the levels for Zn in all Farms and Cu in Farm 1 were higher than levels obtained in their findings.

In general heavy metal concentrations in the fruits of *Lycopersicon esculentum* were higher than *Capsicum annuum* fruits. This difference in the levels of heavy metals entering the edible part of the plants may depend on the type of plant and plant-soil interactions. According to Bitala (2008), organic acids in plants also enhances phytoavailability of metals to plants as it increases the dissolution of metals from insoluble mineral phases in soil. This dissolution increases metal mobility in the vicinity of roots; increases desorption of heavy metals and rare earth elements from soils and increase metal concentrations in the soil solution.

Further, the level of heavy metals in the fruits may be influenced by the size of the fruits (biomass). Naturally, *Lycopersicon esculentum* fruits are bigger in size than *Capsicum annuum* fruits and may have the propensity to accumulate more heavy metals in their tissues. Given its texture *Lycopersicon esculentum* has a larger volume to mass ratio and hence more surface for the accumulation of heavy metals.

Again the number of seeds in the fruits of the vegetables may affect their heavy metal concentrations, because seeds being the main reproductive part of plants store up nutrients and metals. Research has shown that seeds accumulate more heavy metals than other fleshy parts of a fruit (Khairiah *et al*., 2009). In this research the variety of tomato used had more seeds than that of the variety of pepper. The higher heavy metal concentrations of tomato fruits over that of pepper could have been influenced by the concentrations in the seeds, since the whole fruits (fleshy part and seeds) were ash together.

It could be observed that Cd and Pb, two toxic heavy metals and mostly associated with mining were recorded highest in Farm 3 indicating that the STF is indeed affecting the areas close to it. Generally it is expected that Farm 3, the closest of the four farms to the STF should receive the greatest impart of pollutants from its activities which could be as a result of spillage or atmospheric deposition being it dry or wet deposition. However, this was not the case for all the metals in this study and may be due to the fact that, the heavy metals emitted from the mining activities have become airborne and once pollutants become airborne, they can remain at their source or be transported hundreds of kilometres by wind and rain and deposited near and far from their source (Getis *et al.,* 2004).

Also, the contamination may not entirely be coming from the mining activities as all the Farms except Farm 3 were close to commercial roads (only AGA cars ply the road near Farm 3). Farms 1 and 2 are located close to the Apitikoko - Apitiso main road whilst Farm 4 is located close to the Obuasi – Cape Coast main road. According to Suruchi and Khana (2011), cultivation areas near highways are exposed to atmospheric pollution in the form of metal containing aerosols from the fumes of vehicles that ply the road and these aerosols can be deposited on soil and absorbed by the vegetables or alternatively deposited on the leaves and fruits and then absorbed.

Farm 4, the farthest from the STF recorded the least level of heavy metal concentrations in the fruits but recorded highest for both the shoots and roots. However, the fruits recorded the highest level of As, same as the shoots and roots. High level of As in Farm 4 suggests that aside the soils of Obuasi being high in As, the environment is also polluted with As.

The ranking order of heavy metals levels in the fruits of both vegetables among the four farms in the decreasing order was: Fe>Zn>As>Cu>Pb>Cd. Iron (Fe), Zn and Cu occur naturally in plants and are also needed by plants as principle micro essential elements and vital for the growth of plants (Codex, 2011), thus their high levels of accumulation by the vegetables. Even though As is toxic to plants, its level in the fruits were high. This may be due to the high As levels in the soils of Obuasi and its high translocation from the soils to the plants and within the plants and also, absorption of airborne As by the fruits. Lead (Pb) and Cd, two other toxic non-essential elements to plants were present in lower levels because they are released during mining activities and/or the fumes of vehicles that ply the roads close to the farms.

The decreasing trend of the metals obtained in this study corresponds with that of Elbagermi *et al*. (2012), for *Lycopersicon esculentum* fruit (Zn>Cu>Pb>Cd) but contradict the work of Shilev and Babrikov (2005), for both vegetable fruits (Zn>Pb>Cu>Cd). The differences in the trend may be due to the different geological location, the source of pollution and probably the type of soil on which the plants were grown.

Even though this research establishes that the levels of heavy metals in the fruits of *Capsicum annuum* and *Lycopersicon esculentum* are very polluted and unfit for human consumption, of the four farms, it is safer to consume fruits of *Capsicum annuum* and *Lycopersicon esculentum* from Farm 4.

5.2 Heavy metal concentrations in the shoots of *Capsicum annuum* and *Lycopersicon esculentum*

The concentration of metals in fruits of plants is mostly dependent on the concentrations in the plants' shoots and roots, thus even if the shoots and roots are not consumed it is important to determine their metal concentration as it can help in determining the rate of metal translocation. Analysis of heavy metals in the shoots of plants may suggest the atmosphere pollution degree (Smical *et al*., 2008).

Findings from this study indicated higher levels of heavy metals in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* plants than that of recommended standard (Normal Plant Value stated by Sharma and Chettri (2005)). Levels of heavy metals in the shoots of *Capsicum annuum* and *Lycopersicon esculentum* plants were below and within the range of critical plant concentration of heavy metal (CPC) stated by Sharma and Chettri (2005).

Works with similar findings to this study have been recorded by Shilev and Babrikov (2005), (*Capsicum annuum* and *Lycopersicon esculentum*).

Nonetheless, this work recorded lower levels of heavy metals for Cd (4.84 to 5.89 mg/kg) and Pb (34.16 to 41.96 mg/kg) and higher levels for Cu (54.73 to 170.63 mg/kg) and Zn (409.93 to 878.89 mg/kg) in *Capsicum annuum* shoots when compared to findings of Shilev and Babrikov (2005),; Cd (18.1 mg/kg), Pb (67.2 mg/kg), Cu (54.4 mg/kg) and Zn (202 mg/kg), working in a non ferrous metal smelting polluted area of Plovdiv region in Bulgaria. Also, lower levels for Cd (1.8 to 3.92 mg/kg) and Pb (18.13 to 29.16 mg/kg) and higher levels for Cu (36.69 to 97.11 mg/kg) and Zn (411.26 to 857.19 mg/kg) in *Lycopersicon esculentum* shoots were recorded in this study when compared to findings of Shilev and Babrikov (2005),; Cd (24.9 mg/kg), Pb (105.6 mg/kg), Cu (54.3 mg/kg) and Zn (477 mg/kg). This difference in concentration may be due to difference in geological location and the source of pollution which in this study was mining and their work was non ferrous metal pollution.

In general, shoots of *Capsicum annuum* recorded higher heavy metal levels than *Lycopersicon esculentum* shoots. However, *Lycopersicon esculentum* shoots recorded higher Zn level than *Capsicum annuum* shoots in Farms 1, 2 and 4. This may be due to the plant – metal interaction and affinity of the plants to the metals (Bitala, 2008). *Capsicum annuum* shoots may have higher tolerance and/or need for the heavy metals than *Lycopersicon esculentum* shoots resulting in *Capsicum annuum* shoots accumulating higher heavy metals than *Lycopersicon esculentum* shoots.

Also, the harder stems of *Capsicum annuum* than that of *Lycopersicon esculentum* shoots may account for their ability to accumulate more heavy metals. Again, by virtue of the plants shape and form, *Capsicum annuum* shoots may be receiving more atmospheric pollutants than *Lycopersicon esculentum* shoots.

Since heavy metals can travel long distance when airborne (Getis *et al.,* 2004), their concentrations can even be higher at areas distance away from their source than areas close to their source. This coupled with urbanization and subsequently industrialization of Kwabenakwa community (where Farm 4 is located) than Apitikoko community (where Farms 1, 2 and 3 are located) may resulting in higher heavy metals levels in Farm 4. Highest levels of most of the heavy metals (Cd, Cu and Zn) were recorded in Farm 3 and may be due to its close location to the STF thus receiving greater influence from its operations. Looking at the distances of Farms 1 and 2 from the STF and being the next polluted farms respectively after Farm 3 indicates that pollution within the concessional area decreases with increasing distance away from it.

The source of heavy metal pollution may also be coming from the fumes of vehicles that ply the roads close to the four farms (Suruchi and Khana, 2011). Again, the use of previous year seeds which have accumulated heavy metals already may result in the higher levels of the metals in the shoots.

Heavy metals levels in the shoots of the two vegetables in the decreasing order was: Fe>Zn>Cu>As>Pb>Cd. Iron (Fe), Zn and Cu are needed by plants as principle micro essential elements and vital for the growth of plants thus their high level of accumulation by the vegetables. Arsenic (As), Pb and Cd are lower than the other metals because they are non-essential and toxic to the plants but are present because of their natural presence in the soil (As) and are released during mining activities (Pb and Cd) and from the fumes of vehicles that ply the roads (Pb) thus being airborne and absorbed by the shoots when they settle on them. The presence of these heavy metals in the soils of the study area also makes them available in the shoots of the plants when absorbed by the roots and translocated to the shoots.

The decreasing trend of the metals recorded in this study contradicts the work of Shilev and Babrikov (2005), for both vegetable shoots (Zn>Pb>Cu>Cd). The differences in the trend may be due to the different geological location, the source of pollution and probably the type of soil on which the plants were grown.

5.3 Heavy metal concentrations in the roots of *Capsicum annuum* and *Lycopersicon esculentum*

Analysis of heavy metals in the roots of plants may indicate the degree of heavy metal accumulation in polluted soils, offer clues on the soil pollution degree and help in determining the rate of metal translocation within plants (Smical *et al.*, 2008).

Findings from this study indicated higher levels of heavy metals in the roots of *Capsicum annuum* and *Lycopersicon esculentum* plants than that of recommended standard (Normal Plant Value stated by Sharma and Chettri (2005)). Levels of heavy metals in the roots of *Capsicum annuum* and *Lycopersicon esculentum* plants were below and within the range of critical plant concentration of heavy metal (CPC) stated by Sharma and Chettri (2005). Works with similar findings to this study have been recorded by Shilev and Babrikov (2005), (*Capsicum annuum* and *Lycopersicon esculentum*).

Nonetheless, this work recorded lower levels of heavy metals for Cd (1.86 to 2.61 mg/kg) and Pb (12.64 to 26.59 mg/kg) and higher levels for Cu (59.72 to 126.69 mg/kg) and Zn (194.53

to 305.14 mg/kg) in *Capsicum annuum* roots when compared to findings of Shilev and Babrikov (2005),; Cd (14.4 mg/kg), Pb (57.6 mg/kg), Cu (42.6 mg/kg) and Zn (222 mg/kg), working in a non ferrous metal smelting polluted area of Plovdiv region in Bulgaria. Also, lower levels for Cd (3.83 to 5.23 mg/kg) and Pb (27.19 to 35.98 mg/kg) and higher levels for Cu (32.96 to 103.63 mg/kg) and Zn (594.28 to 911.59 mg/kg) in *Lycopersicon esculentum* roots were recorded in this study when compared to findings of Shilev and Babrikov (2005),; Cd (18.9 mg/kg), Pb (99.0 mg/kg), Cu (55.5 mg/kg) and Zn (321 mg/kg). This difference in concentration may be due to difference in geological location and the source of pollution which in this study was mining and their work was non ferrous metal pollution.

In general, roots of *Lycopersicon esculentum* recorded higher heavy metal levels than roots of *Capsicum annuum*. This may be due to the plant – metal interaction and affinity of the plants roots to the metals (Bitala, 2008). It may be that *Lycopersicon esculentum* roots have higher tolerance and/or need for the heavy metals than *Capsicum annuum* roots resulting in *Lycopersicon esculentum* roots accumulating higher heavy metals than *Capsicum annuum* roots. Also, the roots of *Lycopersicon esculentum* may have well developed root system which enables them draw or extract more metals than *Capsicum annuum* roots.

Long range and transboundary travel of pollutants either by air or water (rain) can make their concentrations higher at areas distance away from their source than areas close to their source. Other anthropogenic activities taking place in Kwabenakwa community (where Farm 4 is located) than Apitikoko community (where Farms 1, 2 and 3 are located) due to difference in population may result in higher heavy metals levels in Farm 4. Within the concessional area, Farm 3 recorded highest levels of the heavy metals. This may be due to its close location to the STF thus receiving greater influence from its operations. Farms 1 and 2 the next polluted farms respectively after Farm 3 indicates that pollution within the prime mining area decreases with increasing distance away from it.

The main source of pollution of the roots of the two vegetables in all the four farms is the STF and its mode of transport may be via the air as once pollutants become airborne, wind and rain can carry them hundreds of kilometres depositing them near and far from their source (Getis *et al.,* 2004). The source of heavy metal pollution may also be coming from the fumes of vehicles that ply the roads close to the four farms (Suruchi and Khana, 2011). These airborne pollutants settle on the soils of the farms and are absorbed into the roots of the plants.

Heavy metal levels in the roots of the two vegetables in the decreasing order was: Fe>Zn>As>Cu>Pb>Cd. Iron (Fe), Zn and Cu are needed by plants as principle micro essential elements and vital for the growth of plants thus their high level of accumulation by the vegetables. Soils in Obuasi have high As levels and thus the roots absorbing more from the soil even though As is not essential for the growth of plants. Lead (Pb) and Cd are lower than the other metals because they are non-essential and toxic to the plants but are present because they are released during mining activities and/or are also present in fumes of vehicles that ply the roads thus being airborne and deposited on the soils and subsequently absorbed by the roots of the plants.

The decreasing trend of the metals recorded in this study contradicts the work of Shilev and Babrikov (2005), for both vegetable roots (Zn>Pb>Cu>Cd). The differences in the trend may be due to the different geological location, the source of pollution and probably the type of soil on which the plants were grown.

5.4 Heavy metal concentrations in soil of the four farms

Soil is an essential part of the environment serving as a medium for plant growth, pool to dispose of undesirable materials, a transmitter of many pollutants to surface water, groundwater, atmosphere and food (Addo *et al*., 2012). It is therefore important to determine the levels of pollutants (heavy metals) in soils as their contamination of water and food may affect the health of consumers.

Increase levels of heavy metals in Farm 4 (which also served as control due to its distance from the concessional area) than the rest of the farms indicate that there might be atmospheric transport of heavy metals, into adjoining soils through moisture movement or wind erosion of dried tailings. Also, there might be anthropogenic activities like burning of firewood both domestically and industrially and illegal mining (Galamsey) going on close or within the township hence contaminating the air and subsequently the soil.

Within the concessional area, Farm 3 which is the closest to the STF has the highest level of heavy metals, indicating that upon efforts by AGA to suppress dust, areas close to the dam are being polluted with heavy metals. This confirms report of Antwi-Agyei *et al*. (2009), that gold mine tailings dams are source of trace elements contamination in adjoining environmental media, including soils, plants, water bodies and sediments in Obuasi and thus if additional measures are not put in place the concentrations may exceed international levels.

It has been reported that soils in Obuasi are rich in Fe (Ahmad and Carboo, 2000; Kumi-Boateng, 2007). The high levels of Fe recorded in the soils of the four farms in this research confirm these reports.

Findings from this research confirm reports that the soils in the Obuasi Municipality have high levels of Arsenic (Kumi-Boateng, 2007; Antwi- Agyei *et al*., 2009). The levels is among the highest in the world, and has been linked to the principal gold-bearing ore in the area, which is rich in arsenopyrite (FeAsS) mineralization (Amonoo-Neizer *et al*., 1995; Ahmad and Carboo, 2000; Kumi-Boateng, 2007). Mining at Obuasi has been reported to give rise to substantial airborne As pollution from ore-roasting as well as river-borne As pollution derived from nearby tailings. This explains why As was the second highest heavy metal in the soils and even exceeded both the WHO and USEPA standards.

Lower levels of Zn, Cu and Pb recorded indicate that, they may be strongly iron-bound (Antwi- Agyei *et al*., 2009) and their presence in the soils may be dependent on their potential intrusion and their rate of mobility in the soil from the tailings dams. The presence of Cd in the soils may be due to the metal's intrusion and mobility in the soil from the tailings dam and other anthropogenic activities going on close and far from the farms. These may be the reason for its higher levels than the WHO standard.

Ranking order of heavy metals recorded in the soils of this study followed the same trend as that reported by Antwi- Agyei *et al.* (2009), in Obuasi (As>Zn>Cu>Pb) but contrary to observations by Shumlyanskyy *et al.* (2005), in Ukraine (Pb>Zn>As>Cu) this difference as suggested by Antwi- Agyei *et al.* (2009) might be attributed to differences in soil properties, due to different locations.

5.5 Bioaccumulation ratio: relationship between levels of heavy metals in soil and vegetables

Bioaccumulation ratio gives an indication of an organism's ability to accumulate metals in its tissues. It also helps to know whether an organism is a hyperaccumulator of metals. Hyperaccumulators are organisms that have a bioaccumulation ratio greater than 1. Due to bioaccumulation and biomagnification through food chains and webs, when plants are polluted with heavy metals, toxic burden of these heavy metals in humans becomes higher as some livestock can also consume them.

Overall the whole vegetable plants had higher concentrations of heavy metals than the soils except for As in *Lycopersicon esculentum* plants in Farms 1 and 3 (Table 9). The higher concentrations of the heavy metals in the plants indicate that there is a high potential for their transport through the food chain. This confirms report of Cunningham (2001), that toxins that are dilute in the environment can reach dangerous levels in the cells and tissues of organisms through bioaccumulation process. Also, all the seeds used in cultivation on all four farms were from previous harvest and may account for the high heavy metal levels in the plants than the soils.

Fruits of the two vegetable plants in all four farms were hyperaccumulators of all the heavy metals. Nonetheless, *Capsicum annuum* fruits obtained bioaccumulation ratio less than 1 for As and Fe in all four farms, Cd in Farms 2 and 4 and Pb in Farm 4. Similarly, *Lycopersicon esculentum* fruits obtained bioaccumulation ratio less than 1 for As in all four farms, Fe in Farms 2, 3 and 4 and Cd in Farm 4. These lower bioaccumulation ratios indicate that translocation of the metals from the shoots to the fruits was low and may be influenced by plant factors, differences in metal characteristics and plant cells mechanisms (Cunningham, 2001; Bitala, 2008).

The decreasing order of bioaccumulation ratio of the heavy metals in the two vegetable plants was: Zn>Cu> Pb>Cd>Fe>As. This trend is consistent with Singh *et al*. (2012) who also observed a decreasing trend of Zn>Cu>Pb>Cd in *Lycopersicon esculentum* plant. Zinc (Zn) and Cu recording the first and second highest bioaccumulation ratios respectively imply that they are needed more by the plants. It has been reported by Codex (2011), that Zinc (Zn) and Cu are two essential elements required for health growth of plants. It could also mean that they bioavailable in the soil thus making them potentially mobile for accumulation by the plants. This disputing the assertion by Antwi-Agyei *et al*. (2009), that Cu, Zn and Pb might not necessarily be bioavailable because they are strongly iron-bound in soils of Obuasi.

Iron (Fe) recording lower bioaccumulation ratio by the plants does not necessarily mean they are not needed by the plants as Fe helps in the growth of plants and can be attested to in Tables 1, 3 and 5 as the highest accumulated metal by the plants. The low bioaccumulation ratio of Fe further confirms that soils in Obuasi are rich in Fe, indicating that Fe is not highly available for accumulation.

Arsenic (As), being the lowest bioaccumulated metal by the plants indicates that soils in Obuasi are highly contaminated with As. It is not needed by the plants as they are harmful to the plants thus a non-essential metal of plants supporting Codex (2011) report.

Considering the bioaccumulation ratios of all the heavy metals, it can be inferred from Table 9 that the decreasing order of bioaccumulation ratios of all the heavy metals in the farms was Farm 1>Farm 4>Farm 3>Farm 2. This trend can be attributed to plant factors, differences in metal characteristics, differences in soil physical and chemical properties, soil- plant interactions and plant cells mechanisms (Cunningham, 2001; Bitala, 2008).

Both vegetables recorded lowest bioaccumulation ratios of heavy metals in their fruits (edible part) than the vegetative parts (shoot and root). This means that translocation of heavy metals from the vegetative to the reproductive shoot in the plants is low. Low heavy metals accumulation in fruits than in shoots and roots have also been observed by Singh *et al*. (2012). In contrast, Barman and Lal (1994), reported higher accumulation of heavy metals (Cu, Zn, Pb, Cd) in edible parts than in non-edible plant parts.

Capsicum annuum can be regarded as a good hyperaccumulator reflecting in its bioaccumulation ratio greater than one. Its ability to accumulate heavy metals mostly in the shoots suggests that it is a good phytoextractors of heavy metals (Ogundiran and Osibanjo, 2008). Similarly *Lycopersicon esculentum* can also be regarded as a good hyperaccumulator reflecting in its bioaccumulation ratio greater than one. However, *Lycopersicon esculentum* plants accumulated heavy metals mostly in their roots suggesting that they are good excluders of heavy metals (Ogundiran and Osibanjo, 2008).

Generally, it can be stated that the two vegetable plants are hyperaccumulators for all the heavy metals since they obtained bioaccumulation ratios greater than one. This implies the two vegetables are polluted and hence unfit for human consumption.

CHAPTER SIX

6.0 CONCLUSION AND RECCOMENDATIONS

6.1 Conclusion

Based on the WHO and USEPA acceptable standards of heavy metals in soil and the findings of this research, it can be concluded that the soils of Obuasi have high levels of As and Cd and the levels of Pb, Cu, Fe and Zn are within the recommended standards.

Capsicum annuum and *Lycopersicon esculentum* plants grown in the two farming communities within Obuasi are polluted with the heavy metals and are hyperaccumulators of these heavy metals. *Capsicum annuum* plants are good phytoextractors of heavy metals. On the other hand, *Lycopersicon esculentum* plants are good excluders of heavy metals. Iron (Fe) was accumulated mostly in the roots of both plants followed by their shoots and fruits.

The levels of heavy metals in fruits of both vegetables in all four farms were very high. Being that both vegetables are commonly and widely consumed by humans the high levels of these heavy metals pose severe health risk to humans. Thus the fruits of *Capsicum annuum* and *Lycopersicon esculentum* plants cultivated in these two farming communities within Obuasi are unfit for human consumption.

Within the concessional mining area, Farm 3 which is closest to the STF (100m away) recorded higher levels of heavy metals in the plants and soils than Farms 1 and 2 (650m and 700m respectively) away from the tailings dam. However, Farm 4 which is outside the concessional mining area recorded the highest levels of heavy metals in the plants and soils and thus is more polluted than the three other farms within the concession.

This study demonstrates that Mining in Obuasi contributes a great deal to heavy metals contamination of the soils and plants within and around the concessional areas though it may not be the only source of contamination. Other sources of heavy metals introduction into the environment could be from natural and anthropogenic activities. Result also indicates that heavy metals can be transported to long distances and in very high levels.

6.2 Recommendations

Since the As and Cd levels of the soils are higher than internationally accepted standards, As and Cd hyperaccumulator plants should be planted for phytoremediation of these soils so that they would be used for agricultural purposes.

AGA should strategise and device new improved and better ways of operation so as to reduce and control environmental pollution.

Research should be carried out to determine the heavy metals levels of the seeds and vegetative propagates of food stuffs in Obuasi as these are likely to be reused for future cultivation.

Assistance should be given to farmers by the Obuasi Municipal Assembly and/or AGA to help them purchase new uncontaminated seeds and vegetative propagators to serve as new inputs in cultivation of their agricultural lands after it been remediated to help reduce the level of contamination in the crops.

Due to the health problems associated with these heavy metals there is the need to continually examine the levels of heavy metals in foodstuffs in and around Obuasi in order to maintain and/or improve measures to reduce their levels in foodstuffs and ultimately prevent these avoidable health problems.

The right institution mandated to set local standards of acceptable levels of heavy metals in foodstuffs in Ghana should do so and make the information available to the public as to the best of my knowledge, at the time of this research there was no standard set by Ghana.

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APPENDICES

Appendix A. Coordinates, Distance of farms from STF and Farm Sizes

ID	x	Y	z (m)	Distance from STF (m)	Farm size (ha)
Farm 1	194865.425	167392.39	208	650	0.1124
Farm 2	195206.74	167259.4	215	700	0.1442
Farm 3	195100.45	167916.2	232	100	0.1240
Farm 4	210214.31	171718.24	241	15000	0.1520

Appendix B:

Samples of *Lycopersicon esculentum* plant parts

A. Fruits of *Lycopersicon esculentum*

B. Shoots of *Lycopersicon esculentum*

C. Roots of *Lycopersicon esculentum*

Samples of *Capsicum annuum* plant parts

A. Fruits of *Capsicum annuum*

B. Shoots of *Capsicum annuum*

C. Roots of *Capsicum annuum*

Appendix C. ANOVA tables of the various plant parts of the two vegetables and soil

C1. Fruits

ANOVA

Arsenic

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	37945.712	7	5420.816	3.273E3	.000
Within Groups	39.752	16	1.656		
Total	37985.464	23			

ANOVA

Cadmium

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8.722	7	1.246	19.473	.000
Within Groups	1.536	16	.064		
Total	10.257	23			

ANOVA

Lead

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	479.781	7	68.540	313.606	.000
Within Groups	5.245	16	.219		
Total	485.026	23			

ANOVA

Copper

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4652.745	7	664.678	3.102E3	.000
Within Groups	5.143	16	.214		
Total	4657.888	23			

ANOVA

Iron

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3618800.940	7	516971.563	7.858E4	.000
Within Groups	157.897	16	6.579		
Total	3618958.837	23			

ANOVA

Zinc

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	228121.706	7	32588.815	4.751E3	.000
Within Groups	164.625	16	6.859		
Total	228286.332	23			

C2. Shoot

ANOVA

Arsenic	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	156580.806	7	22368.687	6.782E3	.000
Within Groups	79.163	16	3.298		
Total	156659.969	23			

ANOVA

Cadmium	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	49.517	7	7.074	78.752	.000
Within Groups	2.156	16	.090		
Total	51.672	23			

ANOVA

Lead	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1725.353	7	246.479	3.365E3	.000
Within Groups	1.758	16	.073		
Total	1727.111	23			

ANOVA

Copper	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	59021.676	7	8431.668	1.336E5	.000
Within Groups	1.515	16	.063		
Total	59023.191	23			

ANOVA

Iron

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1758599.963	7	251228.566	3.051E4	.000
Within Groups	197.598	16	8.233		
Total	1758797.561	23			

ANOVA

Zinc

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1194422.780	7	170631.826	1.314E4	.000
Within Groups	311.660	16	12.986		
Total	1194734.440	23			

C3. Root

ANOVA

Arsenic

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	161437.826	7	23062.547	6.832E3	.000
Within Groups	81.018	16	3.376		
Total	161518.844	23			

ANOVA

Cadmium

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	39.840	7	5.691	78.397	.000
Within Groups	1.742	16	.073		
Total	41.583	23			

ANOVA

Lead	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1541.516	7	220.217	2.113E3	.000
Within Groups	2.502	16	.104		
Total	1544.017	23			

ANOVA

Copper	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	24233.535	7	3461.934	1.920E4	.000
Within Groups	4.327	16	.180		
Total	24237.862	23			

ANOVA

Iron	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	578811.211	7	82687.316	2.161E4	.000
Within Groups	91.823	16	3.826		
Total	578903.034	23			

ANOVA

Zinc	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2085791.476	7	297970.211	8.910E4	.000
Within Groups	80.258	16	3.344		
Total	2085871.733	23			

C4. Soil

ANOVA

Arsenic

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	16064.128	3	5354.709	36.652	.000
Within Groups	1168.774	8	146.097		
Total	17232.901	11			

ANOVA

Cadmium

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.394	3	.798	31.531	.000
Within Groups	.202	8	.025		
Total	2.597	11			

ANOVA

Lead

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	99.111	3	33.037	7.701	.010
Within Groups	34.320	8	4.290		
Total	133.431	11			

ANOVA

Copper

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	170.805	3	56.935	65.337	.000
Within Groups	6.971	8	.871		
Total	177.776	11			

ANOVA

Iron

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8528.775	3	2842.925	157.195	.000
Within Groups	144.683	8	18.085		
Total	8673.457	11			

ANOVA

Zinc

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1155.650	3	385.217	17.846	.001
Within Groups	172.687	8	21.586		
Total	1328.338	11			

Appendix D. ANOVA tables of the metals in the various plant parts of the two vegetables and soil

D 1. Fruits

ANOVA

Farm_1_pepper_fruit

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	94490.049	5	18898.010	4.721E3	.000
Within Groups	72.052	12	4.003		
Total	94562.101	17			

ANOVA

Farm_2_pepper_fruit

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	712258.404	5	142451.681	4.153E5	.000
Within Groups	6.173	12	.343		
Total	712264.578	17			

ANOVA

Farm_3_pepper_fruit

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	289143.562	5	57828.712	3.280E4	.000
Within Groups	31.735	12	1.763		
Total	289175.297	17			

ANOVA

Farm_4_pepper_fruit

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	81510.347	5	16302.069	6.223E4	.000
Within Groups	4.715	12	.262		
Total	81515.062	17			

ANOVA

Farm_1_tomato_fruit

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3885917.303	5	777183.461	2.612E5	.000
Within Groups	53.557	12	2.975		
Total	3885970.860	17			

ANOVA

Farm_2_tomato_fruit

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2904167.168	5	580833.434	1.623E5	.000
Within Groups	64.432	12	3.580		
Total	2904231.599	17			

ANOVA

Farm_3_tomato_fruit

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1128151.675	5	225630.335	1.360E5	.000
Within Groups	29.857	12	1.659		
Total	1128181.533	17			

ANOVA

Farm_4_tomato_fruit

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1645288.537	5	329057.707	5.304E4	.000
Within Groups	111.676	12	6.204		
Total	1645400.213	17			

D2. Shoot

ANOVA

Farm_1_pepper_shoot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3830176.601	5	766035.320	2.379E5	.000
Within Groups	57.967	12	3.220		
Total	3830234.567	17			

ANOVA

Farm_2_pepper_shoot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3004376.213	5	600875.243	8.898E5	.000
Within Groups	12.156	12	.675		
Total	3004388.369	17			

ANOVA

Farm_3_pepper_shoot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3609436.065	5	721887.213	9.532E4	.000
Within Groups	136.318	12	7.573		
Total	3609572.383	17			

ANOVA

Farm_4_pepper_shoot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3213525.143	5	642705.029	9.144E5	.000
Within Groups	12.652	12	.703		
Total	3213537.795	17			

ANOVA

Farm_1_tomato_shoot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5325959.171	5	1065191.834	2.914E5	.000
Within Groups	65.804	12	3.656		
Total	5326024.975	17			

ANOVA

Farm_2_tomato_shoot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4528923.321	5	905784.664	1.986E5	.000
Within Groups	82.098	12	4.561		
Total	4529005.419	17			

ANOVA

Farm_3_tomato_shoot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2296891.119	5	459378.224	2.411E6	.000
Within Groups	3.430	12	.191		
Total	2296894.549	17			

ANOVA

Farm_4_tomato_shoot

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2488655.699	5	497731.140	4.010E4	.000
Within Groups	223.425	12	12.413		
Total	2488879.124	17			

D3. Root

ANOVA

Farm_1_pepper_root

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4528609.546	5	905721.909	1.517E6	.000
Within Groups	10.749	12	.597		
Total	4528620.295	17			

ANOVA

Farm_2_pepper_root

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4911501.737	5	982300.347	1.020E6	.000
Within Groups	17.338	12	.963		
Total	4911519.075	17			

ANOVA

Farm_3_pepper_root

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6597264.238	5	1319452.848	2.191E6	.000
Within Groups	10.841	12	.602		
Total	6597275.079	17			

ANOVA

Farm_4_pepper_root

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7246127.398	5	1449225.480	1.141E6	.000
Within Groups	22.861	12	1.270		
Total	7246150.260	17			

ANOVA

Farm_1_tomato_root

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7892054.529	5	1578410.906	1.123E6	.000
Within Groups	25.300	12	1.406		
Total	7892079.829	17			

ANOVA

Farm_2_tomato_root

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7788710.841	5	1557742.168	9.460E5	.000
Within Groups	29.641	12	1.647		
Total	7788740.482	17			

ANOVA

Farm_3_tomato_root

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5912767.442	5	1182553.488	4.225E5	.000
Within Groups	50.383	12	2.799		
Total	5912817.825	17			

ANOVA

Farm_4_tomato_root

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7745937.457	5	1549187.491	2.949E5	.000
Within Groups	94.556	12	5.253		
Total	7746032.013	17			

D 4. Soil

ANOVA

Farm_1_soil

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2960291.315	5	592058.263	5.293E4	.000
Within Groups	134.224	12	11.185		
Total	2960425.539	17			

ANOVA

Farm_2_soil

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2970092.069	5	594018.414	2.830E4	.000
Within Groups	251.869	12	20.989		
Total	2970343.938	17			

ANOVA

Farm_3_soil

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3129937.116	5	625987.423	1.283E4	.000
Within Groups	585.502	12	48.792		
Total	3130522.619	17			

ANOVA

Farm_4_soil

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3258971.361	5	651794.272	1.407E4	.000
Within Groups	556.042	12	46.337		
Total	3259527.404	17			