UNIVERSITY OF EDUCATION, WINNEBA

# ASSESSMENT OF HEAVY METALS IN SELECTED DUMPSITE SOILS AND PLANTS IN KUMASI AND ASANTE MAMPONG, GHANA

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# HEAVY METAL ASSESSMENT IN SELECTED DUMPSITE SOILS AND PLANTS IN KUMASI AND ASANTE MAMPONG, GHANA

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A THESIS IN THE DEPARTMENT OF CROP AND SOIL SCIENCES EDUCATION,
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# DECLARATION

## STUDENT'S DECLARATION

I, Kwabena Kyere declare that this dissertation with the exception of quotations and references contained in published works which have all been identified and acknowledged is entirely my own original work and it has not been submitted either in part or whole for another degree elsewhere.

**SIGNATURE**…………………………………

**DATE**….……………………………………...

## SUPERVISORS' DECLARATION

We, hereby declare that the preparation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

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# DEDICATION

This work is dedicated to my wife (Mrs. Evelyn Tuffour Kyere) and my children (Kwasi Asiedu Kyere, Kofi Nimako Kyere) and my parents (Grace Adwoa Serwaa and Richard Berchie).

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| CSIR – SRI | Council for Scientific and Industrial Research - Soil Research Institute |
| MOFA | Ministry of Food and Agriculture |
| IGEO | Geoaccumulation Index |
| EF | Enrichment Factor |
| RTEF | Relative Top soil Enrichment Factor |
| TR | Transfer Ratio |
| TF | Translocation Factor |
| KYE | Kyeremfaso dumpsite soil |
| UEW | University of Education Winneba, Mampong forest background soil |
| SUA | Suame magazine Kumasi dumpsite soil |
| MED | Meduma Kumasi background soil |
| AYE | Ayeduase Kumasi dumpsite soil |
| KNUST | Kwame Nkrumah University of Science and Technology botanical gardens Background soil |

# ABSTRACT

This study investigated dumpsite farmers’ soil physicochemical knowledge, heavy metals and their pollution levels in selected dumpsites and background soils and plants in Kumasi and Asante Mampong, Ghana (latitude 5° 50ʿ 7.46’’ N, longitude 0° 15ʿ 2.25’’ W). Chi - square ($\chi^2$) test showed that dumpsites farmers’ soil knowledge had no association ($p = 0.21$) with farmers’ educational level but showed a significant ($p = 0.02$) association with farmers awareness that dumpsites soil contain toxic elements; and ($p = 0.03$) farmers awareness that plants on dumpsites absorb toxic elements. Metals level were determined in soils at 0 - 15 cm and 15 - 30 cm depths with edible parts of plantain and cocoyam; 0 - 30 cm depth of sampled soils in pots with lettuce under field conditions using an XL3t GOLD XRF mass spectrometer. Physicochemical properties of dumpsite soils were higher than that of background soils. Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb were higher by 15 – 25 %. Soil Cu, Zn and Hg at 0 - 15 cm and 15 - 30 cm; soil Ni, Zn and Hg in pots from Magazine dumpsite were all above WHO (2015) limits in soils. Cr, Fe and Hg in plantain leaves and fruits from Magazine dumpsite; Hg in cocoyam leaves from Kyeremfaso dumpsite, and Hg in cocoyam corms from Magazine dumpsite; Cr, Fe, Ni and Cd in lettuce shoots and roots in pots in Magazine dumpsite were above allowable levels by FAO/WHO (2011). Cr and Cd; Fe and Zn; Ni and Cu; Cu, Zn and As; Zn and As; As and Pb; Hg and Pb association showed they have similar contamination sources. Cr and Fe; Cu, Cr and Zn showed antagonistic and synergistic type of behavior. Soil pH, SOM, CEC, Clay and soil available P influenced Cr, Fe, Ni, Cu, Zn, As and Cd. Pollution indices (Igeo, EF, RTEF, TR and TF) indicated very high contamination for Fe, Cu, Zn and Hg in the order of KYE < AYE < SUA. Education on dumpsites farming must be intensified and excavate dumpsites to landfill sites.

# CHAPTER ONE

# 1.0 INTRODUCTION

## 1.1 Background to the study

The population of Ghana has been estimated to be growing annually at a rate of 2.3% (GSS, 2013). This exponential growth in population, coupled with other issues associated with growing economies has posed a significant stress on the environment (Ahlijay, 2015) especially on lands for farming and other urban infrastructure and services (Owusu-Sekyere *et al.,* 2013). Dumpsites in Ghana are usually turned into other land uses such as crop cultivation, while some are excavated for soil amendment because they are known of the rich mineral and organic matter known to be rich in soil nutrients and organic matter for plant growth (Ogunyemi *et al.*, 2003; Akanchise *et al.,* 2020).

The decline in soil fertility coupled with comparatively high cost of chemical fertilizers have all contributed in making dumpsites soil better choice and alternative source of nutrient rich soils for backyard farmers as an. Owusu- Sekyere *et al.* (2013a) and Mwingyine (2008) have found that dumpsites are commonly used for direct cultivation of vegetables and also as good source of compost to support mainland agricultural activities because in most third world countries, dumpsite soils comprise of higher proportion (50 - 90 %) of organic matter materials (Asomani - Boateng and Murray, 1999). Currently, considerable pollutions from refuse disposal activities of man have introduced heavy metals into the soil environment and as a result have attracted the attention of researchers and policy makers. Heavy metals in the soil environment are of great ecological significance due to their toxicity at certain concentrations, translocation through food chains and their non - biodegradable nature accounts for their accumulation in the biosphere (Aekola *et al.,* 2008). Human electronic waste materials on dumpsites such as plastics, paper, metal rubbish and batteries which are known to be sources of heavy metals are hazardous to man and his environment (Alloway and Ayres, 1997; Pasquini and Alexander, 2004; Woodbury, 2005). Heavy metals are non - biodegradable, can undergo global ecological circles (Aekola *et al.,* 2008) and have toxic effects on living organisms at certain levels of concentrations. These dumpsites would help identify how the plants found on them are exposed to heavy metals (Opaluwa *et al.,* 2012).

Available plant nutrients in the soil solution may also be found in soils polluted with municipal, domestic or industrial wastes which may be bio - accumulated in roots, stems, fruits, grains and leaves of the crops (Fatoki, 2000) or in the form of mobile ions present in the soil or through foliar absorption (Opaluwa *et al.,* 2012), and may finally find their way into human food chain.

Agbeshie *et al.* (2020) conducted a study in Sunyani Municipality to determine the risk of heavy metal pollution and physicochemical properties of soils at a waste dumpsite. They found from the fifteen soils sampled at 0 – 30 cm depth found that the soil at the dumpsite was contaminated with Fe (< 30 mgkg$^{-1}$), but was within the permissible limits recommended by FAO / WHO (2001). Agbeshie *et al.* (2020) used geoaccumulation index (I $_{geo}$) assessment module and found that, dumpsites soil studied were moderately to strongly contaminated with heavy metals. Akanchise *et al.* (2020) studied the distribution of heavy metals in soils from abandoned dumpsites in Kumasi, Ghana and found that, there were moderate concentrations of heavy metals (As, Cd, Cr, Cu, Pb, Hg, Ni and Zn) in dumpsite soils at Amakom and Kronum with few of the metal concentrations exceeding International soil quality guidelines while geoaccumulation index showed generally no pollution.

In Ghana, a study conducted in Accra, Kumasi, Mampong and rural community dumpsites by Agyarko *et al*. (2010) found that, the levels of Iron and Nickel loads in plants from the refuse dump soils in Accra, Kumasi and Asante Mampong were beyond the normal ranges of 40 –500 ug $g^{-1}$ (Fe) and 0.02-5.00 ug $g^{-1}$ (Ni). Stewart *et al*. (1974) shared a similar view. These metals might also end up in the sink when they are leached out from the dumpsites (Opaluwa *et al.,* 2012).

Plants on polluted soils absorb heavy metals in the form of free moving ions in the soil through plants xylem and phloem vessels where they are bi-accumulated in their leaves, stem, fruits, grains and the root of the plant (Adebiyi *et al.,* 2018). However, a higher concentration of heavy metals in the soil can result in higher level of uptake by the plant (Ebong *et al.,* 2008). Critically examining these dumpsite soils, background soils and plants found on them and their safety levels in crops is important because of the high demand for human consumption in Ghana.

## 1.2 Problem Statement and Justification

The use of soils on and around dumpsites in rural and urban areas in Ghana is common for food production especially vegetables (Abgeshie *et al.,* 2020). The continues use of both active and abandoned dumpsites into other land uses such as crop cultivation and as soil amendment because of the rich mineral and organic matter content ( Akanchise *et al*., 2020), without the knowledge of the risk associated with heavy metals uptake by plants (Abgeshie *et al.,* 2020) couple with its excess accumulation in the environment threatens the health of plants and animals because metals exert biological effects on all life forms (Luo *et al.,* 2012; Cai *et al.,* 2015). Backyard farming on dumpsite soils in the Ashanti region of Ghana is gaining popularity due to the fact that some of these wastes at the dumpsites provide nutrients for healthy and increased plant growth and such positive effect encourages continued backyard farming on dumpsite soils. The evaluation of heavy metal contamination is an important component of risk assessment at waste dumpsites (Agbeshie *et al.,* 2020) as it may help to reduce the possible accumulation of toxic metals in the food chain in affecting healthy crop production in Ghana.

Studies conducted on the use of dumpsites and their soils for gardening have been helpful. However, going into other areas of interest, backyard farming activities on dumpsite soils are full of prospects and challenges and it has caught the attention of researchers, policy makers and farmers in developing countries like Ghana. A possible way of realizing these prospects and overcoming the challenges is by committing more resources and expertise into a comprehensive study on the use of dumpsite soils in Ashanti region of Ghana. The plant nutrition prospects of dumpsite soils and the pollution levels on these farmlands need much attention in order to supplement the efforts of farmers. The use of dumpsite soils as alternative farm land in urban and peri-urban settlements in Ghana due to inadequate arable lands has caught much attention in a developing country like Ghana. It is believed that, this study may help by informing farmers farming on dumpsite soils about the useful soil nutrients and other toxic nutrients in these soils. Although dumpsite soils serve as an alternative farmlands in some areas in Ashanti region, toxic metals level in dumpsites need to be considered before crop production in order to enable farmers realize the full potential of dumpsite soils to boost crop production in Ghana for food and poverty alleviation.

Hypothesis:

1. Farmers farming at dumpsites are aware of risk of heavy metals in such soils
2. Dumpsites contained heavy metals above toxic levels
3. Plants grown at dumpsites can absorb heavy metal posing risk to the food chain.
4. Crops grown at agricultural fields amended with dumpsites soil or compost can accumulate heavy metals posing risk to human health through the food chain.

## 1.3 Objectives of the studies

The main objective of the study was to assess the concentration levels of some heavy metals in selected dumpsites and background soils and plants in selected urban and rural dumpsites in the Ashanti Region of Ghana.

The specific objectives were to:

1. Assesss dumpsites farmers' knowledge of soil physicochemical properties of dumpsites
2. Assess some heavy metals in selected dumpsites and background soils.
3. Assess the accumulation levels of heavy metals in plantain and cocoyam grown at selected refuse dumpsites and background soils
4. Evaluate heavy metal levels in soils and lettuce plants grown in pots containing dumpsite soils under field conditions

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Waste Dumpsite Soils

A waste dumpsite is where waste materials are disposed of and is the oldest form of waste management (Ibrahim *et al*., 2013) in Ghana. Waste dumpsite contains high concentrations of heavy metals and are later absorbed and accumulated by the plants growing within such sites (Hammed *et al*., 2017) more than their counter parts found on normal agricultural soils in Ghana, most among them are vegetables which are the most exposed food crops to environmental pollution due to aerial burden (Jolly *et al*., 2013). In modern times, pollutions from the activities of human have introduced some of these heavy metals into the ecosystem (Opaluwa *et al*., 2012) while others occur naturally in the ecosystem with large variations in concentrations. However, they may occur naturally in low concentration and are found to be toxic even at low concentrations (Dinis and Filiza, 2011). When these metals slowly accumulate and distribute in the soil profiles over time, the soil can act as a long term sink for these toxic metals (Amesaki, 2018).

Dumpsite soils contain heavy metals such as copper (Cu), iron (Fe), mercury (Hg), silver (Ag), lead (Pb) and chromium (Cr) (Tafera *et al*., 2018), which persist and accumulate over a long time in soils and vegetations and thus resulting to serious environmental pollution (Mtunzi *et al*., 2015). Many areas near urban centres where wastes are dumped contain high concentrations of heavy metals in their ecosystem (Adelekan and Abegunde, 2011) and their deposits in the soil are not degraded and may persist in the soil environment for a long time causing serious environmental pollution (Oyelola, 2009). In these dumpsites, heavy metals such as cadmium (Cd), Copper (Cu), Cromium (Cr), lead (Pb), Zinc (Zn) and Nicked (Ni) are usually found due to remains from metals and other products (Shayley *et al*., 2009) and the plants grown on them have the tendency of taking metals (Orji *et al*., 2018). The dumpsite wastes contain heavy metals so their presence and subsequent uptake by food crops can pose serious human health risk (Darko *et al.,* 2020).

The distribution of heavy metals on waste dumpsite soils in Ghana is related to the population of the rural and urban dwellers, their standard of living, consumption pattern and industrial development. Agyarko *et al*. (2010) studies in Accra, Kumasi and Adidwan where refuse dump soils varied in concentrations of most metals like Cd, Hg, Pb, Cu, Zn, Mo and As and attributed those differences in concentration to the fact that, metals found in the cities (Accra and Kumasi) and a municipal (Mampong) were higher than those from Adidwan - a rural settlement due to the higher population and industrial activities in cities and municipalities coupled with higher level of assorted waste than in rural settlement. Ebong *et al*. (2008) shared a similar view by attributing such differences to living standard, consumption patterns and level of industrial development between cities and rural communities. Bamidele *et al.* (2014) have also asserted to the fact that differences in physical and chemical properties of soils within dumpsites and background sites might be due to economic activities of the people within the rural, urban towns and cities. Metals like As, Cd, Co, Cu, Fe, Hg, Mn, Pb, Ni and Zn found in such rural and urban wastes (Sule *et al*., 2019) are critical measurement parameters for assessing the risks of refuse dump soils (Hammed *et al.,* 2017) especially metal accumulation at the top soil (Moses, 2006) which if not checked can cause a more widespread contamination of soil, sediments and vegetables

(Jafaru *et al*., 2015). Generally, top soil layer contains the largest amount of pollutants (Addis and Abebaw, 2017).

### 2.1.1 Uses of dumpsite soils

The soil which is a primary recipient of solid wastes (Nyle and Ray, 1999) receives tonnes of these wastes from industrial, domestic and agricultural sources (Ogunmodede and Adewole, 2015). These wastes end up interacting with the soil system changing their physical and chemical properties (Piccolo and Mbagwu, 1997). For instance, especially soil organic matter in dumpsites help to influence the degree of aggregation and aggregate stability by reducing soil bulk density and increasing soil total porosity and hydraulic conductivity in heavy clay soils (Ogunmodede and Adewole, 2015).

Soils found on dumpsites, sites for disposal of waste materials (Musa *et al*., 2019) are used as farmlands and is a common practice in urban and sub-urban communities within developing countries (Musa *et al*., 2019) such as Ghana because when some of these waste decay they enhance soil fertility (Ogunyemi *et al*., 2015). Akanchise *et al.* (2020) reported that, sometimes, soils from dumpsites are excavated for soil amendments elsewhere because of the rich mineral and organic content. However, a considerable proportions of plastics, papers, metals and batteries known to be hazardous to man and his environment are present on dumpsites (Pasquini and Alexander, 2004; Wood bury, 2005).

In Ghana, dumpsite soils are commonly used for farming activities (Jafaru *et al*., 2015). Agyarko *et al.* (2015) reported in their study that plants on dumpsites perform better than those found in the surrounding areas. Dumpsite soils found to support plants growth also have the tendency to be taken up by plants (Orij *et al.,* 2018). The nutritional supports from dumpsites for plants affirms the reason why dumpsite soils are used in nursery pots for raising seedlings despite toxic metals contamination in them (Jafaru *et al.,* 2015) while other organic components from dumpsites are collected and apply on farmlands as manure by farmers (Ebong *et al.,* 2008). It is common to see crops grown around dumpsites despite the presence of heavy metals and their subsequent uptake by food crops can pose serious human health risk (Darko *et al.,* 2020).

Heavy metal loads from refuse dump soils studied by Ogunmodede and Adewole (2015) reported to be higher in concentration than in the control (background) values especially for chromium (Cr), iron (Fe), nickel (Ni), copper (Cu) and zinc (Zn) and they attributed this to the fact that, refuse dumps receive considerable waste proportions of product packaging, waste cloths, glass and bottles, newspapers, paints, batteries, industrial dust, ash, tyre, metal cans and containers, medical waste, abandoned vehicles and insulations which are known to be sources of metals (Woodburry, 2005).

### 2.1.2 Physicochemical properties of dumpsite soils

Soil physicochemical parameters like texture and organic matter contents are important with regards to the forms of heavy metals present and their bioavailability (Audinalp and Cresse, 2009). Heavy metals which form part of dumpsites soil chemical composition are metallic chemical elements that have relatively high density and are toxic at low concentrations (Ambika *et al.,* 2016). Dumpsites soils may also comprise of other materials that contain heavy metals and as a result are of great concern (Olakunle *et al*., 2018) to farmers and consumers in Ghana. Soil which is one of the important natural resource which provides the main mineral elements for plant growth and crop production (Uma *et al*., 2016) is without contamination from waste materials found on them but on the contrary, essential mineral materials from these wastes also help to increase nitrogen, pH, CEC, Base saturation and organic matter (Anikwe and Nwobodo, 2001). Organic components of these wastes can provide nutrients for increased plant growth because, dumpsites are known to be rich in soil nutrient for plant growth and development (Ogunmodede and Adewole, 2015) as decayed and composted wastes enhance soil fertility (Ogunyemi *et al*., 2003).

Organic matter influences the concentration of heavy metals in soil through the release of heavy metals such as Pb and Hg bonded to organic matter in addition, there is a reduction in heavy metal levels in soils especially in the soil surface by forming complexes (Ashworth and Alloway, 2004). Most refuse dumpsites contain considerable amount of ash, and some of these ash are dumped while others are produced from the burning of refuse on dumpsites from time to time to get rid of organic materials, and this activity help to oxidize the metals content (Nurudeen and Aderibigbe, 2013). Wastes end up interacting with the soil system thereby changing the physical and chemical properties (Piccole and Mbagwu, 1997). Soil organic matter has also been found by Ogunmodede and Adewole (2015) to influence the degree of aggregate stability, reduction in soil bulk density, increase soil total porosity and hydraulic conductivity in heavy clay soils. In an earlier study, the enhanced levels of cadmium (Cd) in dumpsites was attributed to large deposits of PVC plastics, nickel cadmium batteries, insecticides, motor oil and the disposal of sewage in dumpsites (Jarup, 2003). Other chemical properties of dumpsites soil with respect to heavy metals were in these concentrations: Fe (1059.2 mgkg$^{-1}$) in sub-surface soils (15 - 30 cm) also comprise of control soils (uncontaminated soils) with Fe (665.3 mgkg$^{-1}$); Pb (99.1 mgkg$^{-1}$ and 95.2 mgkg$^{-1}$); Ni (308.5 mgkg$^{-1}$ and 5.9 mgkg$^{-1}$); Cr (2.2 mgkg$^{-1}$ and 2.1 mgkg$^{-1}$) as reported by Ukpong *et al*. (2013). Dumpsite soils physicochemical properties play a major role in soil nutrition as they can be used as a nutrient rich soil indicator (Tripathi and Misra, 2012), because nearly all human activities generate waste; and the way in which wastes are handled and disposed of can pose risks to the environment and public health (Zhu *et al*., 2008). On dumpsites, an organic matter which is an important soil chemical property was reported in a study by Tripathi and Misra (2012), to be at 0.39 - 0.58% as compared to their adjoining areas (0.32 - 0.58%) and attributed it to the presence of many organic waste residue which end up adding organic matter after decay and an inorganic waste will produce high bulk density in a dumpsite and may reduce root length and limit root penetration in a dump soil.

Tripathy and Misra (2012) found that, soil texture plays a very important role in plant species establishment and development and also influences other physical parameters of the soil. Another way which is beneficial to a dumpsites farmer is a situation where a dumpsites soil does not only accumulate organic matter but also results in a buildup of the soil organic matter content. Engege and Lemoha (2012) found that, dumpsite soil showed variability in soil properties with depth because there was a significant ($P \leq 0.05$) difference in heavy metal content, exchangeable cations, soil pH as well as bulk density with respect to soil depth.

## 2.2 Dumpsites farmers' awareness of soil physicochemical properties

### 2.2.1 Socio - demography of farmers in Ghana

In Ghana, farming activities in some communities are dominated by males and majority of these farmers are below 51 years of age (Agyarko *et al.,* 2011) an indication that an active age group are actively involved in farming in Ghana. Other similar study has reported of a male (65%) dominated farming activity as compared to female (35%) minority with a youthful average age of 43 years in farming while the majority (77.8%) are educated up to the primary school level (Dawoe *et al.,* 2012). A study has found that, farmers' knowledge of their soils was not influenced by their main source of income, gender, education and age (Sierra *et al.,* 2016).

### 2.2.2 Reasons for farming on dumpsites

Soil is one of the most important resources of nature where plants grow for their day to day nutrient needs (Tale and Ingole, 2015). An assessment of the phenomenon of residential development close to a solid waste dumpsites at Pantang, found that farmers farm on dumpsites because, dumpsites land are fertile due to the decomposition of refuse (organic materials), other reason was that it is a way of protecting their lands from intrusion while other respondents said it is the only idle land available and renting a dumpsite land is relatively cheaper was also a reason (Ahlijah, 2015).

Wunzani *et al.* (2019) found that, soils from dumpsites are rich with plants micronutrients and macronutrients and those refuse dumps from dumpsites can be used as compost for soil amendment. Farmers, especially in a developing country like Ghana, as observed by

Monohara and Belagali (2014) that compost of solid wastes contain a considerable variety of micro and macro nutrients as well as relatively stable source of organic matter essential for plant growth. In addition, agricultural application of municipal solid wastes (MSW) as a natural source for plant and soil conditions is the most cost effective option (Bamidele *et al.,* 2014) for local farmers. Dumpsites are easily accessible land in addition to the perception that its high plant nutrient content are used up by crops planted as affirmed by Amadi *et al.* (2013) that, soils obtained from dumpsites are used for plantings of vegetables and other food crops. In developing country, like Ghana have a local soil physicochemical knowledge in which site previously used as dumpsites are often converted to farmlands as observed by Onwughara *et al.* (2010).

### 2.2.3 Farmers' awareness of dumpsites soil physicochemical properties

Farmers and Scientists understand soil fertility in different ways because scientists sometimes take account of the soil's nutrient status, without considering its physical properties, but farmers' perception of soil fertility are not limited to nutrient status alone but also physical properties (Corbeels *et al.,* 2000). An understanding of physical and chemical condition of any soil is essential for proper implementation of many management practices so the physicochemical idea of soil is very important because both physical and chemical properties affect the soil productivity example, this physico-chemical idea of a soil is based on various parameters like pH, electrical conductivity, texture, moisture, temperature, soil organic matter, available nitrogen, phosphorus and potassium (Tale and Ingole, 2015).

African farmers in the rural areas to whom development efforts are directed have their own body of knowledge that enables them arrive at decisions, which could help better their lots (Kolawole, 2002). African farmer's knowledge on a fertile soil can be likened to a modern concept of a quality soil which is the ability of a soil to sustain plant and animal productivity, to increase quality water and air and to contribute to plant and animal health (Doran and Zeiss, 2000). Farmers in Ethiopia in a similar study used a local system to classify their soils according to colour, texture and certain physical characteristics indicating that farmers are aware of their soils physicochemical properties (Corbeels *et al.,* 2000).

The Ghanaian farmer knows indigenous soil science with sets of information about the soils they farm on especially the fertility status of their soils by using crop yield, colour of soil, vegetation cover, soil depth, soil organic matter and activities of soil organisms (Agyarko *et al.,* 2011) as evidence of their soil physicochemical knowledge. In order to achieve high yield for their crops due to known and unknown reasons, farmers have resorted to farming on both open and closed dumpsites in Ghana and have proven to increase crop yield. However, the contamination levels of toxic metal elements in dumpsites farmlands have been given less attention to the detriment of healthier food production

In Ashanti region, a similar study reported that farmers have specific indicators they use for assessing their soils as fertile (high soil nutrient content) and infertile (low soil nutrient content) example, crop yield, dark soil colour, earthworms (fertile soil); slow plant growth pale soil colour, few worm casts ( infertile soil) (Dawoe *et al.,* 2012).

#### 2.2.3.1 Sources of knowledge acquisition on soil physicochemical properties by dumpsite farmers

A bunch of studies have been found regarding farmers' preferences and use of information sources (Gupta and De, 2011; Sakib *et al.,* 2015; Rahman *et al.,* 2016) to maximise yield on their farmlands. Farouque *et al.* (2019) concluded in their studies that friends and neighbours play important role in disseminating farming information. Dumpsites farmers' perceived awareness of their soils' physicochemical properties are believed to have got their information from other sources as earlier asserted by De Souza *et al.* (2016) that soil properties information that farmers are familiar with are based on observation and life experience over time, which is accumulatively transmitted over generations.

Farmers locally have acquired knowledge from generations of experience and experimentation that fit local conditions (Laekemariam *et al.,* 2017). Rehman *et al.* (2013) reported in their study that the print media and fellow farmers were the major information source to farmers. Sumane *et al.* (2017) shared a similar finding that, farmers are from farming families, so they obtain their initial agricultural knowledge from their parents, grandparents and other farmers due to the fact that, they see their colleague farmers a reputable experts, particularly due to their practical experience in similar conditions. Other knowledge acquisition for farmers is social networks regarding soil fertility issues and other farming information (Farouque *et al.,* 2019). Rydberg *et al.* (2008) have asserted that farmers can access information when frequently visit personal localite (e.g. friends) or cosmopolite (e.g. agriculture office).

### 2.2.4 Farmers' awareness and perceived effects of heavy metals contamination in soils and plants and its related ailments

Reported effects of heavy metals by farmers contamination in soils and lands can be related to measured common sources of soil contamination (hazardous heavy metals / metalloids) through atmospheric deposition, organic manure, mineral fertilizers, pesticides, industrial sewage discharge and industrial solid waste, municipal agriculture and food waste, coal ash, dumps, logging and timber industry waste paints and other decorative materials commodity impurities, etc (Nriagu and Payna 1988; Yongsheng, 2008; Zhang *et al.,* 2011, Allowey, 2012, Vodyganitskii, 2013, Su *et al.,* 2014). It is reported that about 61.33% of community members studied are aware environmentally friendly agriculture increase growth, quality and productivity of agricultural land (Atmojo, 2010; Utari *et al.,* 2018) and dumpsites farmlands.

Pradika *et al.* (2019) found that people's awareness, reportedly, of heavy metal contaminations on agricultural land is still low. Also people's knowledge and awareness of heavy metals are still low, while community's awareness of environmentally friendly agriculture is high (Atmojo, 2010). However, Coffie (2010) has explained by the fact that landfill site contain dumpsite materials in addition to high prevalence rate of infectious diseases like malaria, cholera, diarrhea and typhoid fever within those communities. At Dompoase dumpsites in the Kumasi Metropolis, within Ashanti region of Ghana, increased self-reported health symptoms such as fatigue, sleepless, and headaches were among residents near the landfill sites (Owusu-Sekyere *et al.,* 2013a)

### 2.3 Heavy metals

Heavy metals are described as those metals with specific gravity higher of more than 5gcm$^{-3}$ (Leah *et al*., 2014). Lenntech (2004) and Duruibe *et al*. (2007) have also explained that, heavy metals refer to any metallic element that has a relatively high density and is toxic or poisonous even at low concentration. Alamgir (2017) also defined heavy metals as any element that has a silvery luster and is a good conductor of heat and electricity. The most common of these metal elements are Copper, Nickel, Chromium, Lead, Cadmium, Mercury, and Iron. Leah *et al*. (2014) have reported that, some elements such as iron and nickel are essential to the survival of all forms of life if they are low in concentrations, in addition to elements like lead, cadmium and mercury which are toxic to living organisms even in low concentrations.

Heavy metals have attracted much concern because of a lot of reasons. Considerable number of them, such as arsenic, cadmium, lead, chromium, nickel, cobalt and mercury are of concern primarily because they harm soil organisms, plants, animals and human beings (Adelekan and Alowode, 2011). The presence of heavy metals in the environment is of great ecological significant due to their toxicity at certain concentrations, translocation through food chains and non-biodegradation which is responsible for their accumulation in the biosphere (Aekola *et al*., 2008). Metals like iron, tin, copper, manganese and vanadium occur naturally in the environment and could serve as plant nutrient on their concentrations (Opaluwa *et al*., 2012). Other metals like mercury, lead, cadmium silver, chromium and many others indirectly distributed as a result of human activities could be very toxic even at low concentrations and can undergo global ecological circles (Aekola *et al*., 2012).

The increasing ecological and global public health concerns about heavy metal contamination are not only exposed to soil and plants, but through human consumption of contaminated farm products, the use of heavy metals in several industries in agriculture, domestic and technological applications (Bradi, 2002). A study in Poland showed heavy metals concentration of Pb (12.5 - 659 mgkg$^{-1}$), Zn (38.1 - 2103 mgkg$^{-1}$) and Cu (12.9 - 595 mgkg$^{-1}$) in 180 allotment garden soils in Wroclaw, and these metals concentration levels depended mainly on the nearby location of industrial pollution sources, with variations in the amount of organic matter soil pH, and the content of plant available macronutrients (Kabala *et al*., 2009). Heavy metals occupy a special position in soil chemistry because they play very important physiological roles in nature (Akpoveta *et al*., 2010; Oves *et al*., 2016).

### 2.3.1 Sources of Heavy Metals in Dumpsite soils

Heavy metals occur in soils (Franzen *et al.,* 2004) and in the ecosystem with large variations in concentration. Heavy metals are not degradable, and as a result may persist and accumulate over a long period in soils and vegetation resulting in serious pollution of the soil environment (Mtunzi *et al.,* 2015). Dumpsite soils are perceived as fertile soils and a valuable asset which creates a congenial climate for crop production but due to human wastes disposal activities, dumpsite soils have become a receptor of many pollutants including pesticides, fertilizers, particulate matters and heavy metals (Maneyahilishal *et al*., 2018). However, if a soil's capacity to hold or retain heavy metals is exceeded, the soil begins to act as a source for heavy metals (Selim, 2013). The contamination of soils by different pollutants has significant influence on human health processes (Rhaman *et al*., 2015). Since heavy metals are not degradable, they persist and accumulate over a long period in the soils and vegetation resulting in serious environmental pollution (Mtunzi *et al.,* 2015). Heavy metals occur in soils naturally (Franzen *et al.,* 2004), in the ecosystem with large variations in concentration.

In modern times, pollutants from the activities of humans have introduced some of these heavy metals into the ecosystem (Opaluwa *et al*., 2012). They are also found to occur naturally in the soil environment from the pedogenetic processes of weathering of parent materials at levels that are regarded as trace (< 1000 $mgkg^{-1}$) and rarely toxic (Kabata - Pendias and Pendias, 2001; Pierzynski *et al*., 2002; Wuana and Okieimen, 2011)). A soil which most often than not suffers from these metal contaminants has been described by Nyle and Ray (1999), as a primary recipient of solid wastes. Tonnes of these wastes are from a variety of sources including: industry, domestic and agricultural activities which find their way into the soil (Ogunmodede and Adewole, 2015). Sources of soil metal contamination affecting predominantly agricultural soils include fertilizers, pesticides, sewage sludge, organic manures and composts (Singh, 2001). In addition, heavy metals accumulate in soils in some localized areas of human activities when compared with areas that have remained under virgin conditions. Some of the anomalous accumulation may also be geology - related (Thornton, 1980). Also, hazardous materials like plastics, papers, batteries, electric bulbs and bottle caps are known to contain heavy metals (Amusan *et al*., 2005; Akpoveta *et al*., 2011; Kolo *et al*., 2014) and similar materials are also found on dumpsites in Ghana. Some human activities such as waste disposal, mining, smelting and fertilizer applications also release heavy metals into the environment (Dinis and Fiuza, 2010;

Ato *et al*., 2010). Other sources of heavy metals pollution have also been reported from compost application (Hogarh *et al*., 2008; Jordâo *et al*., 2006) and urban top soils (Darko *et al*., 2017).

The indiscriminate disposal of wastes (organic and inorganic) in rural and urban settlements coupled with farming on dumpsites soils pose risk to nature, and it is due to the fact that, most soils of rural and urban environments may accumulate one or more of the heavy metals above defined background values high enough to cause risks to human health plants, animals ecosystem or other media (D'Amore *et al*., 2005). It has been explained that, the reason why heavy metals become contaminated in the soil environment is that their rates of generation via man made cycles are more rapid relative to natural ones; the concentrations of the metals in discarded products are relatively high compared to those in the receiving environment (D'Amore *et al*., 2005). On most dumpsites, loads of contaminants that are usually greater than in the surrounding sub-urban or rural areas due to the concentration of anthropogenic activities of urban settlements (Charlesworth *et al*., 2003). It is estimated that heavy metals release from all sources worldwide is around (in metric tons) 22,000 of Cd, 939,000 of Zn (Singh *et al*., 2003).

#### 2.3.1.1 Application of metal - based pesticides and fertilizers

Anthropogenic (human activity) materials such as pesticides and insecticides contaminate the soil environments with heavy metals like Co, Cu, Fe, Mn, Mo, Ni and Zn but are also needed in metal elements deficient soils which help in healthy plant growth (Lasat, 2000). Crops may be supplied with metal elements in addition to the essential soil elements as a foliar spray, however, about 10% of the chemicals have approval for use as insecticides and fungicides in United Kingdom where they were based on compounds like Cu, Hg, Mn, Pb or Zn in pesticides such as copper containing fungicidal sprays such as Bordeaux mixture (copper sulphate) and copper oxychloride (Jones and Jarvis, 1981).

#### 2.3.1.2 Application of Manures and Biosolids

Farmers in Ghana greatly use manures on their farmland, with the use of numerous biosolids like livestock manures, composts and municipal sewage sludge to land inadvertently leads to the accumulation of heavy metals such as As, Cd, Cr, Cu, Pb, Hg, Ni, Se, Mo, Zn, Ti, Sb and others in the soil (Basta *et al*., 2005). Some of these heavy metals relative to their properties are used as growth promoters in animal nutrition but when used at high concentrations may cause metal contamination of soil in the long run (Sumner, 2000).

#### 2.3.1.3 Air - born source

Soil heavy metal contaminants classified as air-born may include stack vapour stream and some fugitive emissions such as dust from waste piles (Raymond and Okieimen, 2011). Others sources of Cr and As are contaminated through atmospheric deposition, Fe and Cr ions through soil erosion, leaching of many heavy metals, sediments re-suspension, Hg and Pb through evaporation from water resources to soil and underground water, natural phenomenons such as weathering and volcanic eruptions have all contributed to heavy metal pollution (Bradi, 2002; Duffus, 2002; He *et al*., 2005).

### 2.3.1.4 Industrial Processes

Wastes are any discarded or abandoned materials that can be solid, liquid, or semi - solid and are always sourced from homes, schools, hospitals and other business areas (Buszewski *et al*., 2000). In addition, wastes disposed on sites through human activities in industry such as textiles tanning, petrochemicals from accidental oil spills or utilization of petroleum - based products and other pharmaceutical facilities are highly variable in composition although some are disposed off on land, and few have benefits to agriculture or forestry (Raymond and Okieimen, 2011). Many industrial products contain metals like Cr, Pb, and Zn which are potentially hazardous because of their contents are referred to as toxic inorganic compound contain lower plant essential nutrients and with no soil conditioning properties (Sumner, 2000). Other metal industrial sources include metal burning in power plants, petroleum combustion, nuclear power stations, high tension lines, plastics, textiles, microelectronic wood preservation and paper processing plants (Arruti *et al*., 2010; Pacyna, 1996). Electrical and electronic parts such as copper pipes and alloy from vehicle scraps littered for a long time on the soil gradually rust and leach into the soil causing phytotoxicity (Nwachuku *et al*., 2010).

### 2.3.2 Essential Heavy Metals

There are eighteen essential heavy metals out of fifty-three total heavy metals which are naturally occurring (Mistra, 2015). Essential heavy metals are needed in trace amounts by living things for their physiological processes (Ehi and Uzu, 2011). Plants usually need a continuous nutritional supply in order to remain healthy and any shortage leads to deficient symptoms (Oves *et al*., 2016). Metals which are essential to plants are required by plants to complete their life cycles. At higher concentrations, the essential heavy metals are hazardous to plants and animal (Ehi and Uzu, 2011), especially when Fe, Cu, Zn, Mn and Ni concentrations exceed the recommended standards (Afzal *et al*., 2013). WHO (1996) found that, metals like Co, Cu, Cr, Fe, Mg, perform various biochemical and physiological functions. These metals are considered as trace elements because of their presence in trace concentrations (ppb range to less than 10 ppm) in various environmental matrices (Kabata - Pendias *et al*., 2001).

Plants in general need many different metals and other elements for growth, development and reproduction, but metals which are naturally present in the soil have increased in concentrations to pollution levels as a result of human activities ranging from mining and agriculture to sewage processing and heavy metal industry (Giovanni *et al*., 2014). Mengel *et al*. (2001) have earlier reported that, there are fourteen mineral elements which are essential to all plants in addition to water, oxygen and carbon dioxide. Metals like, cobalt (Co), chromium (IV) ($Cr^{+4}$), copper (Cu), Iron (Fe), manganese (Mn), Molybdenum (Mo), Selenium (Se), and Zinc (Zn) help in regulating human metabolism (Lokeshappa *et al*., 2012). Most heavy metals are necessary for growth and normal functions of both plants and animals at trace amounts such as Fe, Zn, Mn, Cu, Co and Ni but large amount of any of them may cause acute or chronic toxicity (Addis and Abebaw, 2017). Some essential metals serve as soil conditioners which are of great importance due to their universal medium which supply essential nutrients for plant growth (Pujar *et al*., 2012; Tripathi *et al*., 2015).

#### 2.3.2.1 Chromium (Cr)

Chromium is one of the less common elements and does not occur naturally in elemental form but only in compounds (Wuana and Okieimen, 2011), at high concentrations, chromium is toxic and carcinogenic (Chisti *et al*., 2011). Chromium mobility depends on sorption characteristics of the soil, including clay content; iron oxide content and the amount of organic matter present (Wuana and Okieimen, 2011). Chromium behaviour in soils is controlled by soil pH and redox potentials, especially under moderately oxidizing and reducing conditions and near neutral pH values the element's mobility is low (Kabata - Pendias, 2000). Also, permissible daily dietary intake of chromium by man is 0.2 $mgday^{-1}$ (WHO, 1998). The adsorption of chromium (VI), ($Cr^{6+}$) increases with increasing pH (Kabata - Pendias, 2000) and high doses of chromium causes liver and kidney damages and chromate dusts are known to be carcinogenic (Yaylah - Abanuz, 2011) which is also associated with allergic dermatitis in humans (Scragg, 2006) and it is well known to play a vital role in the metabolism of cholesterol, fat and glucose (Afzal *et al*., 2013). Excess concentration of chromium can affect the roots of plants resulting in wilting of the plant and plasmolysis in root cells (Vijayaragavan *et al*., 2011). Onyedika (2015) has also reported that chromium concentration level at a dumpsite ranged from 33.01 - 48.02 $mgkg^{-1}$ and these values were below the world's soil average (59.50 $mgkg^{-1}$) there were four times higher than that of the control sites which suggested possible anthropogenic sources of chromium in the urban soils.

### 2.3.2.2 Iron (Fe)

Iron is the most abundant element in the earth's crust (Onyedika, 2015). This is the reason why iron is used as a reference element following the assumption that its content in the crust has not been disturbed by anthropogenic activity, and it has been chosen as the element of normalization with its natural sources (98%) vastly dominate input (Tippie, 1984), with its global terrestrial abundance being calculated to be around 45% and it is not considered a trace element in rocks and soils (Onyedika, 2015) but as the most abundant and an essential constituent for all plants and animals (Shah *et al*., 2013), Iron is also responsible for anaemia and neuronegative conditions in human being (Fuortes and Schenck, 2000).

Iron plays a special role in the behaviour of several trace elements and is in the intermediate position between macro and micro nutrients in plants, animals and in humans (Kabata - Pendias, 2011). The major sources of Iron are the iron oxides such as minerals hematite, magnetite and taconite (Onyedika, 2015). Iron concentration in 0 - 15 cm depth (427.00 mgkg$^{-1}$) was highest as compared to 15 - 30 cm depth (424.90 mgkg$^{-1}$) on the same soil but lowest on a control soil with 345.50 mgkg$^{-1}$ (0 - 15 cm depth) (Olowookere *et al*., 2018). This result has been attributed to the fact that, accumulations of heavy metals are concentrated at the soil - surface than the sub-surface (Amadi *et al*., 2012; Olalode *et al*., 2014) and their accumulation on the soil surface may be attributed to the presence of metallic substance in the earth crust, as well as Fe bearing waste (Olayiwola *et al.,* 2017). Agbeshie *et al.* (2020) reported in their study that, Fe metals generally showed mobility from a dumpsite location to a down - site location. Obasi *et al.* (2012) share a similar report about Fe movement in soil and associated it with their high mobility.

### 2.3.2.3 Nickel (Ni)

Nickel is one of the many metals widely distributed in the environmentwhich may be released from both natural sources and anthropogenic activity with input from both stationary and mobile sources (Orj *et al*., 2018). It has been considered to be an essential trace element for human and animal health (Hassan *et al*., 2012). Ipeaiyeda *et al*. (2007) studies produced 11.5 mgkg$^{-1}$ of nickel concentration, and 16.52 - 17.24 mgkg$^{-1}$ nickel concentration in an automobile mechanic waste dump soil in Nigeria (Iwegbue *et al*., 2006). Many authors like Hameed *et al*. (2012) have described nickel as an essential element for plants and animals. At high levels, nickel becomes toxic and causes severe diseases like loss of body weight, loss of vision and heart and liver failure, as well as skin irritations (McGrath and Smith, 1990). Alloway (1995) has given 20 mgkg$^{-1}$ of nickel as the world's average concentration in soil, but calculated world mean of unpolluted soil is 34 mgkg$^{-1}$ (Kabata - Pendias and Pendias, 2001). As earlier said by Poggio *et al*. (2009), nickel toxicity in human beings is not very high but can cause respiratory diseases. WHO (2005) have also recommended routine requirement for mankind at 1 mgday$^{-1}$.

Alloway (1995) discussed that, many domestic cleaning products such as soap (100 - 700 mgkg$^{-1}$) and powdered bleach (800 mgkg$^{-1}$) may prove to be important sources of nickel in urban soil. Other sources of nickel include food stuffs such as chocolate, automobile batteries and various paint wastes (Onyedika, 2015). Nickel finds its way into the ambient air as a result of the combustion of coal, diesel oil and fuel oil and the incineration of waste and sewage (Cempel *et al*., 2006). Nickel concentration in polluted soil may range from 20 - 30 fold (200 - 26,000 mgkg$^{-1}$) higher than the overall range (10 - 1000 mgkg$^{-1}$) found in natural soil (Izosimora, 2005). Ogunmodede *et al*. (2015) reported that, nickel concentration in a dumpsite soil studied ranged from 89.76 - 118.35 mgkg$^{-1}$ and in a control soil site recorded 20.84 mgkg$^{-1}$. In another study, Rahman *et al*. (2005) have found that excess $Ni^{2+}$ in soil causes various physiological alterations and diverse toxicity symptoms such as chlorosis and necrosis in different plant species. Nickel is widely used in electroplating and in the manufacture of batteries (Hameed *et al*., 2013).

### 2.3.2.4 Copper (Cu)

Copper is an essential nutrient that play key roles in photosynthesis, respiration, carbon and nitrogen metabolism and protection against oxidative stress (Giovanni *et al*., 2014) and its addition is a necessity for many enzymes (Shah *et al*., 2013; Ngange *et al*., 2013) and as a macro nutrient for plants (Ngange *et al*., 2013). Cu is used in numerous applications because of its physical properties (Hameed *et al*., 2013). In plants there are about 50 % of copper which is localized in the chloroplast (Banerjee, 2003). Cu is indeed essential, but in high doses can cause anaemia, liver and kidney damage (Wuana and Okienimen, 2011). The solubility of copper is drastically increased at pH 5.5 (Martinez and Motto, 2000). Cu normally accumulates in the surface horizons, a phenomenon explained by the bioaccumulation of the metal and recent anthropogenic sources (Hameed *et al*., 2013). As the third most used metal in the world (Greany, 2005), an essential micronutrient like Cu is required in the growth of both plants and animals (Wuana and Okieimen, 2011).

The worlds' scale value of non-polluted soil of 24 mgkg$^{-1}$ is reported by Kabata - Pendias and Pendias (2001) and though the toxicity for humans is not very high (Poggio, 2009), excess effects of copper on plants are reactive oxygen species (Seacat *et al*., 2002), stunted growth inhibition of lateral development (LIorens *et al*., 2002). In addition their excess results in photosynthesis inhibition (Patsikka *et al*., 2002; Maksymiec and Baszynski, 1999). High concentration of copper causes metal fumes fever, hair and skin discolorations, dermatitis, respiratory tract diseases and some other fatal diseases in human beings (Khan *et al*., 2008). The permissible level of copper intake in food is 2 - 3 mgday$^{-1}$ (WHO, 2005). Toxic levels are naturally present in some soils or may be derived from anthropogenic activities such as the use of copper containing fungicides, urban wastes management and industrial activity (Giovani *et al*., 2005). The mean value levels of copper concentration in plant tissue have been found to be 0.26 mgkg$^{-1}$, 0.37 mgkg$^{-1}$ and 0.56 mgkg$^{-1}$ for roots stems and leaves respectively while that of soil were 0.48 mgkg$^{-1}$ (0 - 15 cm depth) and 0.32 mgkg$^{-1}$ (15 - 30 cm depth) (Ngange *et al*., 2013).

### 2.3.2.5 Zinc (Zn)

Zinc is an essential growth element for plants and animals but can be toxic at elevated concentration (Akobundu and NwanKwaola, 2013) and their excessive concentration in soil lead to phototoxicity as it is a weed killer (Preda and Cox, 2002; Aboud and Nandini, 2009). Zinc has an important role in DNA synthesis, normal growth, brain development, bone formation and wound healing and at high levels, zinc is neurotoxin (Adelekan and Abegunde, 2011). The world range for total zinc concentration in soils is between 10 - 300 mgkg$^{-1}$ (Alloway, 1995) and an average of 100 mgkg$^{-1}$ have been reported for unpolluted soils (Kabata – Pendias and Pendias, 2001).

Zinc may be derived from mechanical abrasion of vehicles, as they are used in the production of brass alloy itself and come from brake linings, oil leak sumps and cylinder heads gaskets (Jiries *et al*., 2001). The anthropogenic sources of zinc are related to industries and the use of liquid manure, composted materials and agrochemicals such as fertilizer and pesticides in agriculture (Romic and Romic, 2003). Environmental contamination of zinc is mainly related to anthropogenic input (Onyedika, 2005) and these anthropogenic sources of zinc are related to manure, composted materials and agrochemical such as fertilizers and pesticides in agriculture (Romic and Romic, 2003). Other studies have also linked high zinc levels in urban soils to accumulation from garden fertilization, traffic and industry input (Imperato *et al*., 2003).

Zinc concentrations are rising unnaturally, due to anthropogenic additions because most zinc is added during industrial activities such as mining, coal and waste combustion and steel processing in addition to some foodstuffs, while some plants inability to handle an uptake of zinc already in their system through an accumulation (Wuana and Okieimen, 2011), negatively influence the activities of microorganism and earthworms retarding the breakdown of organic matter (Greany, 2005). Olowookere *et al*. (2018) have found a high concentration of 22.6 mgkg$^{-1}$ of zinc at 0 - 15cm depth, as compare to a concentration of 21.0 mgkg$^{-1}$ at 15 - 30cm depth and that of a control site at 21.1 mgkg$^{-1}$. Ngange *et al*. (2013) have earlier reported that, the concentration of zinc in their work ranged from 0.15 - 1.70 mgkg$^{-1}$ at depth of 0 - 15 cm and from 0.11 - 1.40 mgkg$^{-1}$ at depth of 15 - 30 cm soil. The mobility of zinc in soils is dependent on its speciation, the soil pH and content of organic matter (IPCS, 2001).

### 2.3.3 Non - Essential Heavy Metals

The contamination of agricultural soils by metals has become an environmental concern due to their potential adverse ecological effects (Ngange *et al*., 2013). The Non-essential metals are considered as soil pollutants due to their acute and chronic toxic effect on plants grown on such soils (Nagajyoti *et al*., 2010). Metals like antimony (Sb), arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), have established biological functions and are considered as non - essential metals (Chang *et al*., 1996). The distribution and uptake of toxic nutrients within plants tissues according to their need for essential mineral nutrients in sufficient amount avoids the accumulation of non-essential elements and toxic levels of essential elements (Williams and Salt, 2009). This is due to the fact that, there exist a very narrow range of concentrations between beneficial and toxic effects of metals (Tchounwou *et al*., 2008).

#### 2.3.3.1 Arsenic (As)

Arsenic is a non - essential metal element and is not only carcinogenic but also has no nutritional value for plant and animal (Amadi *et al*., 2010). Ngange *et al*. (2013) also explained that, arsenic is not a plant nutrient and its accumulation in plants is toxic to animals and human that feed on these plants. An earlier work by Mensah *et al*. (2017) found 3.67 mgkg$^{-1}$ of arsenic concentration at e-waste dumpsites, Korle lagoon. A similar work also produced an arsenic value of 17.08 mgkg$^{-1}$ in e-waste dumpsite in South China (Predhan and Kumar, 2014). Ngange *et al*. (2013), reported in their work a mean level of concentration of arsenic in their soil samples at 0.03 mgkg$^{-1}$ at 0 - 15 cm and 15 - 30 cm depth, while plant parts were 0.02 mgkg$^{-1}$ for roots, stems and leaves. The arsenic concentration in the soil is within the target value of 3.9 $mgkg^{-1}$ and 0.2 $mgkg^{-1}$ reported by Dutch (2005) as intervention values for standard soils and water (Pagmantidis *et al*., 2008).

### 2.3.3.2 Cadmium (Cd)

Cadmium is not required for plants growth (Ngange *et al*., 2013) and it is extremely toxic even at low concentration (Shah *et al*., 2013). Cadmium is one of the big three heavy metal poisons and is not known for any essential biological function (Wuana and Okieimen, 2011). Food intake and tobacco smoking are the main routes by which cadmium enters the human body (Manahan, 2003). Nurudeen and Aderibigbe (2013) reported in their work a highly contaminated value at 19.35 $mgkg^{-1}$ as a result of dumping and burning of refuse at dumpsite from time to time. Opaluwa *et al*. (2012) also found 0.48 $mgkg^{-1}$ and 0.84 $mgkg^{-1}$ (at study sites respectively). Soil values of cadmium at an average rate of 0.41 $mgkg^{-1}$ had also been reported by Kabata - Pendias (2011). Soil cadmium levels may be from different origins such as agricultural amendment, sludge and atmospheric deposition (Alloway, 1995), the burning of fossil fuels and tyres, the use of lubrication oils, vehicle wheels, application of solid wastes from industries and home, sewage sludge, waste water irrigation and phosphate fertilizer application (Kisku *et al*., 2000).

Cadmium exposure is found to be associated with renal failure due to high accumulation in the kidney (Kazi *et al*., 2008). Mensah *et al*. (2017) have reported of cadmium concentration of about 103.70 $mgkg^{-1}$ in an e - waste site at the Korle Lagoon area of Accra Ghana. A cadmium level in world soils is around 3 $mgkg^{-1}$ as reported by WHO (Chiroma *et al*., 2014).

### 2.3.3.3 Mercury (Hg)

Mercury contamination in soils is believed to be from a base - metal processing and some chemical industrial activities and also from mining activities, sewage wastes and the use of fungicides (Yaylah - Abanuz, 2011). Mercury concentration in uncontaminated soils are found to be from 0.04 - 0.08 $mgkg^{-1}$ in Israel (Greany, 2005). According to Wuana and Okieimen (2011), the release of mercury from coal combustion is a major source of mercury contamination and is associated with kidney damage (Scragg, 2006), and acidic conditions ($pH < 4$) which favour the formation of methyl mercury whereas higher pH values favour precipitation of $HgS_{(s)}$ (Wuana and Okieimen, 2011).

### 2.3.3.4 Lead (Pb)

Lead is a non-essential metal element which is extremely toxic at low concentration (Afzal *et al*., 2013). It can cause learning disabilities and hyperactivity in children (Hunt, 2003). It is known that lead containing dust particles take time in the atmosphere and deposit quickly in the near vicinity of roads, hence contributing to further accumulation of lead on the roadside soil surface (Al - Chalabi and Hawker, 2000). Pb has been shown to accumulate to high levels in urban environments from a range of sources including that derived from leaded petrol (Moller *et al*., 2000), calcium carbonate particles or in phosphate concentrations (Kabata - Pendias and Pendias, 2001). The species of lead vary considerably with soil type; it is mainly associated with clay minerals, magnesium oxides, ironoxides, aluminum hydroxides and organic matter (Hameed *et al*., 2013). The worlds' average Pb in unpolluted soil is 44.0 $mgkg^{-1}$ (Kabata - Pendias and Pendias, 2001). Lead can enter the environment especially through numerous activities (mining, smelting and manufacturing) and can be toxic to human health (Poggio *et al*., 2009).The most serious source of exposure to soil lead is through direct ingestion of contaminated soil or dust and as a result higher concentrations are more likely to be found in leafy vegetables and on surface of root crops (Wuana and Okieimen, 2011). Rosen (2002) had earlier found that, soil lead levels above 300 mgkg$^{-1}$ is from lead contaminated soil or dust deposits on the plants rather than from uptake of lead by plants. Generally, it has been considered safe to use garden produce grown in soils with total lead levels less than 300 mgkg$^{-1}$ (Wuana and Okieimen, 2011). Further studies conducted by Kabata - Pendias (2011), also found that, the worlds' calculated average of lead on unpolluted soils has concentration level of 27.00 mgkg$^{-1}$ and although lower than a value given by Onyedika (2015), in residential area (136.76 mgkg$^{-1}$); industrial area (159.67 mgkg$^{-1}$), while lead concentration on a dumpsite soil at different depths were; 0 - 15 cm (1.3 mgkg$^{-1}$), 15 - 30 cm soil depth (0.7 mgkg$^{-1}$) and on control or uncontaminated sites was 1.1 mgkg$^{-1}$ and showed a significant ($P \leq 0.05$) differences between each of the sites (Olowookere *et al*., 2018).

## 2.4 Availability of Heavy metals in soils and uptake by plants on dumpsites

Soil is a precious natural resource upon which economic activity like agriculture and existence of life depend (Getachew and Habtamu, 2015) but its properties and quality can be adversely affected by the over concentration of waste released from agriculture, industry, municipal and individual household (Soffianian *et al*., 2014). These wastes deteriorate the quality of soil and influences sustainable development (Getachew and Habtamu, 2015). The situation by which accumulation of heavy metals are concentrated at the soil-surface than the sub-surface is reported by Amadi *et al*. (2012) and Ololade (2014) in that, soils show remarkably high levels of metals such as copper, iron, and zinc which decrease with depth, and is the reason why surface soils have been found as better indicators for metabolic burdens (Anikwe and Nwobodo, 2002). An understanding of the occurrence and availability of heavy metals and metabolic burdens in soils are of major importance to environmental health, crop and livestock production, food and water quality and ecotoxicology.

Heavy metal dynamics in soils are complex, and the bioavailability, mobility, and toxicity of metals in the soil fractions are influenced by variety of factors including the properties of both the soil and the metal (Adriano *et al*., 2004; Buekers, 2007; Naidu and Bolan, 2008). Therefore, an understanding of the effects of soil properties on the behaviour of heavy metals in the soil is essential for assessing the extent of the soil contamination with metals (Alamgir, 2017) from dumpsites. Heavy metals, once entered the soil can undergo a number of processes that may be retained in soil solution as free ions or complexed to inorganic or organic ligands; adsorbed onto soil surfaces; hydroxides and carbonates; or fixed chemically as solid compounds (Lasat, 2000). The metals may also subject to plant uptake, transport through the vadose zone, and diffuse into porous materials (Alamgir, 2017).

The concentration or availability of metals in soil is controlled by various physical and chemical processes such as exchange, adsorption and desorption, complexation, precipitation and dissolution, oxidation, reduction, sequestration and occlusion, diffusion and migration, metal competition, biological immobilization and mobilization and plant uptake (Kabata - Pendias, 2010; Wuana and Okieimen, 2011).

Alamgir (2017) discussed that, metal behaviour in soils is a dynamic process and bioavailability of metal is regulated by physical, chemical and Biological properties of soils. Many other elements such as lead (Pb), Cadmium (Cd), chromium (Cr) and mercury (Hg) can also be found in vegetables and accumulate in the food chain (Pan *et al*., 2016). Plants like vegetables can take up these metals by absorbing from polluted soils and by atmospheric deposition of particulate matter from different sources and are first absorbed in the apoplast of roots and transported further into other parts of the plant cells (Gupta *et al*., 2019). Plants roots uptake of metals is controlled by many factors such as soluble contents of trace elements (metals) in soil, soil pH, organic matter, cation exchange capacity, plant growth stages, crop type, fertilizers and soil type etc. (Lente *et al*., 2014; Yadav *et al*., 2018).

A soils redox potential which determines the tendency of the soil solution to accept or donate electrons (Sheoran *et al*., 2016) is very important because, Gupta *et al*. (2019) found that, metals are present in their ionic forms in the soil solution. Thus, the mobility of such metals from soil to plants depend on their oxidation state for example, Cr exists in two oxidation states of which the reduced form ($Cr^{+3}$) is quite insoluble in water while $Cr^{+6}$ is highly soluble and readily available in the soil solution to the plants (NRC, 2003).Transportation plays a significant role in metals or trace elements accumulation in plants in that, trace elements are transported to the ground part of the plant and then accumulated under the effect of transpiration (Gupta *et al*., 2019). Also, when transpiration is flourishing, plant accumulates more trace elements and its enrichment capacity is also stronger (Hao *et al*., 2012). Gupta *et al*. (2019) found that, leafy vegetables accumulate much higher content of trace elements than other vegetables and crops due to higher translocation and transpiration rate. The transfer of metals from root to stem and then to fruit during the transpiration and translocation process is longer in non-leafy vegetables and results in lower accumulation (Itanna, 2002; Khan *et al*., 2009).

Plants absorb essential and non - essential elements from the soil in response to concentration gradient and selective uptake of ions or by diffusion (Peralta - Videa *et al*., 2009). Also metal distribution in plants is quite heterogeneous and is controlled by genetic environmental and toxic factors (Natasa *et al*., 2015). The dynamics of heavy metals in plant - soil interactions depend mainly on the level of soil contamination and plant species (Guala *et al*., 2001). Different plant parts contain different heavy metals (Natasa *et al*., 2015) because plants absorb heavy metals from the soil through the root and from the atmosphere through above ground vegetative organs (Mmolawa *et al*., 2011). Ukpong *et al*. (2013) shares a view that, in order for root uptake of heavy metals to occur, a soluble species must exist adjacent to the root membrane for some finite period and also concluded that, the waste dumpsites worked on had higher concentration of heavy metal than control site and that of the surface soil (0 - 15 cm) than subsurface soil (15 - 30 cm) depth, by extension this means that, deep rooted crop might have lower metal than shallow rooted crop. Amusan and Olawale (2005) found that, the rate of metal uptake by plants could be influenced by factors as metal species, plant species, soil pH, CEC, organic matter, soil texture and interaction among the target elements.

### 2.4.1 The role of soil properties on metal availability in soils

The soil is one of the most important natural resource which provides the main mineral elements for plants growth and crop production (Uma *et al*., 2016). The formation of 1cm top soil layer requires 100 - 400 years (Deshmukh, 2012). The physicochemical properties of metal ions that influence metal sorption rate include atomic weight, ionic radius, hydrated ion radius, electronegativity, reduction potential and covalent bonding couple with metals behaviour in soils as a dynamic process and how its bioavailability is regulated by physical, chemical and biological properties of the soil (Alamgir, 2017). Kirmanni *et al*. (2011) noted that, large number of factors control metal accumulation and bioavailability associated with soil and climatic conditions, plant genotype and agronomic management. Some recent studies have indicated that, there is a significant impact of carbonates on the sorption and retention of metals (Shirvani *et al*., 2006; Ahmed *et al*., 2008; Irha *et al*., 2009). All the physicochemical and biological properties are useful but the factors considered most important are: soil pH, soil texture, clay mineralogy, organic matter, redox potential, and cation exchange capacity (CEC) (Adriano, 2001; Bolan *et al*., 2013; Selim, 2013). Several studies have indicated the possibility of the combined effects of soil properties on metals sorption and desorption (Harter and Naidu, 2001; Appel and Ma, 2002; Dutta *et al*., 2011).

#### 2.4.1.1 Soil pH

The soil pH is defined as the negative logarithm of the hydrogen concentration (Alamgir, 2017) and generally has the greatest effect of any single factor on the solubility or retention of metals in soils (Ghosh and Singh, 2005; Alloway, 2012). Soil pH or hydrogen ion concentration is an important quality of natural soils (Umar *et al*., 2016). The soil pH of natural soil has 7 - 8.5 but a variation may be due to biological activity, temperature, disposal of municipal waste (Oyedele *et al*., 2008). Umar *et al*. (2016) further explained that, soil pH directly affects the life and growth of plant soil.

Soil pH is a master variable influencing the chemical, physical and biological properties of soil (Chakraborty, 2015; Neina, 2019) as in the case of a metal like cadmium whose uptake by plants is enhanced by low soil pH (Rajkumar *et al*., 2012). A study has established that, with increasing soil pH, the solubility of most trace elements will decrease leading to low concentration in soil solution (Kabata - Pendias, 2011). At acidic pH medium, more protons ($H^+$) are available to saturate metal binding sites; therefore, metals are less likely to form insoluble precipitates (Alamgir, 2017). Generally metal sorption increases with increasing pH and when pH falls below 5, metals mobility is enhanced as a result of the increased proton concentration (Mclaughlin *et al*., 2000; Paulose *et al*., 2007). Metal availability is relatively low when pH is around 6.5-7, (Adelekan and Alawode, 2011), but lower pH would favour availability, mobility and redistribution of metals example Pb and Cd in the various fractions (Oviasogie and Ndio Kwere, 2008). Proshad *et al*. (2018) share a similar view that, at low soil pH ($pH < 5$), solubility of hazardous elements are increased. Eze *et al.* (2018) have further reported that, heavy metals are generally more mobile at $pH < 7$ than $pH > 7$. At basic conditions, metal ions can replace such protons to form other species, such as hydroxo - metal complexes (Olaniran *et al*., 2013). Desorbing protons can leave negatively charged groups at the surface, which act as Lewis bases that coordinate metal ions (Alamgir, 2017) and the adsorbed protons can form proton bonds between surface groups and metal complexes and generate positive charges at the surface repelling or attracting respectively positively or negatively charged metal complexes (Selim and Kingery, 2003).

Alamgir (2017) concluded that, soil pH increases are often correlated with mineralogy, changes in solution chemistry and base cation concentration at high pH; at lower pH there is high acidic cation concentration and higher metal solubility. Gupta *et al*. (2019) have found that pH is considered to be the main factor which affects the solubility of metals in the soil and this assertion was earlier confirmed by Sheoran *et al*. (2016) that, metal decreases at high pH and increases at low pH values. A decrease in soil pH increases the mobility of positively charged heavy metals as a result of proton competition with these metals and decrease in negative binding sites (Horckmans *et al*., 2007) and under alkaline (increase pH) conditions, functional groups present in soil organic matter, dissociate, thereby increasing the bioavailability of heavy metals that are bound to organic matter (Fine *et al*., 2005).

#### 2.4.1.2 Soil Texture and Clay Mineralogy

Soil texture and mineral types play an important role in mobility of metals in soil and it reflects the relative amounts of sand, silt and clay particles in a soil (Alamgir, 2017). The texture of soil influences the solubility and bioavailability of metals in the soil and this is due to the fact that, the availability of trace elements is highest in loamy sand followed by clay loam, and find-textured clay soils (Gupta *et al*., 2019). Sheoran *et al*. (2010) further discussed that, trace elements retainability is higher in fine-textured soils (clay and clay loam) as compared with coarse - textured soils (sand) due to the presence of more pore spaces in sand. Clay fraction of a soil contain particles less than 0.002 mm in size, particles less than 0.001mm are the soil colloids and the most active portion of the soil which largely determines the physical and chemical properties of a soil, clay has a high sorption capacity and a strong ability to bind metallic elements due to their large specific area, clay has chemical and mechanical stability, clay is layered structured and have high cation exchange capacity (CEC) (Alamgir, 2017). The larger pore space and lower sorption capacity cause sandy soils to weakly absorb heavy metals unlike clay soils with high sorption capacities that play an importance role in metals absorption by plants (Alamgir, 2017).

#### 2.4.1.3 Soil Organic Matter

Organic carbon in soils consists basically of humic substances which are formed by decomposition of organic matter and the humic substances from organic source have a powerful complexing and chelating entities whose sorption characteristics or properties depend on their chemical composition (Nurudeen and Aderibigbe, 2013). Soil organic matter comprises of non-humic substances and humic substances, the humic substances or humus is comprised of humic and fulvic acids (Gupta *et al*., 2019). The main mechanisms involved in the retention of metals by organic matter are complexation and adsorption but their sphere and ion exchange reaction may also take place sometimes (Evans, 1989). McBride *et al*. (2015) reported no correlation between organic matter and specific metals like lead (Pb) and arsenic (As). Soil organic matter has been of particular interest in studies of heavy metal sorption by soils, because organic matter is known to form strong complexes with heavy metals which has a high affinity for humic acids, organo-clays, and oxides coated with organic matter (Connell and Miller 1984: Elliot *et al*., 1986; Faffney *et al*., 1996; Karaca, 2004; Ghosh and Singh, 2005).

Soil organic matter serves as a reactive adsorbent pool for trace metals, due to their high surface area and their high reactivity associated with various S-O- and N-functional group. Organic matter can reduce or increase the bioavailability of heavy metals in soil through immobilization or mobilization by forming various insoluble or soluble heavy metal organic complexes (Alamgir, 2017). The complexation reaction follows the formula;

$$R - L^{1+} + M^{m+} \rightarrow R - L - M^{m+1-} \qquad (2.1)$$

Where R is the C - chain, L the active group which actually binds, M the metal, and m +1 are the valencies of metal and ligand, respectively. The effect of soil organic matter on metals in soils depends on its amounts, composition, and dynamics (Alamgir, 2017). Soil organic matter is important for the retention of metals in the soil thereby decreasing mobility, bioavailability and enhances the usefulness of soil for agricultural purposes (Akpoveta *et al.,* 2010). Several studies have indicated that the reactions between organic acid and heavy metals are related to the amount and place of the carboxyl and hydroxyl groups (Shan *et al*., 2002; Gao *et al*., 2003: Schwab *et al*., 2008). Generally citric acid is the most effective in terms of desorption of different metals (Cu, Ag, Pb, Cd, Zn), followed by malic > acetic > tartaric > oxalic acid as organic acid with more carboxyl group form more stable ligand (Vranova *et al*., 2013; Yan *et al*., 2014), the more stable of the ligand formed the more difficulty for it to be adsorbed by the soil and sediment, and thus metal leaching is much easier (Gao *et al*., 2003).

The binding of heavy metals by organic matter is a complex process, due to the diversity of its connections with the mineral phase (Harter and Naidu; 2001; Lamb, 2010). Organic matter which is described as the level of mineral elements for plant development and growth

(Odai *et al*., 2008) has been classified for cultivation as; < 2.0% as low; (values below critical limits); 2.1 - 3.0% as medium (values above critical limit) and > 3.1 as high (Enzezer *et al*., 1988). Most organic matter contents in dumpsites soils are high and Odai *et al.* (2008), explained that, dumpsites receives much organic wastes and this confirms why farmers consciously choose to farm on such sites. Eze *et al.* (2018) reported that, high values of soil organic matter in dumpsite soils may be to due high anthropogenic activities such as indiscriminate dumping of refuse and decomposition of dead plants. Qadir *et al.* (2008) also affirmed that, dumpsites have higher organic matter contents.

#### 2.4.1.4 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) is a dominant factor in heavy metals retention and is defined simply as the sum total of exchangeable cations that a soil can adsorb or the number of cation adsorption sites per unit weight of soil expressed as centimoles per kg (cmolkg$^{-1}$) (Alamgir, 2017). CEC is a factor that plays a vital role in the availability of metals in soil (Gupta *et al*., 2019). The soil with low CEC such as sand has less binding power to metals and other cations as compared to the soil with high CEC such as clay (Bhargava *et al*., 2012). Soil CEC levels increase concomitantly with increasing soil clay content, while the availability of metal ions decreases (Gupta *et al*., 2019). CEC for clay soils usually exceeds 30 cmolkg$^{-1}$ while the value ranges from 0 - 5 for sandy soils (Alamgir, 2017). The capacity of soils for adsorbing heavy metals is correlated with their CEC (Fontes *et al*., 2000; Harter and Naidu, 2001). The greater the CEC values, the more exchange sites of soil minerals will be available for metal retention (Alamgir, 2017).

**Table 2.1 Relationship between cation exchange capacity (CEC) and soil texture**

| CEC (meq100g$^{-1}$) | Soil Texture |
|---|---|
| 3 - 5 | Sands |
| 10 - 15 | Loams |
| 15 - 25 | Silt Loams |
| 20 - 50 | Clay and Clay Loams |
| 50 – 100 | Organic soils |

*Source: Culman et al. (2019).*

### 2.4.1.5 Oxidation - reduction potential

Oxidation - reduction potential (redox potential) is one of the critical factors regulating the speciation and bioavailability of metals in soils (Alamgir, 2017). The redox potential of soil determines the tendency of the soil solution to accept or donate the electrons (Sheoran *et al*., 2016). Alamgir (2017), further explained that oxidation and reduction (redox potential) reactions are common in soils which occur together because as an electron cannot exist as an isolated entity; it is transferred from one species (the reductant) to another (the oxidant).

Several metals are present in their ionic forms in the soil solution thus the mobility of such metals from soil to plants depends on their oxidation state for example, Cr exists in two oxidation states of which the reduced form i.e $Cr^{+3}$ is quite insoluble in water while the oxidized form ($Cr^{+6}$) is highly soluble and readily available in the soil solution to the plants (NRC, 2003). The extent to which a soil is reduced or oxidized is generally assessed by the values of ‘Eh and Pe’ where ‘Pe’ is a redox potential which is expressed in terms of electrochemical energy (millivolts) and assumes a system at thermodynamic equilibrium

(Alamgir, 2017). Oxidized soils have values ranging from +400 to +700 mV while reduced soils may have values from -250 to -300 mV (Roberts *et al*., 2005).

Redox reactions play a major role in the formation and reactivity of some soil oxides (Fe and Mn) responsible for metal sorption and also controls the chemical speciation of several metalloid contaminants (As, Cr and Se) thus affecting sorption (McLaughlin *et al*., 2000). Generally reducing conditions cause a reduction in heavy metal mobility (Kabata - Pendias and Pendias, 1991; Gonsior *et al*., 1997). Oxidation – reduction reactions may not only affect the partitioning of redox-active trace metals like Cr, or Mo, but also of redox stable metals like Zn, Cu, or Ni, in soil or aquatic environments (Lander and Reutherr, 2004).

#### 2.4.1.6 Interaction with other metals

The presence of certain trace elements affects the availability of other metals in the soil and hence in the plant (Gupta *et al*., 2019). Antagonistic and synergistic behaviour thus exists among trace elements (Chibuike and Obiora, 2014), example, Cd is reported to antagonize the inhibitory effect of Zn on the total amount of mineralized carbon (Salgare and Acharekar, 1992). Similarly, Cu and Zn, as well as Ni and Cd, have been reported to compete for the same membrane carriers in plants (Clarkson and Luttge, 1989). Lead availability is affected by the other metals and reduced when interacting with Cd, Cr, Cu, Ni and Zn due to antagonistic effect (Orronoa *et al*., 2012). Despite the fact that presence of one trace elements affects the presence of another one, different species of some metal also affect each other (Abedin *et al*., 2002).

### *2.4.2 Plant related factors*

An uptake and accumulation ability of different trace elements (heavy metals) is dissimilar in different vegetables (Yadav *et al*., 2018) and crops in general, due to the difference in physiology, morphology and anatomy of each plant, leaf inclination angle and branch density (Shahid *et al*., 2016) are some morphological characters which affect the foliar uptake of trace elements. Like root uptake, foliar uptake of trace elements may occur in a dose dependent manner (Gupta *et al*., 2019). Xiong *et al*. (2014) suggested that small particles might diffuse through both the stomatal and cuticular pathways to enter the plant. Leaf penetration through stomatal pathway is generally easier because the cuticle of the sub-stomatal cells is comparatively thinner compared to external one (Roth - Nebel, 2007). The plant with numerous thin roots has high accumulation capacity of trace elements than one with few thick roots (Chandran *et al*., 2012).

Transpiration also plays a significance role in trace elements accumulation in plants (Gupta *et al*., 2019) because when transpiration is flourishing, plant accumulates more trace elements and its enrichment capability is also stronger (Hao *et al*., 2012). Leafy vegetables accumulate much higher translocation and transpiration rates (Gupta *et al*., 2019). The transfer of metals from root to stem and then to fruit during the transpiration and translocation process is longer in non-leafy vegetables and results in lower accumulation (Itanna, 2002; Khan *et al*., 2009): Plants absorb essential and non - essential elements from the soil in response to concentration gradient and selective uptake of ions or by diffusion (Peralta -Videa *et al*., 2009).

### *2.4.3 Effects of heavy metals on Soil*

Heavy metal pollution of the soil is caused by various metals especially Cu, Ni, Cd, Zn, Cr and Pb (Hinojosah *et al*., 2004) whose accumulation is an important requirement in environmental science (Nurudeen and Aderibigbe, 2013). Heavy metals sorption in soil is influenced by factors such as clay, pH, CEC and organic matter content (Adekunle *et al*., 2007). Metals pollution occur largely from industrial domestic and agricultural wastes as well as composition of fossil fuels by automobiles and (Nurudeen and Aderibigbe, 2013). The adverse effects of heavy metals on soil biological and biochemical properties are well documented (Singh and Kalamdhad, 2011). Soil properties like organic matter, clay contents and pH having major influences on the extent of the effects of metals on biological and biochemical properties (Speira *et al*., 1999). The soil enzymes activities are influenced in different ways by different metals due to the different chemical affinities of the enzymes in the soil system (Karaca *et al*., 2010).

An increase in metal concentrations adversely affects soil microbial properties such as respiration rate and enzyme activities (Singh and Kalamdhad, 2013). The contamination of soil by heavy metals are of global concern and present a serious problem (Muniatu and Otiato, 2010; Panagos *et al*., 2011) because soils contamination had shown to inhibit soil microbial activities and in turn reducing soil fertility, inhibiting the germination of certain seeds and producing nutrient imbalance in plants with adverse effect on synthesis and functioning of many biologically active compounds (Nurudeen and Aderibigbe, 2013).

### 2.4.4 Effects of heavy metals on plants

Plants have a natural propensity to take up metals (Achazai *et al*., 2011). Heavy metals effect on the growth of plants varies according to the particular heavy metal involved in the process (Chibuike and Obiora, 2014). The uptake of heavy metals by plants and subsequent accumulation along the food chain is a potential threat to animal and human health (Sprynskyy *et al*., 2007). These heavy metals are potentially toxic are to plantsand thus resulting in chlorosis, weak plant growth, yield depression and may even be accompanied by reduced nutrient uptake and reduced activity to fix molecular nitrogen in leguminous plants (Guala *et al*., 2010). Elevated lead (Pb) in soils may decrease soil productivity and a very low lead (Pb) concentration may inhibit some vital plant processes, such as photosynthesis, mitosis and water absorption with toxic symptoms of dark green leaves, wilting of older leaves, stunted foliage and brown shoot roots (Bhattachargya *et al*., 2008).

### 2.4.5 Effects of heavy metals on human and animal health

Utilization of food crops contaminated with heavy metals is a major food chain route for human exposure (Singh and Kalamdhad, 2011). Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues (Sobha *et al*., 2007). Ingestion of toxic metals like chromium has undesirable impacts on humans and the associated harmful impacts become perceptible only after several years of exposure (Khan *et al*., 2008). Cadmium toxicity on large organs like liver, placenta, kidneys, lungs, brains and bones have been identified (Sobha *et al*., 2007). Clinical signs of Zn toxicosis have been reported as vomiting, diarrhea, bloody urine, yellow mucus membrane, liver failure, kidney failure and anaemia (Duruibe *et al*., 2007).

Excessive human intake of Cu may lead to severe mucosal irritation and corrosion, widespread capillary damage, hepatic and renal damage and central nervous system irritation followed by depression (Singh and Kalamadhad, 2011). Excessive Ni exposure may vary from skin irritation to damage to the lungs, nervous system, and mucos membranes (Argun *et al*., 2007). Acute Pb poisoning may result to a dysfunction in the kidney, reproductive system, liver and brain which may lead to sickness and death (Odum, 2000). Cr is toxic and has no known function in human biochemistry and physiology (Singh and Kalamdhad, 2011). As inhibits the production of adenosine triphosphate (ATP) during respiration (Singh and Kalamdhad, 2011). Heavy metals are not only harmful to people who work (farm) on contaminated soils, but people who have been living in nearby areas (Abishek and Surrendra, 2016) and consumers of farm products from those areas. Although Cu is needed for biochemical process in crops, increased concentration of Cu is detrimental to human health (Tariq *et al*., 2016).

## 2.5 Crop Production on dumpsites

Many dumpsites in the rural and urban communities in Ghana including abandoned refuse dumpsites are used for cultivation of crops especially vegetables (Twumasi *et al*., 2016). The constructions of roads and buildings have been blamed for the losses of otherwise agricultural lands (Kugelman, 2012). Most Ghanaian communities over the years have promoted backyard farming (Appeaning, 2010) because many families in these rural and urban communities depend upon backyard farming (Zezza and Tasciotti, 2010) which include both livestock and crops (Cofie *et al*., 2005). The activities of backyard dumpsite farmers are not without soil pollution problems which are full of serious health implications especially with regards to crops grown on such soils (Steffang *et al*., 2017; Nwaogu *et al*., 2014). However, these dumpsites are commonly used for direct cultivation of vegetables and also as a good source of compost to support mainland agricultural activities (Owusu - Sekyere *et al*., 2013; Mwingyine, 2008). Both active and closed dumpsites in Ghana are all utilized since these soils are considered as nutrient rich by farmers in Ghana using wide range of crops from vegetables to tree crops for food, medicinal and other economic use.

### 2.5.1 Plantain (Musa sapientum) farms on dumpsites

Plantain is a tree - crop herb belonging to the Musaceae family with high starchy fruits which serve as a staple crop in most parts of the tropics including Nigeria (Iniobong and Uduakobong, 2017) and Ghana. Plantain is one of the common food tree crops found on dumpsites in Ghana, the reason being that they thrive well in waste dumpsites soils (Iniobong and Uduakobong, 2017). Plantain fruits have high fibre content which makes it a diet for lowering blood cholesterol and relieving of constipation thereby putting colon cancer at bay (Okareh, 2015). In Ghana, apart from human feeding on the mature fruits, the fresh leaves are also used to feed livestock. Plantain has a high demand for organic matter and thrives well in waste dumpsites where they produce healthy bunches of fruits (Iniobong and Uduakobong, 2017). Leachates from these dumpsites contribute to heavy metals in the soil (Ukpong *et al*., 2013) and it is the commonest occurring group of soil contaminant (Ideria *et al*., 2010). In Ghana, due to scarcity of arable lands in urban areas plantain is cultivated in dumpsites in densely populated cities and rural communities, most especially in strategic locations where all sorts of solid waste materials are dumped (Iniobong and Uduakobong, 2017).

Higher levels of heavy metals such as lead, cadmium were found to be higher in waste dumpsites soils than in soils, some distances away from the dumpsites (Ukpong *et al*., 2013; Amos - Tautau *et al*., 2014; Olufunmilayo *et al*., 2014; Tanee and Eshami - Mario, 2015) and growing plantain in such dumpsites absorbed these heavy metals along with other nutrients and accumulated them in their fruits. It was found out that all the dumpsites fruits had significantly (p = 0.05) higher heavy metals contents than those from the control site for example: dumpsite fruits Pb levels (7.63 - 8.67 $mgkg^{-1}$), control site fruits Pb (1.13 $mgkg^{-1}$); dumpsite site Cr levels (6.59 - 7.33 $mgkg^{-1}$), control site fruits Cr levels (2.23 $mgkg^{-1}$); dumpsites fruits Ni levels (2.66 - 3.36 $mgkg^{-1}$), control site fruits Ni levels (1.14 $mgkg^{-1}$); dumpsites fruits Cu levels (2.44 - 5.26 $mgkg^{-1}$), control fruits Cu levels (2.00 - 3.22 mgkg-1) (Iniobong and Uduakobong, 2017). Plantain has shown the ability to absorb metals and metals concentrations in their leaves have also showed a good correlation with the concentration of metals in soil (Bekteshi and Bora, 2013). Plantain and banana (Musa spp) roots feed well between 20 - 40 cm in depth (though roots have been found to reach 1.5 - 1.8 m deep in exceptional soils) (Draye *et al.,* 2005; Turner *et al.,* 2007).

### 2.5.2 Cocoyam (Xanthosoma sagitifolium) farms on dumpsites

Soil which serves as a vital resource for sustaining basic human needs (Ogunmodede and Adewole, 2015) also serves as a sink and recycling factory for both liquid and solid wastes (Wild, 1995). In the Ashanti region of Ghana, Cocoyam is one of the commonest crops found on dumpsites. (Asomani - Boateng and Murray, 1995) and these are known to contain toxic metal elements as a result of human activities and some of these materials are inorganic and as a result are not biodegradable and have toxic effects on living organisms at certain level of concentration (Ogunmodede and Adewole, 2015). However, most edible crops are indiscriminate in their extraction of nutrients from the soil and thus will extract the non - desirable heavy metals alongside the required essential nutrients to man, may cause blood and bone disorders, kidney damage and decreased mental capacity and neurological damage (NIEHS, 2004; Ogunmoded and Adewole, 2015).

**Table 2.2 Metal concentration (mgkg$^{-1}$) in cocoyam from Atinkankan dumpsite**

| Plant | Parts | Cd | Cr | Cu | Fe | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| Cocoyam | Tuber | 5.20 ± 0.01 | BDL | 11.05 ± 0.01 | 110.00 ± 0.01 | BDL | 46.04 ± 0.02 | 92.00 ± 0.00 |
| | Leaf | 7.30 ± 0.01 | 1.00 ± 0.01 | 0.01 ± | 68.12 ± 0.02 | 6.03 ± 0.01 | 30.10 ± 0.00 | 48.70 ± 0.00 |

*BDL - Below detectable limit. Source: Ogunmodede and Adewole (2015).*

Amusan *et al*. (2005) have reported that crops like cocoyam differ in their ability to uptake metals as soils are able to biodegrade almost all organic compounds found in waste by converting them into harmless substances unlike inorganic substances which are non - biodegradable, persist and accumulate in the soil (Ukpong *et al*., 2013). Therefore, dumpsites used as fertile grounds for the cultivation of crops results in increased uptake of heavy metals either as mobile ions or through foliar absorption (Amusan *et al*., 2005). Cocoyam root system is fibrous and lies mainly at a soil depth of up to 1 m (Onwueme, 1994; Onyeka, 2014).

### 2.5.3 Lettuce (Lactiva sativa) farms on dumpsites

Lettuce production on dumpsites agricultural lands contribute to production of vegetables especially in urban communities where arable lands are scarce (Dubbeling and De Zeeuw, 2011) and most of these vegetables like lettuce used for cultivation are hyper accumulators of most of the essential heavy metals (Singh *et al.,* 2012) and non- essential heavy metals such as lead and cadmium (Twumasi *et al*., 2016). Dumpsites used in agriculture for crops like lettuce cultivation are an important source of dangerous heavy metals derived from components of industrial products (Fuge, 2013; Wuana and Okieimen, 2011) and thus agricultural activities on such lands provide entry route for heavy metals in the food chain (Twumasi *et al*., 2016). Most leafy vegetables like lettuce are hyper accumulators of some non - essential heavy metals (Singh *et al*., 2012). Higher concentrations of heavy metals have earlier been detected in fruits and vegetables harvested from waste dumpsites (Imasuen and Omorogiera, 2013; Cortez and Ching, 2014; Tanee and Eshalomi - Mario, 2015).

When plants like lettuce are cultivated on these dumpsites soils, they absorb some of these heavy metals and bioaccumulate them in their roots, stems, fruits, grains and leaves (Fatoki, 2000). A study on a dumpsite and a control site found that, metal concentrations in lettuce on dumpsites found Cd level (0.13 - 0.67 mgkg$^{-1}$) higher than control site lettuce Cd level (0.010 mgkg$^{-1}$ Cd) while control soil Cd level (0.243 - 13.623 mgkg$^{-1}$) was lower than Cd level ranged in dumpsite soil (90.013 - 7.197 mgkg$^{-1}$) (Twumasi *et al*., 2016). A report indicates that maximum allowable level of Cd in soil is supposed to be 0.27 mgkg$^{-1}$ in lettuce 0.02 mgkg$^{-1}$, Cd level in fruity vegetable was 0.05 mgkg$^{-1}$; Cd while Pb maximum allowable level in soil is 0.420 mgkg$^{-1}$, in lettuce 0.3 mgkg$^{-1}$ Pb and in fruity vegetable it is expected to be 0.1 mgkg$^{-1}$ Pb (FAO / WHO, 2011). Lettuce has a rooting depth of up to 0.3 m at harvest (Thorup-Kristensen, 2001).

**Table 2.3 Metal concentration levels in cultivated lettuce (*Lactuca sativa L.)***

| Heavy metals | Mean concentration of metal (mgkg$^{-1}$) |
|---|---|
| $Cu^{2+}$ | 8.00 |
| $Fe^{2+}$ | 384.412 |
| $Mn^{2+}$ | 26.113 |
| $Zn^{2+}$ | 76.457 |
| $Pb^{2+}$ | 5.942 |
| $Ni^{2+}$ | 3.083 |
| $Cd^{2+}$ | 5.633 |

*Source: Kabir et al. (2011)*.

**Table 2.4 Allowable concentration limit of heavy metals in soils and plants (mgkg$^{-1}$)**

| Metals | Concentration in soil (mgkg$^{-1}$) | Concentration in plants (mgkg$^{-1}$) |
|---|---|---|
| P | 100.00 | 0.30 |
| Cr | 100.00 | - |
| Ni | 52.00 | 67.00 |
| Cu | 10.00 | 73.00 |
| Cd | 3.00 | 0.10 |
| As | 20.00 | - |

*Source: WHO / FAO (Chiroma et al., 2014): in Iniobong and Uduakobong (2017).*

**Table 2.5 FAO/WHO guidelines for metals in food / vegetables**

| Metals (mgkg$^{-1}$) | levels in plants (mgkg$^{-1}$) | Normal range in plant (mgkg$^{-1}$) |
|---|---|---|
| Cd | 1 | < 2.4 |
| Cu | 30 | 2.5 |
| Pb | 2 | 0.50 – 30 |
| Zn | 60 | 20 – 100 |
| Fe | 48 | 400 – 500 |
| Ni | - | 0.02 – 50 |
| As | 30 | 0.5 – 20 |

*Source: FAO/WHO (2011).*

**Table 2.6 Concentration ranges of metals (mgkg$^{-1}$) in soils and plants and critical concentrations in plants**

| Metals | Normal range in soils (mgkg$^{-1}$) | Normal range in plants (mgkg$^{-1}$) | Critical plant concentration (mgkg$^{-1}$) |
|---|---|---|---|
| Cr$^{*}$ | 5 - 1500 | 0.03 - 14 | 5 - 30 |
| Fe$^{\#}$ | 5000 - 100 000 | 40 - 500 | - |
| Ni$^{*}$ | 2 - 750 | 0.02 - 5 | 15 - 50 |
| Cu$^{*}$ | 2 - 250 | 5 - 20 | 20 - 100 |
| Zn$^{*}$ | 1 - 900 | 1 - 400 | 100 - 400 |
| As$^{*}$ | 0.1 - 40 | 0.02 - 7 | 5 - 20 |
| Cd$^{*}$ | 0.01 - 2 | 0.1 - 2.4 | 5 - 30 |
| Hg$^{*}$ | 0.01 - 0.5 | 0.005 - 0.17 | 1 - 3 |
| Pb$^{*}$ | 2 - 300 | 0.2 - 20 | 30 - 300 |

*Source: $^{*}$Radojevic and Baskin (2006); $^{\#}$Stewart et al. (1974).*

**Table 2.7 WHO/FAO heavy metals threshold in soils**

| Metals | Soil metal limit (mgkg$^{-1}$) |
|---|---|
| Cr | - |
| Fe | - |
| Ni | 50.00 |
| Cu | 100.00 |
| Zn | 300.00 |
| As | 20.00 |
| $^{*}$Cd | 3.00 |
| Hg | 2.00 |
| Pb | 5.00 |

*WHO/FAO (2001); FAO/WHO (2007)* $^{*}$

**Table 2.8 Heavy metal permissible (mgkg$^{-1}$) limits in plants**

| Metal | Level | Level |
|---|---|---|
| Ni | 10 ** | 50*** |
| Cr | 1.30** | 70*** |
| Cd | 0.02** | 0.35*** |
| Cu | 10** | 100*** |
| Pb | 2** | 100*** |
| Zn | 50** | *300 |
| Fe | 20** | - |

****FAO/WHO (2007); **FAO/WHO (2009); *(Shal et al., 2011).*

**Table 2.9 Permissible limit for total metals (mgkg$^{-1}$) in various soil pH ranges in UK and Germany**

| | UK (1989) | | | Germany (1992) | |
|---|---|---|---|---|---|
| Metal | pH 6 - 7 | pH 5.5 - 6 | pH 5 - 5.5 | pH 6 - 7 | pH 5 - 6 |
| Zn | 300 | 250 | 200 | 200 | 150 |
| Cu | 135 | 100 | 80 | 60 | 60 |
| Ni | 75 | 60 | 50 | 50 | 50 |
| Cd | 3 | 3 | 1.5 | 1.5 | 1.0 |
| Cr | 400 | 400 | 100 | 100 | 100 |
| Pb | 300 | 300 | 100 | 100 | 100 |

*Permissible limits Adapted from (Ghorbani et al., 2006).*

### 2.6 Evaluation of soil heavy metal pollution

A soil pollution index is a powerful tool for processing, analyzing and carrying raw environmental information to decision makers, managers, technicians and the public (Caeiro *et al*., 2005). Gong *et al*. (2008) have classified pollution indices into two main types (i) single indices and (ii) integrated indices and some of the single indices identified and used in this studies were geoaccumulation index, enrichment factor, relative top soil enrichment factor, transfer ratio and translocation factor.

#### 2.6.1 Geoaccumulation Index (Igeo)

An index of geo- accumulation was originally defined by Muller (1969) in order to determine and define metal contamination in sediments (Banat *et al*., 2005). The Igeo – accumulation index was distinguished into seven classes by Muller (1996); (Buccolieri *et al*., 2006): Igeo $\leq$ 0, class o, unpolluted: 0 < Igeo $\leq$ 1, class 1; from unpolluted to moderately polluted; 1 < Igeo < 2, class 2 moderately polluted: 2 < Igeo ≤ 3, class 3, from moderately to strongly polluted; 4 < Igeo ≤ 5, class 5, from strongly to extremely polluted; and Igeo 75, class 6, extremely polluted . Igeo is considered as an effective tool for assessing contamination from hazardous element and one of the most important purpose of assessing geo - accumulation index (Igeo) is to characterise the level of pollution in soil (Proshad *et al*., 2018).

The toxic levels of heavy metals (transferred from soil to plants) may be classified according to their capacity of being transferred from soil to plants (Sule *et al*., 2019), because the concentration of heavy metals present in plant tissues as a fraction of total metal concentration in the soil reflects its bioavailability (Misra *et al.,* 2009). Many studies have reported data on, especially, the transfer of heavy metals from soil to plants and vegetables through roots and shoots (Uchido *et al*., 2009). In order to simplify the pollution levels, in the dumpsites and non-dumpsites soils, pollution index; geoaccumulation index, may be considered as an effective tool for assessing degree of contamination from hazardous element (Islam *et al.,* 2018). This technique is used universally for determination of soil metal concentrations nowadays (Santos *et al*., 2003). Islam *et al*. (2018) have reported that, one of the most important purposes for assessing metal concentrations is to characterize the level of pollution from soil. Forster *et al*. (1993); Umme *et al.* (2016), explained that, to quatify the degree of pollution in a refuse dump soils, Geoaccumulation index (Igeo) was used. The $I_{geo}$ was determined by the following equation (Miller, 1969; Bozke *et al*., 2004; Agyarko *et al*., 2014).

$$I_{geo} = \text{In} (Cn / 1.5 \text{ x } Bn) \qquad (2.2)$$

Where: Cn - measured concentration of metal in the refuse dump soil in mgkg$^{-1}$, Bn - background value of heavy metal (mgkg$^{-1}$); and 1.5 background matrix concentration factor. The degree of pollution of the soils (Refuse dump soils) by the metals was assessed (Table 2.10) using the Geoaccumulatuion index ($I_{geo}$) classification by Forstener *et al*. (1993).

**Table 2.10 Geoaccumulation index classification**

| $I_{geo}$ - Index | $I_{geo}$ - class | Contamination intensity |
|---|---|---|
| < 0 | 0 | practically uncontaminated |
| 0 – 1 | 1 | uncontaminated to moderate |
| 1 - 2 | 2 | moderate |
| 2 - 3 | 3 | moderate to strong |
| 3 - 4 | 4 | strong |
| 4 - 5 | 5 | Strong to very strong |
| > 5 | 6 | Very strong |

*Source: Forstener et al. (1993); Buccolieri et al. (2006).*

### *2.6.2 Enrichment Factor (EF)*

To determine anthropogenic input of metals in soils and sediments, an enrichment factor is used as an appropriate technique (Ali *et al*., 2013). The enrichment factor (EF) was initially developed to speculate on the origin of elements in the atmosphere and precipitation of seawater Due *et al.* (1975). It was progressively extended to the study of soils, lake sediments, peat, tailing, and other environmental materials (Reimann and Di Caritat, 2005). An enrichment factor (EF) was calculated as the following in preference (Buat - Menard and Chesselet, 1979):

$$EF = \frac{Cn\ (Sample)/Cref\ (Sample)}{Bn(background/Bref\ (background)} \qquad (2.3)$$

Where;

Cn - content of the examined elements in the examined environment

Cref - content of the examined elements in the reference environment.

Bn - content of the reference element in the examined environment

Bref - Content of the reference element in the reference environment.

It is assumed that the considered reference element should have little variation in occurrence and present very small amount in the study environment. However, a geochemical characteristics element occurring in high concentration may be used, but should have no synergistic or antagonistic effect towards the examined element such as Sc, Mn, Al and Fe have been commonly used as reference elements (Loska *et al*., 1997). Franco - Uria *et al*. (2009) found that, to assess the magnitude of hazardous elements in the environment, the enrichment factor is assumed an impressive tool, for determination of anthropogenic influences of hazardous elements in soil. According to Birch and Olmos (2008), an EF > 1.5 is an indication of human influence, an EF of 1.5 - 3 indicates minor human influence; 3 - 5 indicates moderate human influence; 5 - 10 indicates severe human influence, whilst > 10 indicates very severe modification. In computing for the EF, the enrichment of the dumpsites was analyzed by using the concentration of the control (uncontaminated) samples being taken as the reference immobile (acceptable normalization) (Eze, 2015). Ghrefat *et al*. (2011) reported that, enrichment factor (EF > 1) greater than 1 suggest that the sources are more likely to be anthropogenic or human induced.

Tippie (1984) explained that, Fe chosen as the element of normalization was because of its natural sources (98%) which vastly dominate its input, Eze (2015) also confirmed Fe as a suitable immobile element. Liu *et al*. (2005) have also reported of using either Fe or Mn. On the basis of the enrichment factor; five contamination categories are generally recognized: EF < 2, depletion to mineral enrichment; 2 ≤ EF < 5, moderate enrichment: 5 ≤ EF < 20, significant enrichment; 20 ≤ EF < 40, very high enrichment; and EF > 40, extremely high enrichment (Sutherland, 2000; Yongming *et al*., 2006).

### 2.6.3 Relative top soil enrichment factor (RTEF)

A relative top soil enrichment factor which may be attributed to trace elements or heavy metals recycling by plant and retention by organic matter (Siegel, 2002) can be calculated from this:

RTEF = Total metal contents at 0 - 15 cm depth / Total metal content at 15 - 30 cm depth (2.4)

(Colbourn and Thornton, 1978).

**Table 2.11 Classification of pollution indices - Enrichment Factor (EF) and Relative Top soil Enrichment Factor (RTEF)**

| EF | Category | RTEF | Interpretation |
|---|---|---|---|
| EF < 2 | no mineral enrichment | 1 ≤ RTEF < 2 | no contamination |
| 2 ≤ EF < 5 | moderate enrichment | RTEF > 2 | contamination |
| 5 ≤ EF < 20 | significant enrichment | RTEF > 2 | contamination |
| 20 ≤ EF < 40 | very high enrichment | RTEF > 2 | contamination |
| EF > 40 | extremely high enrichment | RTEF > 2 | contamination |

*Source: (Sutherland, 2000; Yongming et al., 2006; Ngange et al., 2013).*

### 2.6.4 Transfer ratio (TR)

Transfer ratio is the ratio of the heavy metal concentration in a crop to the total heavy metal concentration in the soil at the site (Chamberlain, 1983; Harrison and Charmaine, 1989; Smith 1996). Transfer factor may also be defined as the ratio of the concentration of metals in plants to the total concentration of that metal in the soil (Hammed *et al*., 2017). Natasa *et al*. (2015) explained that TR, signifies the amount of heavy metal in the soil that ended up in the vegetable crop (Odai *et al*., 2008). Transfer ratio or factor from soil to plan is a key module of human exposure to heavy metals through food chain (Eze *et al.,* 2018). Hammed *et al*. (2017) in a heavy metal content investigation at 0 **-** 30 cm soil depth with maize plant found that, the level of heavy metals transfer for site A was in order Cu > Cd > As > Fe > Co > Pb > Zn > Ni while for site B, was Cd > Cu > Fe > Co > As > Pb > Ni > Zn. So the transfer ratio / factor for plants on the dumpsites were higher than TR for plants on background or non-dumpsites (Hammed *et al*., 2017). However, Agyarko *et al*. (2010) reported higher transfer ratio values on background soils than on dumpsite soils with high metals load and attributed it to the fact that some soil factors apart from the total soil content of the metals also affect the rate of metal uptake by plants specifically higher levels of organic matter, available phosphorus (phosphates) and exchangeable cations such as Ca and Mg might have affected the metals level and subsequently leading to lower transfer ratios of the metals in the refuse dump soils than the background soils

The Transfer Ratio (TR) of metals from dumpsites soil to plant is calculated using the formular: $TR = (C_{plant} / C_{soil})$ (2.5)

Where:

$C_{plant}$ - concentration of metals in plants, $C_{soil}$ - concentration of metals in soil (Lokeshwari and Vhandrappa, 2006). Transfer ratio or factor (TF) may also be calculated as a ratio of concentration of a specific metal in plant tissue to the concentration of some metal in soil both in same units (Rangmaekar *et al*., 2013a).

Natasa *et al*. (2015) found translocation and accumulation of Cd, Pb, Cu in ten different crops and indicated highest transfer factor of Cu (0.1 - 1.0), Pb (0.01 - 0.1) and further explained that, transfer factor (TF) decreases when plants are grown in soils with higher level of heavy metals. Transfer factor with higher values (> 1) indicates higher absorption of metal from soil by the plant, whiles lower values (< 1) indicate poor response of plants towards metal absorption and the plant can be used for human consumption (Rangmaekar *et al*., 2013b). Jolly *et al*. (2013) and Chindo *et al*. (2016) indicated in their work that Cu with the highest transfer factor (0.86) could be explained with the fact that factors such as pH, exchange binding capacities, climate change and morphology of the plant might have contributed to low transfer factor values on dumpsites soils. Cui *et al.* (2004), earlier, also found that, plant species, physiological stage, uptake capacity, growth rate are among the major determinants of metal transfer from a soil to the crop.

### 2.6.5 Translocation factor (TF)

The translocation of metals from one part of a vegetable (crop) to another part of the plant is a function of root shoot transport, which can be expressed as the translocation factor (TF) (Gosh and Singh, 2005). It is expressed as:

$$TF = (C_{shoot} / C_{root}) \quad (2.6)$$

Where, $C_{shoot}$ is the concentration of the metal in the above ground portion of the vegetable (crop); $C_{root}$ is the metal concentration in the below ground portion (Gosh and Singh, 2005).

A plant will have a high capacity to transport element from root to shoot when the above ground concentration is higher than the below ground concentration (Nafiu, 2010).

# CHAPTER THREE

# 3.0 MATERIALS AND METHODS

## 3.1 Study 1 – Farmer's Awareness of Dumpsites Soil Physicochemical Properties

### 3.1.1 Locations of study

Study one interviewed farmers from three dumpsites communities at Mampong - Kyeremfaso dumpsite (Lat. 7º 05' 27.9'' N, Long. 1º 24' 19.2'' W); Kumasi - Suame Magazine dumpsite (Lat. 6º 43' 26.9'' N, Long. 1º 37' 22.6'' W) and Kumasi - Ayeduase dumpsite (Lat. 6º 40' 31.29'' N, Long. 1º 33' 42.9'' W) within the Ashanti region of Ghana (Lat. 5º 50' 7.46''N, Long. 1º 15' 2.25'' W). Figure 3.1 shows the locations of the dumpsites within the Kumasi Metropolis and Mampong Municipal.

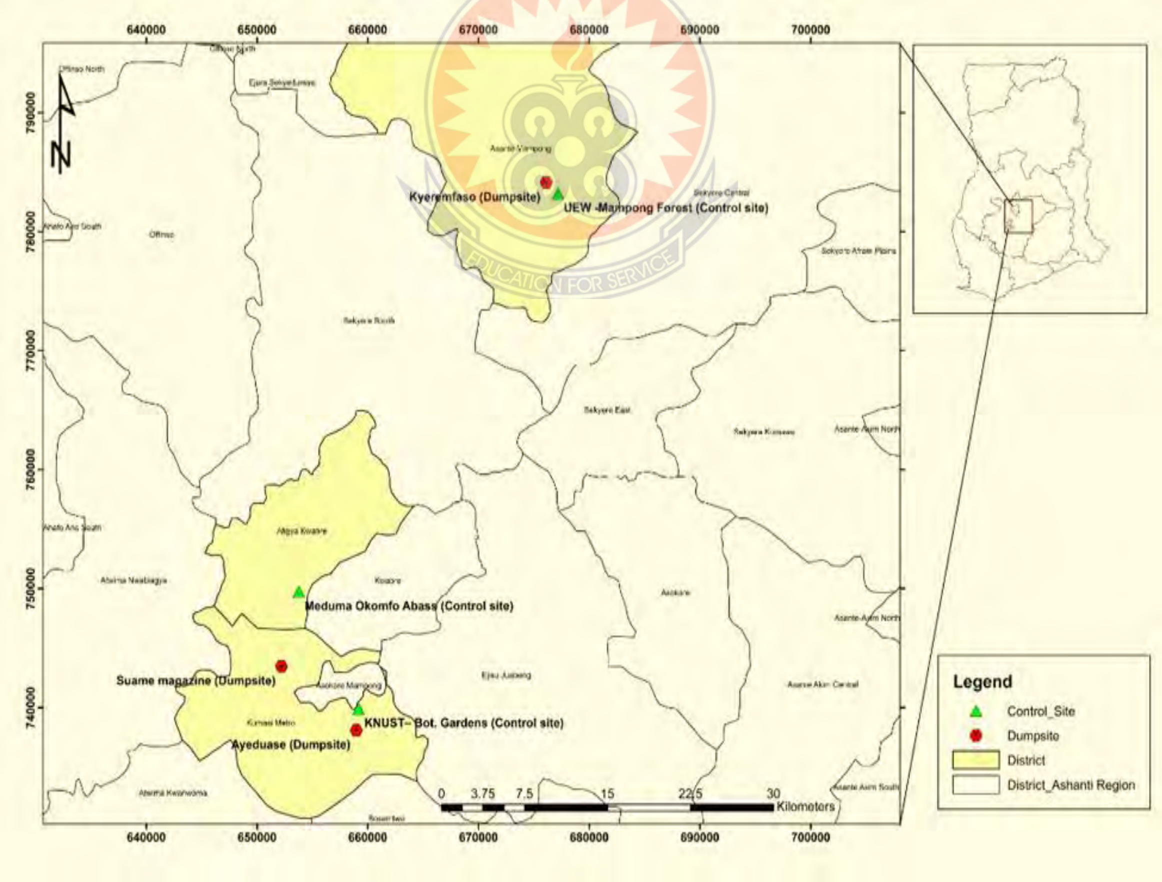

Fig. 3.1 The site map of studied locations in Ashanti region, Ghana.

### 3.1.2 Climate and Vegetation

The Ashanti region of Ghana experiences double maxima rainfall in a year, with peaks in May/June as the major season and October as the minor season. Mean total annual rainfall ranges from is between 1100 mm to 1800mm. The mean annual temperature ranges between $25.5^0$ C in the southern districts and $32^0$ C in the northern parts of the region. Humidity is high averaging about 85% in the southern districts and 65% in the northern part of the region (MOFA, 2020).

### 3.1.3 Demography

The study locations are within Ashanti region of Ghana with a population of 3,612 950 (19.1 % of the national total (Ghana Population Census, 2000). The sex ratio (Male: Female) for the entire region was 1 : 0.98. The population density is 148.1 persons / $km^2$ (Ghana Population Census, 2000) and is higher than the national average of 79.3. The regions' population growth rate of 3.4% is above the national average of 2.7%. The economically active population (15 – 49 years) in the region is 1,612,467 (representing 19.45% of national figure of 8,292,114 (Ghana Population Census, 2000). Of this 706,888 are engaged in agriculture (farming, forestry, fishing and hunting), representing 43.8. Sex ratio; 50% males and 50% females. Approximately 65% of the total population depends on agriculture for their livelihood (Ghana Statistical Service, 2016).

### 3.1.4 Soil Types

Soils in Ashanti region are mainly of two types; Forest Ochrosols found in the southern districts while the Savanna Ochrosols are confined to the northern districts. The pH and nutrient status of the soils will support crop production (Table 3.1) (CSIR - Soil Research

Institute, 2020). The physical characteristics outlined (Table 3.2) showed that the soil bulk density and texture classification can support food and cash crops (Field data).

**Table 3.1 Fertility status of soils in Ashanti region, Ghana**

| Locations | Soil Types | Soil pH | Organic matter (%) | Total N | Available P | Soil pH |
|---|---|---|---|---|---|---|
| Offinso – Ejura (Northern District) | Savanna Ochrosols | 5.3 - 7.8 | 1.5 - 3.0 | 0.2 - 0.3 | 0.12 - 12 | 50 - 100 |
| Kwadaso-Juaso, Obuasi (Southern District) | Forest Ochrosol | 4.3 - 7.0 | 1.5 - 3.0 | 0.1 - 0.2 | 0.12 - 12 | 50 – 100 |

*Source: Soil Research Institute, CSIR - Kumasi (2020).*

**Table 3.2 Soil physicochemical properties of the six studied soil sites**

| Treatment / Location | BD ($gcm^{-3}$) | Sand (%) | Silt (%) | Clay (%) | Texture |
|---|---|---|---|---|---|
| 1 / Mampong Kyeremfaso | 1.54 | 94.00 | 2.00 | 4.00 | Sand |
| 2 / Mampong UEW forest | 1.58 | 88.00 | 6.00 | 6.00 | Sand |
| 3 / Kumasi Suame | 1.12 | 94.00 | 2.00 | 4.00 | Sand |
| 4 / Kumasi Meduma | 1.61 | 68.00. | 10.00 | 22.00 | Sand Clay Loam |
| 5 / Kumasi Ayeduase | 1.59 | 80.00 | 16.00 | 4.00 | Loamy Sand |
| 6 / Kumasi KNUST | 1.41 | 86.00 | 10.00 | 4.00 | Loamy Sand |

*Source: Field data.*

### 3.1.5 Sampling procedure

A purposive sampling technique was used during a preliminary visit to the communities and the available dumpsites and hundred farmers were selected. They were dumpsite farmers within Kumasi and Mampong. Fifty respondents were identified from Mampong - Kyeremfaso dumpsite community within the Mampong Municipal; thirty respondents were identified at Kumasi - Suame dumpsite community within the Kumasi Metropolis and twenty respondents were identified from Kumasi - Ayeduase dumpsite community also within Kumasi Metroplolis. The

### 3.1.6 Data collection

Data was collected using a semi - structured questionnaire which was administered to fifty dumpsite farmers at Kyeremfaso dumpsite a rural community within Mampong municipal, thirty dumpsite farmers at Kumasi - Suame Magazine and twenty dumpsite farmers at Kumasi Ayeduase. The data was analyzed with SPSS (Version 21) (Analytical Software, 2018).

## 3.2 Study Two – Assessment of heavy metals levels in Selected Soils and their accumulation levels in plantain and cocoyam

### 3.2.1 Locations

The study was conducted at Mampong - Kyeremfaso dumpsite (KYE) (Lat. 7º 05’ 27.9’’ N, Long. 1º 24’ 19.2’’ W) with corresponding Mampong University Education Winneba forest, background site (UEW), (Lat. 7º 04’ 57.78’’ N, Long. 1º 23’ 44.98’’ W); Kumasi - Suame magazine dumpsite (SUA) (Lat. 6º 43’ 26.9’’ N, Long. 1º 37’ 22.6’’ W) with corresponding

Kumasi - Meduma background site (MED) (Lat. 6º 46’ 50.9’’ N, Long. 1º 36’ 30.9’’ W); Kumasi - Ayeduase dumpsite (AYE) (Lat. 6º 40’ 31.29’’ N, Long. 1º 33’ 42.9’’ W) with corresponding Kumasi Kwame Nkrumah University of Science and Technology botanical gardens, background site (KNUST) (Lat. 6º 41’ 30.28’’ N, Long. 1º 33’ 36.2’’ W). The study locations are all found within the Ashanti region of Ghana (Lat. 5º 50‘ 7.46’’N, Long. 0º 15‘ 2.25’’ W) which is centrally located in the middle belt of Ghana. It shares boundaries with six of the sixteen political regions VIZ :- Bono, Bono East, and Ahafo regions in the north, Eastern region in the east, Central region in the south and Western region in the south west.

### 3.2.1 Soils

The soil physical characteristics of the various study sites are outlined in Table 3.2 and support farmers in their year long crop production (Field data).

### 3.2.2 Climate

Refer to study one for a detailed description of the study soil sampling sites climate.

### 3.2.4 Treatments

There were six locations from which the sites were sampled for analysis. These comprised three (3) background (control site) soils with their corresponding dumpsites soil. An average distance of 2 km was between every dumpsite and its corresponding background site within the Ashanti region (Table 3.3).

**Table 3.3 Treatments – dumpsites and their Corresponding background soils**

| Dumpsite / GPS Coordinates | Corresponding Background site / GPS Coordinates |
|---|---|
| Mampong Kyeremfaso (T1) /<br>Lat. 7° 05’ 27.9’’ N<br>Long. 1° 24’ 19.2’’ W | Mampong UEW forest (T2) /<br>Lat. 7° 04’ 57.78’’ N<br>Long. 1° 23’ 44.98’’ W |
| Kumasi Suame Magazine (T3) /<br>Lat. 6° 43’ 26.9’’ N<br>Long. 1° 37’ 22.6’’ W | Kumasi – Meduma (T4) /<br>Lat. 6° 46’ 50.9’’ N<br>Long. 1° 36’ 30.9’’ W |
| Kuamsi – Ayeduase (T5) /<br>Lat. 6° 40’ 31.29’’ N<br>Long. 1° 33’ 42.9’’ W | Kumasi – KNUST Botanical garden (T6) /<br>Lat. 6° 41’ 30.28’’ N<br>Long. 1° 33’ 36.2’’ W |

*Source: Field data.*

### 3.2.5 Soil sample collection

In Study two, soil samples were collected from 0 - 15 and 15 - 30 cm of soil depths. Five (5) sampling spots from each of the six (6) locations included three (3) dumpsites and three (3) background sites giving a total of sixty (60) soil samples for the two sampling depths collected from February to March, 2019. Systematic sampling technique was used to locate the sampling spots at 5 m distance between each sampling spot around the dumpsites and the background / control sites. There was an average distance of 2 km between each dumpsite and a background site. Soil cores containing plastics, scrap metals and other materials were separated before crushing the soil sample in a porcelain mortar and passed through a 2 mm sieve and placed in a zip - lock bags for detailed analytical studies.

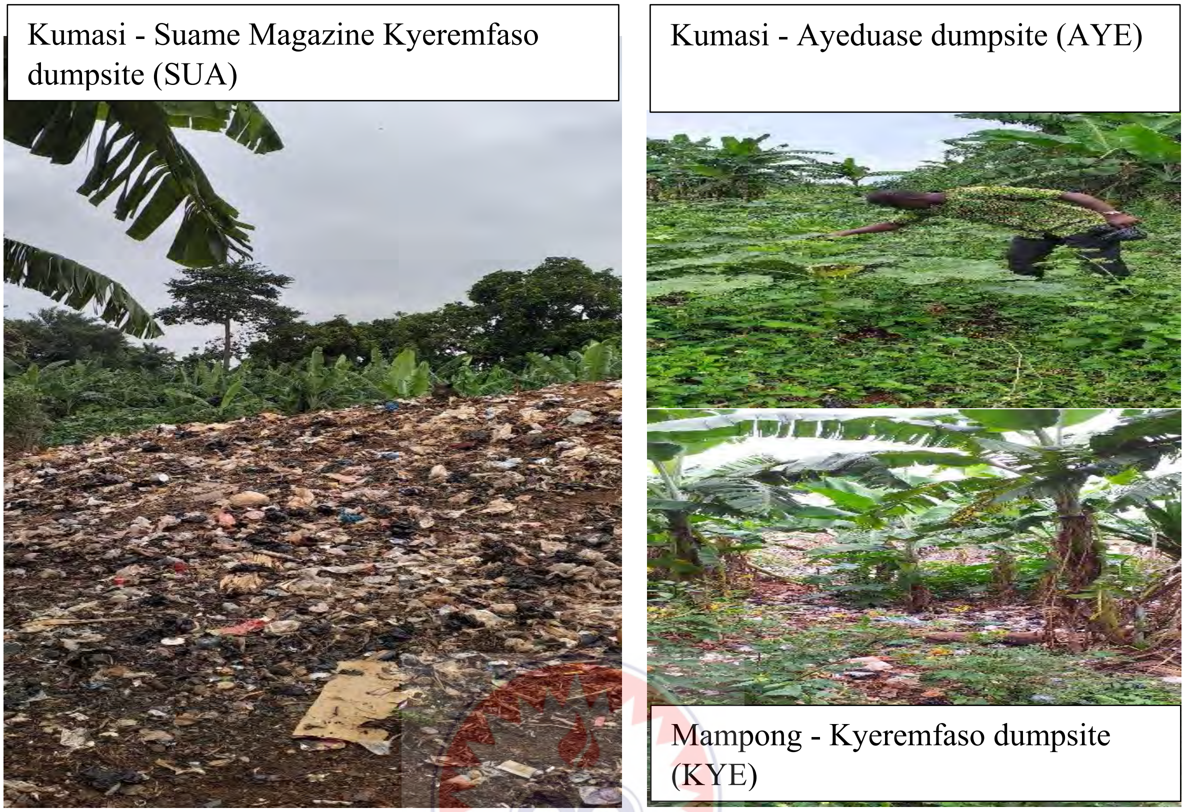

**Figure 3.2 Dumpsites soil sampled locations in Ashanti region, Ghana**

*Source: Field data*

**Figure 3.3 Background soils locations in Ashanti region, Ghana**

### 3.2.6 Plant sample collection

In study two, plantain and cocoyam young apical leaves with their fruits and corms samples were collected from all dumpsites and background sites, washed with deionized water and oven dried at 60 ºC for 24 hours and ashed in furnace at 450 ºC before bagging in a zip - lock bag for analysis. Similar plantain and cocoyam leaves, fruits and corms which were taken at approximately 2 km away from each dumpsite served as the basis of comparison from a non - polluted source (Sekara *et al.,* 2005).

### 3.2.7 Soil analytical methods

The soils for study two were collected in triplicates for a routine soil physicochemical properties determination at the UEW, Mampong campus general laboratory, CSIR - Soil Research Institute, Kwadaso Chemistry laboratory and KNUST SHEATH Chemistry laboratory. The soil samples were air - dried, ground and passed through a 2 - mm mesh sieve before analysis.

### 3.2.8 Physicochemical analysis under Study Two

#### 3.2.8.1 Physicochemical analysis

Physicochemical properties of the studied site soils were; particle size analysis, bulk density, soil pH, total organic carbon, total nitrogen, available phosphorus, available potassium, CEC, ECEC, Base saturation, Exchangeable acidity.

### 3.2.8.2 Soil pH

Soil pH was determined in a 1:2.5 suspension of soil and water using an Hl 9017 Micro-processor pH meter. A 20 g soil sample was weighed into 100 ml polythene bottle. To this 50 ml distilled water was added from a measuring cylinder and the bottle capped. The solution was shaken on a reciprocation shaker for two hours. After calibrating the pH meter with buffer solutions at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension (Rowel, 1994) .

### 3.2.8.3 Bray's No 1 Phosphorus (Available phosphorus)

The readily acid – soluble forms of P were extracted with a HCl: $NH_4F$ mixture called the Bray's No.1 method as described by Bray and Kurtz (1945) and Olsen and Sommers (1982). Phosphorus in the extract was determined on a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as reducing agent. A 2.0 g soil sample was weighed into a shaking bottle (50 ml) and 20 ml of extracting solution of Bray-1 (0.03 M $NH_4F$ and 0.025 M HCl) was added. The sample was shaken for one minute by hand and then immediately filtered through a fine filter (Whatman No. 42). One ml of the standard series, the blank and the extract, 2 ml boric acid and 3 ml of the coloring reagent (ammonium molybdate and antimony tartarate solution) were pipetted into a test tube and homogenized. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrophotometer at 660 nm wavelength.

A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6 mg P/l was prepared from a 12 - mg/l stock solution by diluting 0, 10, 20, 30, 40 and 50 ml of 12 mg P/l in 100 ml volumetric flask and made to volume with distilled water. Aliquots of 0, 1, 2, 4, 5 and 6 ml of the 100 mg P/l of the standard solution were put in 100 ml volumetric flasks and made to the 100 ml mark with distilled water.

Calculations:

P (mg/kg) = (3.1)

Where; a = mg/l P in sample extract ; b = mg/l P in blank; s = sample weight in gram;

mcf = moisture correcting factor; 20 = ml extracting solution,

6 = ml final sample solution

### 3.2.8.4 Total Organic Carbon

The organic carbon (OC) content of the soil was determined using the Walkley - Black Wet Oxidation Method, (Page *et al*., 1982). In this analysis, 2.0 g of soil sample was weighed into a 500 ml Erlenmeyer flask. 10 ml of 1.0 M potassium dichromate ($K_2Cr_2O_7$) was added by means of a pipette followed by 20 ml of concentrated sulphuric acid ($H_2SO_4$). The conical flask was swirled for about a minute in a fume chamber (owing to the evolution of gas) and allowed to stand on an asbestos sheet for 30 minutes. Two hundred milliliters (200 ml) of distilled water was added and swirled to ensure thorough dilution, 10ml orthophosphoric acid ($H_3PO_4$), and, finally 2.0 ml diphenylamine indicator was added. The excess $Cr_2O_7$ in suspension was back titrated with 1.0 N ferrous sulphate solution. Near the end point, the purple colour changed rapidly to green. A blank solution was also prepared in the same way. The percentage carbon of soil samples from each spot and depth was determined from the formula;

$$\%\,Total\ OC = \frac{(m.e.K_2Cr_2O_7 - m.e.F_eSO_4)\ \times 0.003 \times (f) \times 100}{Weight\ of\ soil} \tag{3.2}$$

Where, $m.e. = Normality\ of\ solution\ \times\ ml\ of\ solution$ used, 0.003 is m.e. weight of C and ***f*** (correction factor) = 1.33

SOC content was characterized based on method used by Nelson and Sommers (1982). Soil Organic Matter (SOM) was converted by multiplying soil organic carbon level by conversion factors ranging from 1.73 to obtain organic matter values (Baldock and Nelson, 2000).

### 3.2.8.5 CEC

A 5g of soil sample was weighed and transferred into a 50-ml centrifuge tube. A 25 ml or 1.0M sodium acetate solution was added to the tube and a stopper was fixed and shaken in a mechanical shaker for 5 minutes. The solutions were centrifuged at 2000 rpm for 5 minutes till supernatant liquid is clear. The liquid was decanted and the extraction was repeated three times. The mechanical shaker, the centrifuge, and decantation process with ethanol was repeated until the electrical conductivity (EC) of the decant read less than 40 mS/cm (FAO, 2008).

### 3.2.8.6 Particle Size Analysis

The particle size analysis was determined by the hydrometer method after dispersion in sodium hexametaphosphate solution (Day, 1965). Samples for particle size analysis were taken from the 0 - 30 cm depth. This method was used because it allows for the non-destructive sampling of suspensions undergoing settling and also, provides for multiple measurements on the same suspension so that detailed particle-size distribution can be obtained with minimum effort. 51 g of air-dried soil from each plot were weighed into milk-shake cup bottles. 10 ml of 5 % Calgon (Sodium hexametaphosphate) alongside with 100 ml of distilled water were added to the soil. The Calgon served as a dispersing agent for the soil particles. The mixture was shaken with a mechanical shaker for 20 minutes and the content was poured into a 1000 ml measuring cylinder, the milk-shaped bottle cap was rinsed with distilled water and added to the content to reach the 1000 ml mark. The cylinder with the content was shaken to distribute the particles equally throughout the suspension and first hydrometer and temperature readings were taking after 40 seconds. The suspension was left to stand for three (3) hours to allow the soil particles to settle. Hydrometer and temperature readings were taken after three hours and the percent fractions of each soil component was calculated as follows:

$$\% \, Sand = 100 - [H_1 + 0.2\,(T_1 - 20) - 2] \quad \times 2; \tag{3.3}$$

$$\% \, Clay = H_2 + [0.2(T_2 - 20) - 2] \times 2; \tag{3.4}$$

$$\% \, Silt = 100 - (\% \, Sand - \% \, Clay); \tag{3.5}$$

Where, ***$H_1$*** is the first hydrometer reading after 40 seconds; ***$H_2$*** is the second hydrometer reading after three hours, ***$T_1$*** is the first temperature reading after 40 seconds and ***$T_2$*** is the second temperature reading after three hours. The textural class was determined using the textural triangle.

#### 3.2.8.7 Soil Bulk Density

Bulk density was determined for 0-15 cm depth which is within the zone of active root activity for most food crops grown on the plots. The core method was used (Blake, 1965). The core sampler was driven into the soil to the desired depth of 0 - 15cm. It was then carefully removed to preserve a known volume of soil as it existed in situ. The sample was dried at 105 °C for 24 hours in an oven. The volume of the core sampler was measured and the weight of sample determined before and after drying. The bulk density was then calculated from the formula:

$$\text{Bulk Density} = \frac{\text{Oven dry mass of soil}}{\text{Volume of sample}} \quad (\text{gcm}^{-3}) \qquad (3.6)$$

Four bulk density determinations were made for each treatment and their respective mean values were calculated. Sample calculation is shown in the Appendix B.

### 3.2.9 Heavy metals analysis

#### 3.2.9.1 Soil sample collection and preparation

The soil samples were picked at 0 – 15 cm and 15 – 30 cm depths with a soil auger from Mampong - Kyeremfaso dumpsite, Mampong - UEW forest background soil, Kumasi - Suame magazine dumpsite, Kumasi - Meduma background soil, Kumasi - Ayeduase dumpsite and Kumasi - KNUST botanical gardens background soil. The soils collected were thoroughly mixed for a uniform mixture from all the study sites. The samples collected were placed in 15 cm x 15 cm zip lock bags for detailed analysis.

A total of 120 soil samples were picked from the six dumpsites and three background soils at 0 - 15 cm and 15 - 30 cm soil depths, respectively between February and March, 2019 in the dry season. Systematic sampling technique was used to locate the soil sampling spots at 5 m distance between each spot around each of the dumpsite and background soils. The soil samples were crushed in porcelain mortar, thoroughly mixed and passed through 2 mm mesh sieve and placed in about 15 cm x 15 cm zip lock bags for detailed analysis. The soil samples were further prepared by weighing 0.5 g of soil samples into a porcelain crucible and ignited at 45 ºC in furnace to destroy organic matter, then digested twice with 10 ml of a mixture of 1:1 mixture of concentrated $HNO_3$ and HF IN A 100 ml polypyrene beaker and placed over a water bath for evaporation till dryness. The residue was dissolved in 20 ml of 2 M $HNO_3$ and diluted to the mark in 100 ml volumetric flask. This was done at the Chemistry Research laboratory of the KNUST, Ghana.

Heavy metals concentration in soils was determined using X-Ray Fluorescence spectroscopy (XRF) system where Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb were quantified: The results were expressed as milligrams per kilogram ($mgkg^{-1}$) of the dry matter in soils sampled from all the sites according to standards of US - EPA (2007).

#### 3.2.9.2 Plant sample preparation

Sampled plantain and cocoyam leaves and fruits from three dumpsites and three control sites in experiment two were washed with deionized water and oven dried at 50 ºC for 24 hours and ashed at 450 ºC before bagging into a zip lock bags for XRF and AAS heavy metal analysis. Similar work was done on all plant leaves and fruits sampled from background sites approximately about 2 km away from dumpsites in order to serve as the basis of comparison from non-polluted source (Sekara *et al.,* 2005) in studies two and three.

### 3.2.9.3 Laboratory analytical studies

Heavy metal concentration determination was carried out using X-ray fluorescence spectroscopy (XRF) system where Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb were quantified: The results were expressed as milligrams per kilogram (mgkg$^{-1}$) of dry matter in soils and plants sampled from all the sites. The soil metals and routine characteristic was carried out at both KNUST SHEATH chemistry department laboratory and the CSIR chemistry laboratory, Kwadaso, Kumasi.

### 3.2.9.4 Soil and Plant laboratory analysis for study two

#### 3.2.9.4.1 XRF Analyses

Heavy metals in soils and plants samples process begins with drying of plantain leaves and fruits, cocoyam leaves and corms samples in study two. Individual plants sampled were ground into powdered form and sieved with 0.002 mm sieve. Samples were examined using a Niton XL3t GOLD field portable X-ray fluorescence (FP-XRF) spectrometer following the United States Environmental Protection Agency Method 6200 protocols (US - EPA, 2007; Darko *et al.,* 2020). A portion of the sieved sample was placed in a small (~ 30 mm) polyethylene container with a propylene film so that it was three-quarters full. It was then placed in the instrument shroud and scanned for 180 seconds (Rweyemamu *et al.*, 2020). Average recoveries obtained by running 3 reference materials (NIST 2709a) were always ≥ 75 ± 5 %. Reproducibility tests conducted by analyzing 9 replicate samples generated average relative percent difference of 21% for As, 11% for Cr, 7.5% for Cu, 9.2% for Ni, 13% for Pb, and 7.7% for Zn indicating satisfactory reproducibility. Typically, the FP-XRF gives results of 24 elements but Cr, Fe, Ni, Cu, Zn, As, Cd, Hg, Pb were the toxicologically important ones used in this study. The method detection limits varied widely between the metals. Optimization of the XRF to generate useable data was also conducted in the study (Davidson, 2013).

### 3.3 Data analysis

The soils, plantain and cocoyam data generated were analysed with GENSTAT (Version 16) Analytical Software, (2016). Data were subjected to analysis of variance (ANOVA) and Fisher's Least Square Difference (LSD) was used to separate the treatment means at 5% ($p < 0.05$) probability level.

### 3.4 Study Three (Field Experiment) - Evaluation of heavy metals contamination in dumpsite soils and accumulation in selected plants under field conditions

#### 3.4.1 Locations

Study Three was conducted on a field in a pot experiment with soil sampled at 0 - 30 cm of depth from the six locations (Mampong - Kyeremfaso dumpsite, Mampong - UEW forest background soil, Kumasi - Suame magazine dumpsite, Kumasi - Meduma background soil, Kumasi - Ayeduase dumpsite soil, Kumasi - KNUST botanical gardens background soil). Lettuce seedlings were planted in pots filled with the sampled soils under field conditions at the Multi - purpose nursery site of the College of Agriculture Education, University of Education Winneba, Mampong - Ashanti Campus (Lat. 7° 08' N, Long. 1° 24' W) located in the forest - Savanna transition zone of Ghana. The site has an altitude of 457.5 m above sea level.

### 3.4.2 Experimental Design and Treatments

A Randomized Complete Block Design (RCBD) with six (6) treatments and three replications was used. The treatments were made up of the soils from the six locations: - (i) Mampong - Kyeremfaso dumpsite soil, (ii) Mampong - UEW forest background soil, (iii) Kumasi - Suame magazine dumpsite soil, (iv) Kumasi - Meduma background soil, (v) Kumasi - Ayeduase dumpsite soil and (vi) Kumasi - KNUST botanical gardens background soil.

### 3.4.3 Management / Cultural Practices

Lettuce variety 'Eden' (65 – day early maturing variety) seeds were procured from a certified agrochemical seller (Kyeiwaa Agrochemical) at Mampong Ashanti. The seeds were nursed under best nursery conditions for three weeks before transplanted onto 30 kg capacity experimental trays each measuring 0.5 m x 0.5 m x 0.1 m filled with soils sampled from the six study sites. Lettuce seedlings were transplanted on to their experimental pots at 20 cm x 15 cm planting distance. Samples of the soil were taken in triplicates at day of experiment and at harvest (6 weeks) for laboratory physical and chemical analytical studies.

### 3.4.4 Soil samples collected and analysis

The soils sampled in triplicates at a depth of 0 – 30 cm from the six location sites were analysed for a routine soil physichochemical properties at the laboratories of UEW, Mampong campus general laboratory, CSIR - Soil Research Institute, at Kwadaso Chemistry laboratory and KNUST SHEATH Chemistry laboratory. The soil samples were air - dried, ground and passed through a 2 - mm mesh sieve and kept in zip lock bags before analysis.

### 3.4.5 Plant sample collected and analysis

Lettuce leaves and roots in pots at harvest were sampled and washed in deionized water, dried and ground for laboratory analytical studies. Refer to Study Two for details.

### 3.4.6 Data analysis

Soils, lettuce leaves and roots data generated were analysed with a GENSTAT (Version 16) Analytical Software, (2016). Data were subjected to analysis of variance (ANOVA) and Fisher's Least Square Difference (LSD) was used to separate the treatment means at 5% ($p < 0.05$) probability level.

## 3.5 Techniques to evaluate the pollution of soils by heavy metal

In order to quantitatively check and describe the concentration trend of metals in the soils and plants studied, the following indexes were used to assess the pollution of heavy metals in dumpsite soils and plants in Studies Two and Three: - Geoaccumulation index (I-geo), enrichment factor (EF), relative top soil enrichment factor (RTEF), transfer ratio (TR) and translocation factor (TF).

### 3.5.1 Geoaccumulation index (Igeo)

This model was employed to quantify the degree of pollution in the refuse dump soils. The geoaccumulation index was calculated as:

$I_{geo} = \text{In}\ (C_n / 1.5 \text{ x } B_n)$ (3.7)

Where $C_n$ – measured concentration of metal in the refuse dump soil ($mgkg^{-1}$);

$B_n$ – background value of heavy metal ($mgkg^{-1}$); and 1.5 - background matrix correction factor

(Förstener *et al.,* 1993; Sutherland, 2000; Agyarko *et al.,* 2010).

### 3.5.2 Enrichment factor (EF)

The enrichment factor (EF) was calculated as;

$$EF = \frac{C_n \text{ (sample)} / C_{ref} \text{ (sample)}}{B_n \text{ (background)} / B_{ref} \text{ (background)}} \qquad (3.8)$$

Where $C_n$ - is the content of the examined element in the examined environment (dumpsite soil)

$C_{ref}$ - is the content of the examined element in the reference environment (background soil)

$B_n$ - is the content of the reference element in the examined environment (dumpsite soil)

$B_{ref}$ - is the content of the reference element in the reference environment (background soil)

(Buat - Menard and Chesselet, 1979; Agyarko *et al.,* 2014).

### 3.5.3 Relative top soil enrichment factor (RTEF)

A relative top soil enrichment factor can be calculated from this relation;

RTEF = Total metal contents at 0 - 15 cm depth /

Total metal content at 15 - 30 cm depth (3.9)

(Colbourn and Thornton, 1978).

### 3.5.4 Transfer ratio (TR)

All the metals in the different samples were quantified using the transfer ratio (TR):

Transfer Ratio (TR) = $C_{\text{plant}} / C_{\text{Soil}}$ (3.10)

Where; $C_{\text{plant}}$ – is the concentration of a specific metal in the plant (mgkg$^{-1}$);

$C_{\text{soil}}$ – is the concentration of that metal in the soil (Hasan *et al.,* 2003)

### 3.5.5 Translocation Factor (TF)

The translocation of metals from one part of a vegetable (crop / plant) to another part of the plant is a function of root shoot transport, which can be expressed as the translocation factor (TF) : - TF = $C_{\text{shoot}} / C_{\text{root}}$ (3.11)

Where, $C_{\text{shoot}}$ is the concentration of the metal in the above ground portion of the vegetable (crop); $C_{\text{root}}$ is the metal concentration in the below ground portion (Gosh and Singh, 2005).

# CHAPTER FOUR

# 4.0 RESULTS

## 4.1 Study 1: - Farmers' Awareness of soil physicochemical Properties

### 4.1.1 Socio - demographic characteristics of dumpsite farmers in the three communities

Out of the total farmers (100) interviewed at all the three communities, majority 75% were males and 25 % were females (Table 4.1). Farmers age groups showed that, majority (79 %) of them were aged between 36 - 45 years followed by a 26 - 35 years (18 %). Farmers between 46 - 55 years were few (2 %), and only one percent (1 %) below 25 years. Majority of farmers (52 %) were married, 38 % being single, two percent (2 %) were divorced, widowed (6 %) and co - habitation (2 %) in that order. Only four percent (4 %) had not received formal school education, eight percent (8 %) have had education up to the tertiary level and 19 % have had primary education, 31 % have had senior high school education with the majority (38 %) of farmers with a middle / junior high school education (Table 4.1).

**Table 4.1 Socio-demographic characteristics of dumpsite farmers in three communities**

| Farmers demographic characteristics | Number of Respondents | | | | |
|---|---|---|---|---|---|
| | Kyeremfaso community | Suame community | Ayeduase community | Frequency | Percentage (%) |
| Gender | | | | | |
| Male | 35 | 24 | 16 | 75 | 75 |
| Female | 15 | 6 | 4 | 25 | 25 |
| **Total** | **50** | **30** | **20** | **100** | **100** |
| Age (years) | | | | | |
| < 25 | 0 | 1 | 0 | 1 | 1 |
| 26 – 35 | 6 | 7 | 5 | 18 | 18 |
| 36 – 45 | 42 | 22 | 15 | 79 | 79 |
| 46 – 55 | 2 | 0 | 0 | 2 | 2 |
| **Total** | **50** | **30** | **20** | **100** | **100** |
| Marital status | | | | | |
| Married | 35 | 10 | 7 | 7 | 52 |
| Single | 10 | 18 | 10 | 10 | 38 |
| Divorced | 0 | 1 | 1 | 1 | 2 |
| Widowed | 5 | 0 | 1 | 1 | 6 |
| Co-habitation | 0 | 1 | 1 | 1 | 2 |
| **Total** | **50** | **30** | **20** | **100** | **100** |
| Level of education | | | | | |
| No formal education | 2 | 2 | 0 | 4 | 4 |
| Primary | 10 | 5 | 4 | 19 | 19 |
| Middle/JHS | 30 | 5 | 3 | 38 | 38 |
| SHS | 8 | 18 | 5 | 31 | 31 |
| Tertiary | 0 | 0 | 8 | 8 | 8 |
| **Total** | **50** | **30** | **20** | **100** | **100** |

### 4.1.2 Reasons for farming on dumpsites

Majority (63 %) of the farmers interviewed at Kyeremfao Mampong, Suame Kumasi and Ayeduase Kumasi showed that, the fertility level of dumpsite soils informed their decision to farm on them. Others 20 % indicated that, dumpsites were the only available land they could access. While 17 % indicated that, dumpsite farmlands are given at cheap cost and that attracted them to grow their crops (Table 4.2).

**Table 4.2 Farmers reason for farming on dumpsites**

| Responses | Number of Respondents | | | Frequency | Percentage (%) |
|---|---|---|---|---|---|
| | Kyeremfaso community | Suame community | Ayeduase community | | |
| Fertile soil | 40 | 13 | 10 | 63 | 63 |
| Only available land | 5 | 9 | 6 | 20 | 20 |
| Cheap cost of land | 5 | 8 | 4 | 17 | 17 |
| Total | 50 | 30 | 20 | 100 | 100 |

### 4.1.3 Farmers awareness of the physicochemical properties of dumpsite soils

Majority (81 %) of farmers were aware of their dumpsites soils' physicochemical properties while 19 % responded otherwise that they were not aware of their soils' physicochemical properties (Figure 4.1). Farmers interviewed from the three communities used specific features to describe their soils' physicochemical properties. Majority (66%) of the farmers described their soil as a high nutrient content soil with only six percent (6 %) describing the soil as a low nutrient content. Twenty eight percent (28 %) of thefarmers indicated their soils had traces of heavy metals in them (Table 4.3).

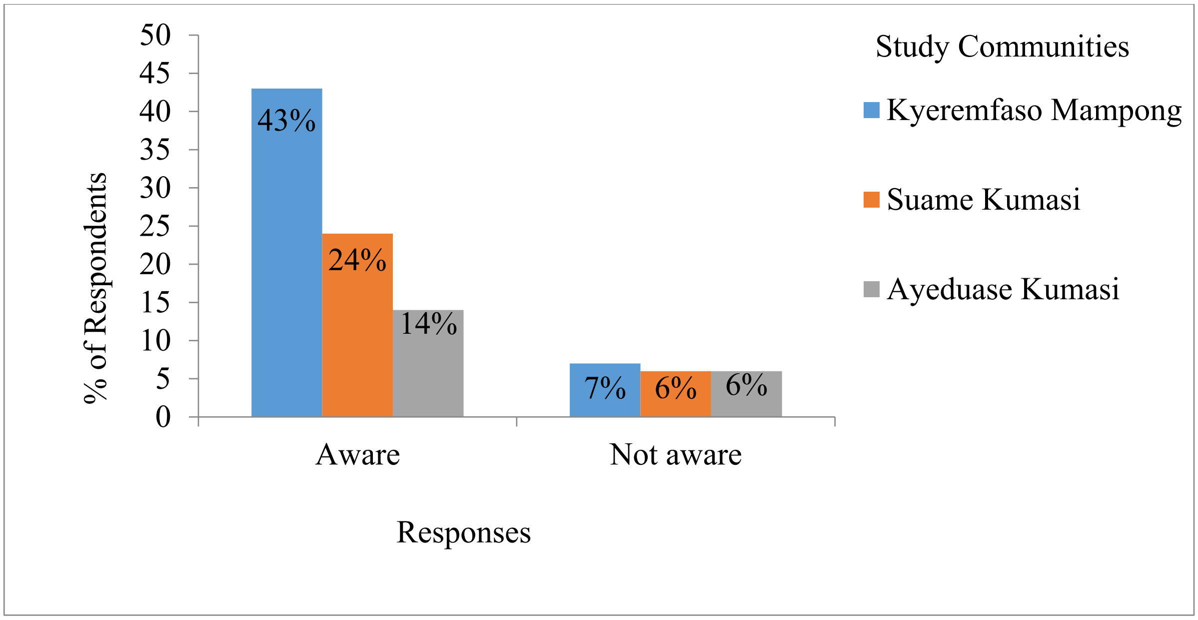

**Figure 4.1 Farmers awareness of their soils' physicochemical properties**

**Table 4.3 Farmers responses to specific features used for describing dumpsite soils in three communities**

| Indicators | Number of Respondents<br>Kyeremfaso community | Suame community | Ayeduase community | Frequency | Percentage (%) |
|---|---|---|---|---|---|
| High soil nutrient content | 43 | 11 | 12 | 66 | 66 |
| Low soil nutrient content | 3 | 2 | 1 | 6 | 6 |
| Heavy metals present | 4 | 17 | 7 | 28 | 28 |
| Total | 50 | 30 | 20 | 100 | 100 |

### 4.1.3.1 Sources of knowledge acquisition on soil physicochemical properties by dumpsite farmers

Farmers were interviewed about their knowledge on dumpsites soil's physicochemical properties. Majority (40%) of farmers reported they got their knowledge from other colleague farmers, 30 % from extension officers, 16 % from the media and 14 % indicated that they got their knowledge from non - governmental organizations (NGO) (Table 4.4).

**Table 4.4 Sources of knowledge acquisition on soil physicochemical properties**

| Sources of knowledge acquisition | Number of Respondents | | | | |
|---|---|---|---|---|---|
| | Kyeremfaso community | Suame community | Ayeduase community | Frequency | Percentage (%) |
| Extension officer | 21 | 4 | 5 | 30 | 30 |
| NGO | 6 | 4 | 4 | 14 | 14 |
| Media | 9 | 6 | 1 | 16 | 16 |
| Other farmers | 14 | 16 | 10 | 40 | 40 |
| Total | 50 | 30 | 20 | 100 | 100 |

### 4.1.4 Farmers awareness of the effects of soil metals contamination on human and animal health

A total number of hundred (100) farmers were interviewed and out of that, ninety four percent (94%) were aware that soil metal elements contamination affects human and animal health. Only six percent (6%) were not aware or had any knowledge of any health effect of soil metal contamination on human and animal health (Table 4.5).

**Table 4.5 Farmers awareness about the effect of soil metals contamination on human and animal health**

| Responses | Number of Respondents<br>Kyeremfaso | Suame | Ayeduase | Frequency | Percentage (%) |
|---|---|---|---|---|---|
| Aware | 47 | 29 | 19 | 94 | 94 |
| Not aware | 3 | 1 | 1 | 6 | 6 |
| Total | 50 | 30 | 20 | 100 | 100 |

On perceived ailments that commonly affect man as a result of soil metals contamination, majority (37 %) mentioned skin rashes, 26 % mentioned cough, 24 % indicated diarrhea and (13 %) cited cholera (Table 4.6).

**Table 4.6 Responses by farmers on perceived ailments that commonly affect man as a result of soil toxic elements contamination**

| Responses | Number of Respondents<br>Kyeremfaso | Suame | Ayeduase | Frequency | Percentage (%) |
|---|---|---|---|---|---|
| Cholera | 8 | 3 | 2 | 13 | 13 |
| Diarrhea | 15 | 4 | 5 | 24 | 24 |
| Cough | 13 | 9 | 4 | 26 | 26 |
| Skin rashes | 14 | 14 | 9 | 37 | 37 |
| Total | 50 | 30 | 20 | 100 | 100 |

### 4.1.5 Chi - square ($\chi^2$) test analysis on association between dumpsites farmers' soil physicochemical knowledge and other selected variables

The Chi - square ($\chi^2$) test studies showed that dumpsites farmers' soil physicochemical knowledg and other variables like dumpsites farmers' educational level ($\chi^2 = 1.83$) showed no significant ($p = 0.21$) relationship, dumpsites farmers' soil physicochemical knowledge relationship with dumpsites farmers' reasons for farming on dumpsites ($\chi^2 = 1.21$) was also not significant ($p = 0.55$), dumpsites farmers' soil physicochemical knowledge association with sources of dumpsites farmers' soil physicochemical knowledge ($\chi^2 = 6.38$) showed no significant ($p = 0.17$), dumpsites farmers' soil physicochemical knowledge association with an awareness that dumpsite soils contain toxic elements ($\chi^2 = 8.24$) were significant ($p = 0.02$). Similarly, dumpsites farmers' soil physicochemical knowledge association with an awareness that plants on dumpsites absorb toxic elements (($\chi^2 = 10.97$) showed a significant ($p = 0.03$) relationship (Table 4.7).

**Table 4.7 Chi - square ($\chi^2$) test analysis on association between dumpsites farmers' soil physicochemical knowledge and selected variables**

| Variables | $\chi^2$ – value | P - value | Significance |
|---|---|---|---|
| Farmers educational level | 1.83 | 0.21 | Not significant |
| Farmers' reasons for farming on dumpsites | 1.21 | 0.55 | Not significant |
| Sources of dumpsites farmers' soil physicochemical knowledge | 6.38 | 0.17 | Not significant |
| Awareness that dumpsites soil contain toxic elements | 8.24 | 0.02 | Significant |
| Awareness that plants on dumpsites absorb toxic elements | 10.97 | 0.03 | Significant |

## 4.2 Study 2: – Assessment of heavy metals level in selected soils and their accumulation levels in plantain and cocoyam.

### 4.2.1 Soil physicochemical properties of soils

The soil physicochemical analytical studies conducted showed that Mampong Kyeremfaso dumpsite soil (KYE) and a Mampong UEW background soil (UEW) have a sand texture. Kumasi Suame dumpsite soil (SUA) has a sand texture, while Kumasi Meduma background soil (MED) was sandy clay loam in texure. Both Kumasi Ayeduas dumpsite soil (AYE) and Kumasi KNUST botanical gardens background soil (KNUST) showed loamy sand texture. There was no significant difference between soil bulk densities of KYE (1.54 $gcm^{-3}$) and UEW (1.58 $gcm^{-3}$), SUA (1.12 $gcm^{-3}$) and MED (1.61 $gcm^{-3}$), AYE (1.59 $gcm^{-3}$), KNUST (1.41 $gcm^{-3}$) (Tables 4.8).

The soil pH value which was higest in KYE (9.04) and lowest in KNUST (6.07) was significantly different ($p = 0.01$) among the sites. Total organic carbon (TOC) was highest in SUA (10.83 %) followed by MED (2.08%), but lowest in AYE (1.56 %). TOC values were significantly different ($p = 0.01$). Total organic matter (TOM) showed a similar trend with highst value in SUA (18.69%) and lowest in AYE (2.69 %). The TOC values were significantly different ($p = 0.01$). Total N was higher in AYE (0.30%) but lowest in KNUST (0.15%). The Toatl N values were generally not significantly different ($p = 0.51$) (Table 4.8) from each other. Available P was highest in KYE (790.43 $mgkg^{-1}$) and lowest in AYE (3.08 $mgkg^{-1}$). The available P values recorded were generally significantly different ($p = 0.02$) (Table 4.8).

Exchangeable cation was high especially Ca in KYE (12.99 meq100g$^{-1}$) than in UEW (5.33 meq100g$^{-1}$), SUA (59.64 meq100g$^{-1}$) in MED Kumasi background soil (13.63 meq100g$^{-1}$) and lower in AYE (2.56 meq100g$^{-1}$) than in KNUST (35.15 meq100g$^{-1}$) with a generally significant difference (p = 0.01). A similar trend was observed for Mg, K and Na (Table 4.8). Exchangeable acidity was higher in KNUST (1.20 meq100g$^{-1}$) and lower in both KYE (0.02 meq100g$^{-1}$) and AYE (0.02 meq100g$^{-1}$) with a significant difference (p = 0.03). CEC was high in SUA (39.34 meq100g$^{-1}$) and lower in AYE (7.38 meq100g$^{-1}$). ECEC was higher in SUA (111.75 meq100g$^{-1}$) and lower in AYE (4.23 meq100g$^{-1}$) with a significant difference (p = 0.01). Base Saturation was higher in SUA (99.91 %) and lower in UEW (96.73 %) (Table 4.8).

**Table 4.8 Soil physicochemical properties of the soil samples used for the study**

| | | | | | | | | Exchangeable cations | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Texture | B.D ($gcm^{-3}$) | pH | T.O.C | T.O.M | Total N | Available P | Ca | Mg | K | Na | Exchangeable acidity | CEC | ECEC | Base saturation |
| | | | | | (%) | | ($mgkg^{-1}$) | | | | | ($meq100g^{-1}$) | | | (%) |
| KYE | Sand | 1.54 | 9.04 | 1.91 | 3.29 | 0.16 | 790.43 | 12.99 | 3.83 | 0.85 | 2.57 | 0.02 | 8.58 | 20.26 | 99.90 |
| UEW | Sand | 1.58 | 6.10 | 1.73 | 2.98 | 0.17 | 17.77 | 5.33 | 1.49 | 0.32 | 0.26 | 0.25 | 8.96 | 7.65 | 96.73 |
| SUA | Sand | 1.12 | 6.67 | 10.83 | 18.69 | 0.21 | 73.58 | 59.64 | 44.73 | 405 | 3.22 | 0.10 | 39.34 | 111.75 | 99.91 |
| MED | Sand Clay Loam | 1.61 | 7.95 | 2.08 | 3.59 | 0.17 | 118.45 | 13.63 | 1.49 | 0.45 | 1.01 | 0.05 | 18.18 | 16.63 | 99.10 |
| AYE | Loamy Sand | 1.59 | 8.40 | 1.56 | 2.69 | 0.30 | 3.08 | 2.56 | 0.85 | 0.35 | 0.46 | 0.02 | 7.38 | 4.23 | 97.49 |
| KNUST | Loamy Sand | 1.41 | 6.07 | 1.65 | 2.84 | 0.15 | 218.68 | 35.15 | 4.69 | 3.97 | 2.74 | 1.20 | 7.68 | 47.74 | 97.49 |
| P - value | | 0.88 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.03 |
| LSD (0.05) | | 0.99 | 1.51 | 1.88 | 0.99 | 0.02 | 21.70 | 1.37 | 1.35 | 1.51 | 1.79 | 0.75 | 1.29 | 1.59 | 1.51 |
| CV (%) | | 0.45 | 11.30 | 31.40 | 9.60 | 5.80 | 12.28 | 3.50 | 7.80 | 0.64 | 0.75 | 0.79 | 4.70 | 2.50 | 0.80 |

*Location: KYE - Kyeremfaso Mampong dumpsite soil; UEW - Mampong background soil; SUA - Suame Kumasi dumpsite soil; MED - Meduma Kumasi background soil; AYE - Ayeduase Kumasi dumpsite soil; KNUST - KNUST Kumasi botanical gardens background soil.*

### 4.2.2 Heavy metals level in selected dumpsites soil at different depths

Concentration levels of metals from soils sampled from the dumpsite and background (Figures 3.3, 3.4 and 3.5) showed significant variation between each of the dumpsites and their background soils. Chromium (Cr) levels in KYE (54.10 mgkg$^{-1}$) was higher than in UEW (49.61 mgkg$^{-1}$) at 0 - 15 cm depth (Table 4.9). Similarly Cr in KYE (87.04 mgkg$^{-1}$) dumpsite soil recorded a higher value than in UEW (71.79 mgkg$^{-1}$) at 15 - 30 cm depth (Table 4.10). Cr levels was highest in SUA (76.76 mgkg$^{-1}$) than in MED (3.25 mgkg$^{-1}$) at 0 - 15 cm depth recorded a similar higher value in SUA (109.69 mgkg$^{-1}$) than in MED (80.48 mgkg$^{-1}$) at 15 - 30cm depth of soil sampled. Cr values in AYE (67.31 mgkg$^{-1}$) was higher than in KNUST (63.19 mgkg$^{-1}$) at 0 - 15cm depth (Table 4.9). At depth 15 - 30cm Cr in AYE (64.35 mgkg$^{-1}$) recorded a higher value than in KNUST (61.32 mgkg$^{-1}$). Generally, Cr values in dumpsite soils recorded higher values than in their background soils at a high significant difference ($p = 0.01$) (Tables 4.9 and 4.10).

Iron (Fe) levels in KYE (10071.78 mgkg$^{-1}$) were higher than in UEW (9661.97 mgkg$^{-1}$) at 0 - 15 cm depth (Table 4.9). At 15 - 30 cm depth, Fe present had similar higher levels in KYE (11844.00 mgkg$^{-1}$) than in UEW (7438.00 mgkg$^{-1}$) (Table 4.10). . Fe at 0 - 15 cm of soil depth was highest in SUA (16548.10 mgkg$^{-1}$) than in MED (13363.69 mgkg$^{-1}$) (Table 4.9). At 15 - 30 cm soil depth, Fe concentration levels was higher in SUA (19914.00 mgkg$^{-1}$) than in MED (13980.00 mgkg$^{-1}$) (Table 4.10). Fe levels was higher in AYE (12705.49 mgkg$^{-1}$) than in KNUST (9846.76 mgkg$^{-1}$) at 0 - 15 cm depth. A similar higher results was found in AYE (9163.00 mgkg$^{-1}$) than in KNUST (8329.00 mgkg$^{-1}$) at 15 - 30 cm depth. Highly significant (p = 0.01) differences was found between all the dumpsites and their background soils and at both depths that were sampled for this study (Tables 4.9 and 2.10).

Nickel (Ni) levels was higher in KYE (16.41 mgkg$^{-1}$) than in UEW (16.29 mgkg$^{-1}$) at 0 - 15cm depth, and also higher in KYE (16.98 mgkg$^{-1}$) than in UEW (16.27 mgkg$^{-1}$) at 15 - 30 cm depth. Ni levels was higher in SUA (113.08 mgkg$^{-1}$) than in MED (17.43 mgkg$^{-1}$) at 0 - 15 cm depth while at 15 - 30 cm depth, Ni was higher in SUA (222.17 mgkg$^{-1}$) than in MED (16.80 mgkg$^{-1}$). At 0 - 15 cm depth, Ni was similarly higher in AYE (17.48 mgkg$^{-1}$) than in KNUST (16.81 mgkg$^{-1}$). At 15 - 30 cm depth, Ni was higher in AYE (16.83 mgkg$^{-1}$) than in KNUST (16.03 mgkg$^{-1}$). There was a highly significant (p = 0.01) difference between all the soils sampled at 0 - 15 cm depth, but no significant (p = 0.08) difference between all soils sampled at 15 - 30 cm depth (Tables 4.9 and 4.10).

Copper (Cu) concentration at 0 - 15 cm depth was higher in KYE (12.31 mgkg$^{-1}$) than in UEW (9.55 mgkg$^{-1}$). Cu concentration at 15 - 30 cm depth was similarly higher in KYE (12.31 mgkg$^{-1}$) than in UEW (10.41 mgkg$^{-1}$). Cu concentration at 0 - 15cm depth was higher in SUA (454.56 mgkg$^{-1}$) than in MED (12.43 mgkg$^{-1}$). Cu concentration at 15 - 30 cm depth was similarly higher in SUA (674.19.56 mgkg$^{-1}$) than in MED (11.81 mgkg$^{-1}$). Cu concentration at 0 - 15 cm depth was higher in AYE (52.24 mgkg$^{-1}$) than in KNUST (9.64 mgkg$^{-1}$). Cu concentration at 15 - 30 cm depth was similarly higher in AYE (63.52 mgkg$^{-1}$) than in KNUST (9.38 mgkg$^{-1}$). At both 0 - 15 cm and 15 - 30 cm soil sampled depths, there was a highly significant (p = 0.01) differences between all the sampled soils (Tables 4.9 and 4.10).

Zinc (Zn) concentration levels at soil depth 0 - 15 cm was higher in KYE (133.30 mgkg$^{-1}$) than in UEW (26.77 mgkg$^{-1}$) soil. At soil depth 15 - 30 cm, Zn concentration level was higher in KYE (108.02 mgkg$^{-1}$) than in UEW (31.23 mgkg$^{-1}$). Zn concentration levels at soil depth 0 - 15 cm was higher in SUA (674.19 mgkg$^{-1}$) than in MED (56.38 mgkg$^{-1}$). At soil depth 15 - 30 cm, Zn concentration level was higher in SUA (4749.72 mgkg$^{-1}$) than in MED (47.48 mgkg$^{-1}$). Zn concentration levels at soil depth 0 - 15 cm was higher in AYE (314.26 mgkg$^{-1}$) than in KNUST (30.47 mgkg$^{-1}$). At soil depth 15 - 30 cm, Zn concentration level was higher in AYE (377.51 mgkg$^{-1}$) than in KNUST (24.91 mgkg$^{-1}$) (Tables 4.9 and 4.10).

Arsenic (As) levels at soil depth 0 - 15 cm was higher in KYE (5.12 mgkg$^{-1}$) than in UEW (4.91 mgkg$^{-1}$). At soil depth 15 - 30 cm, As was similarly higher in KYE (5.21 mgkg$^{-1}$) than in UEW (4.43 mgkg$^{-1}$). As was higher in SUA (7.33 mgkg$^{-1}$) than in MED (7.31 mgkg$^{-1}$) at 0 - 15 cm depth. At soil depth 15 - 30 cm, As was higher in SUA (8.88 mgkg$^{-1}$) than in MED (5.49 mgkg$^{-1}$). At 0 - 15 cm of soil depth, As was higher in AYE (5.56 mgkg$^{-1}$) than in KNUST (5.50 mgkg$^{-1}$). At soil depth 15 - 30 cm, As was higher in AYE (6.78 mgkg$^{-1}$) than in KNUST (5.59 mgkg$^{-1}$). At both depths of soil sampled, a highly significant ($p = 0.01$) defferences was reported with As levels in sampled soils (Tables 4.9 and 4.10).

Cadmium (Cd) levels at soil depth 0-15 cm was higher in KYE (14.41 mgkg$^{-1}$) than in UEW (12.41 mgkg$^{-1}$). At soil depth 15 - 30 cm, Cd was similarly higher in KYE (17.35 mgkg$^{-1}$) than in UEW (16.36 mgkg$^{-1}$). Cd was higher in SUA (6.57 mgkg$^{-1}$) than in MED (6.19 mgkg$^{-1}$) at 0 - 15 cm depth. At soil depth 15 - 30 cm, Cd was higher in SUA (9.04 mgkg$^{-1}$) than in MED (7.61 mgkg$^{-1}$). At 0 - 15 cm of soil depth, Cd was similarly higher in AYE

(17.30 mgkg$^{-1}$) than in KNUST (6.74 mgkg$^{-1}$). At soil depth 15 - 30 cm, Cd was higher in AYE (20.85 mgkg$^{-1}$) than in KNUST (12.45 mgkg$^{-1}$). At 0 - 15 cm depth, a highly significant (p = 0.01) defferences was reported between Cd levels in sampled soils but no significant (p = 0.26) differences occurred at 15 - 30 cm depth with Cd levels in all the selected soils sampled (Tables 4.9 and 4.10).

Mercury (Hg) levels at soil depth 0 - 15 cm was higher in KYE (4.94 mgkg$^{-1}$) than in UEW (4.90 mgkg$^{-1}$). At soil depth 15 - 30 cm, Hg was similarly higher in KYE (5.24 mgkg$^{-1}$) than in UEW (5.04 mgkg$^{-1}$). Hg was higher in SUA (13.47 mgkg$^{-1}$) than in MED (5.20 mgkg$^{-1}$) at 0 - 15 cm depth. At soil depth 15 - 30 cm, Hg was still higher in SUA (16.31 mgkg$^{-1}$) than in MED (5.10 mgkg$^{-1}$). At 0 - 15 cm of soil depth, Hg was higher in AYE (5.56 mgkg$^{-1}$) than in KNUST (5.12 mgkg$^{-1}$). At soil depth 15 - 30 cm, Hg was higher in AYE (6.48 mgkg$^{-1}$) than in KNUST (5.31 mgkg$^{-1}$). At both depths of soil sampled, a highly significant (p = 0.01) defferences was reported with Hg levels in sampled soils (Tables 4.9 and 4.10).

Lead (Pb) levels at soil depth 0 - 15 cm was higher in KYE (3.61 mgkg$^{-1}$) than in UEW (3.51 mgkg$^{-1}$). At soil depth 15 - 30 cm, Pb was similarly higher in KYE (4.06 mgkg$^{-1}$) than in UEW (3.87 mgkg$^{-1}$). Pb was higher in SUA (3.77 mgkg$^{-1}$) than in MED (1.03 mgkg$^{-1}$) at 0 - 15 cm depth. At soil depth 15 - 30 cm, Pb was higher in SUA (133.58 mgkg$^{-1}$) than in MED (3.75 mgkg$^{-1}$). At 0 - 15 cm of soil depth, Pb was higher in AYE (3.99 mgkg$^{-1}$) than in KNUST (1.07 mgkg$^{-1}$). At soil depth 15 - 30 cm, Pb was higher in AYE (109.12 mgkg$^{-1}$) than in KNUST (14.37 mgkg$^{-1}$). At both depths of soil sampled, a highly significant (p = 0.01) differences was reported with Hg levels in sampled soils (Tables 4.9 and 4.10).

**Table 4.9 Total soil metal level at 0 -15 cm from soils of the six locations of the study**

| | Metal level (mgkg$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | 0 - 15 | 0 - 15 | 0 - 15 | 0 - 15 | 0 - 15 | 0 - 15 | 0 - 15 | 0 - 15 | 0 - 15 |
| KYE | 54.10 | 10071.78 | 16.41 | 10.33 | 133.30 | 5.12 | 14.41 | 4.90 | 3.61 |
| UEW | 49.61 | 9661.97 | 16.29 | 9.55 | 26.77 | 4.91 | 12.41 | 4.94 | 3.51 |
| SUA | 76.76 | 16548.10 | 113.08 | 454.56 | 674.19 | 7.33 | 6.57 | 13.47 | 3.77 |
| MED | 3.25 | 13363.69 | 17.43 | 12.43 | 56.38 | 7.31 | 6.19 | 5.20 | 1.03 |
| AYE | 67.31 | 12705.49 | 17.48 | 52.24 | 314.26 | 5.56 | 6.74 | 5.56 | 3.99 |
| KNUST | 61.32 | 9846.76 | 16.81 | 9.64 | 30.47 | 5.50 | 17.30 | 5.12 | 1.07 |
| P - value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 |
| LSD | 4.60 | 936.40 | 0.99 | 73.76 | 1.49 | 0.74 | 4.11 | 1.10 | 0.04 |
| CV (%) | 4.90 | 4.30 | 1.70 | 4.24 | 0.40 | 6.90 | 21.20 | 9.30 | 0.01 |

*Study locations: KYE - Kyeremfaso Kumasi (dumpsite soil); UEW - UEW Mampong Forest (background soil); SUA - Suame Magazine Kumasi (dumpsite soil); MED - Meduma Kumasi (Background soil); AYE - Ayeduase Kumasi (dumpsite soil); KNUST - KNUST Kumasi botanical gardens (background soil).*

**Table 4.10 Total soil metal level at 15 30 cm from soils of the six locations of the study**

| | Metal level ($mgkg^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 87.04 | 17438.00 | 16.98 | 12.31 | 108.02 | 5.21 | 17.35 | 5.24 | 4.06 |
| UEW | 71.79 | 11844.00 | 16.27 | 10.41 | 31.23 | 4.43 | 16.36 | 5.04 | 3.87 |
| SUA | 109.69 | 19914.00 | 222.17 | 674.19 | 4749.72 | 8.88 | 9.04 | 16.31 | 133.58 |
| MED | 80.48 | 13980.00 | 16.80 | 11.81 | 47.48 | 5.49 | 7.61 | 5.10 | 3.75 |
| AYE | 64.35 | 9163.00 | 16.83 | 63.52 | 377.51 | 5.59 | 20.85 | 6.48 | 109.12 |
| KNUST | 63.19 | 8329.00 | 16.03 | 9.38 | 24.91 | 6.78 | 12.45 | 5.31 | 14.37 |
| P - value | 0.01 | 0.01 | 0.08(NS) | 0.01 | 0.01 | 0.01 | 0.26(NS) | 0.01 | 0.01 |
| LSD | 4.22 | 4951.40 | 1.49 | 73.02 | 727.90 | 1.97 | 0.74 | 0.43 | 25.42 |
| CV (%) | 2.90 | 23.10 | 1.60 | 3.52 | 13.41 | 17.80 | 2.90 | 3.20 | 31.20 |

*Study locations: KYE - Kyeremfaso Kumasi (dumpsite soil); UEW - UEW Mampong Forest (background soil); SUA - Suame Magazine Kumasi (dumpsite soil); MED - Meduma Kumasi (Background soil); AYE - Ayeduase Kumasi (dumpsite soil); KNUST - KNUST Kumasi botanical gardens (background soil).*

### 4.2.3 Heavy metals level in plants

#### 4.2.3.1 Heavy metals levels in plantain

The concentrations of Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb in plantain leaves and fruit sampled from the selected study sites showed that, Chromium (Cr) levels in plantain leaves and fruits sampled from KYE, SUA and AYE generally had higher Cr levels in the plantain leaves and fruits than Cr levels in plantain parts sampled from UEW, MED and KNUST and at a significant difference (p = 0.01). (Tables 4.11 and 4.12).

Iron (Fe) levels in plantain leaves and fruit sampled from KYE, SUA and AYE were generally higher than Fe levels in plantain leaves and fruit sampled from UEW, MED and KNUST and at a significant difference (p = 0.01) (Tables 4.11 and 4.12). Nickel (Ni) levels in plantain leaves and fruits sampled from KYE, SUA and AYE were generally higher than Ni levels in plantain leaves and fruit sampled from UEW, MED and KNUST and at a significant difference (p = 0.01). (Tables 4.11 and 4.12). Copper (Cu) levels in plantain leaves and fruits sampled from KYE, SUA and AYE were generally higher than Cu levels in plantain leaf and fruit sampled from UEW, MED and KNUST and at a significant difference (p = 0.01). (Tables 4.11 and 4.12).

Zinc (Zn) levels in plantain leaves and fruits sampled from KYE, SUA and AYE were generally higher than Zn levels in plantain leaves and fruit sampled from UEW, MED and KNUST and at a significant difference (p = 0.01). (Tables 4.11 and 4.12). Arsenis (As) levels in plantain leaves and fruits sampled from the selected sites, KYE, SUA and AYE were generally higher than As levels in plantain leaves and fruit sampled from UEW, MED and at highly significant differences (p = 0.01) (Tables 4.11 and 4.12). Cadmium (Cd) levels in plantain leaves and fruits sampled showed higher Cd levels in plantain leaf and fruit sampled from KYE, SUA and AYE were generally higher than Cd levels in plantain leaves and fruit sampled from UEW, MED and KNUST and at highly significant differences (p = 0.01) (Tables 4.11 and 4.12).

Mercury (Hg) levels in plantain leaves and fruits sampled showed higher Hg levels in plantain leaf and fruit sampled from KYE, SUA and AYE were generally higher than Hg levels in plantain leaves and fruit sampled from UEW, MED and KNUST and at highly significant differences (p = 0.01) (Tables 4.11 and 4.12). Lead (Pb) levels in plantain leaves and fruits sampled generally showed higher Pb levels in plantain leaf and fruit sampled from KYE, SUA and AYE than Pb levels in plantain leaves and fruit sampled from UEW, MED and KNUST and at highly significant differences (p = 0.01) (Tables 4.11 and 4.12).

**Table 4.11 Heavy metals level in plantain leaves from selected dumpsites**

| | Metal level in plantain leaves (mgkg$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 98.08 | 18712.58 | 20.82 | 15.70 | 126.19 | 8.29 | 6.43 | 6.95 | 4.55 |
| UEW | 70.80 | 15420.90 | 18.11 | 11.58 | 49.42 | 7.84 | 5.45 | 5.96 | 3.69 |
| SUA | 62.86 | 13237.22 | 16.10 | 10.3 | 101.56 | 4.81 | 5.52 | 5.28 | 3.53 |
| MED | 29.07 | 10442.45 | 13.93 | 24.07 | 56.46 | 3.16 | 4.74 | 4.44 | 3.50 |
| AYE | 8.61 | 15693.83 | 18.15 | 7.43 | 83.29 | 5.86 | 5.78 | 6.11 | 3.92 |
| KNUST | 8.30 | 7884.00 | 12.21 | 11.69 | 66.40 | 3.18 | 4.45 | 3.89 | 2.65 |
| P - value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| LSD | 6.13 | 741.20 | 0.07 | 7.32 | 8.74 | 1.11 | 1.10 | 0.92 | 0.004 |
| CV (%) | 7.30 | 3.00 | 0.20 | 21.40 | 5.90 | 12.30 | 13.00 | 9.30 | 0.10 |

*Study locations: KYE – Kyeremfaso Mampong (dumpsite soil); UEW – UEW Mampong Forest (background soil); SUA – Suame Magazine Kumasi (dumpsite soil); MED – Meduma Kumasi (background soil); AYE – Kumasi Ayeduase (dumpsite soil); KNUST – KNUST Kumasi botanical gardens (background soil)*

**Table 4.12 Heavy metals level in plantain fruits from selected dumpsites**

| | Metal level in plantain fruits (mgkg$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 53.65 | 14501.60 | 17.14 | 16.09 | 79.39 | 8.05 | 5.08 | 5.73 | 3.72 |
| UEW | 8.44 | 7663.66 | 11.86 | 7.20 | 37.8 | 2.51 | 4.11 | 3.83 | 2.53 |
| SUA | 100.12 | 20442.75 | 21.93 | 67.75 | 186.50 | 8.30 | 6.41 | 7.41 | 36.15 |
| MED | 14.00 | 8941.62 | 12.90 | 7.95 | 41.70 | 3.58 | 4.56 | 4.10 | 2.68 |
| AYE | 8.88 | 7663.66 | 11.86 | 6.31 | 37.80 | 2.51 | 4.11 | 3.83 | 2.53 |
| KNUST | 8.44 | 5986.56 | 10.60 | 7.20 | 17.43 | 1.74 | 3.63 | 3.27 | 2.18 |
| P - value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| LSD | 3.53 | 742.00 | 0.74 | 5.26 | 0.74 | 1.00 | 0.94 | 0.19 | 6.68 |
| CV (%) | 6.00 | 3.80 | 2.80 | 21.50 | 0.60 | 10.00 | 9.50 | 2.20 | 1.28 |

*Study locations: KYE – Kyeremfaso Mampong (dumpsite soil); UEW – UEW Mampong Forest (background soil); SUA – Suame Magazine Kumasi (dumpsite soil); MED – Meduma Kumasi (background soil); AYE – Kumasi Ayeduase (dumpsite soil); KNUST – KNUST Kumasi botanical gardens (background soil)*

#### 4.2.3.2 Heavy metals levels in cocoyam

Cocoyam leaves and corms were also investigated and showed levels of heavy metals concentration. Cr levels in cocoyam corms sampled from AYE (8.30 mgkg$^{-1}$) was lower than Cr levels in cocoyam corms from KNUST (8.36 mgkg$^{-1}$). The cocoyam leaves and corms sampled from KYE, SUA and AYE recorded higher levels of Cr than from UEW, MED and KNUST their corresponding background soils, respectively (Tables 4.13 and 4.14).

Iron (Fe) levels in cocoyam leaves and corms sampled were generally significantly higher ($p = 0.01$) from KYE, SUA and AYE than Fe levels in cocoyam leaves and corms sampled from UEW, MED and KNUST, respectively ($p = 0.01$) (Tables 4.13 and 4.14).

Cocoyam leaves sampled from KYE, SUA and AYE also recorded significantly ($p = 0.01$) higher Nickel (Ni) levels than Ni levels in cocoyam leaves sampled from UEW, MED. However, the Ni levels in the cocoyam corms sampled from KYE, SUA and AYE were not significantly different ($p = 0.08$) from Ni in cocoyam corms sampled from UEW, MED and KNUST between cocoyam leaves but not with cocoyam corms ($p = 0.08$) (Tables 4.13 and 4.14).

Copper (Cu) levels in cocoyam leaves and corm from KYE, SUA and AYE were generally higher and significantly different from Cu levels in cocoyam leaves and corms sampled from UEW, MED and KNUST ($p = 0.01$) (Tables 4.13 and 4.14). Zinc (Zn) levels in cocoyam leaves and corms sampled from KYE, SUA and AYE were generally higher than examined Zn values in than Zn levels in cocoyam leaves and corm sampled from UEW, MED and KNUST with a significant difference ($p = 0.01$). (Tables 4.13 and 4.14). Arsenic (As) level in cocoyam corms sampled from SUA (3.16 mgkg$^{-1}$) was lower than As level in cocoyam corms sampled from MED (3.58 mgkg$^{-1}$). However, As levels in cocoyam leaves at SUA was higher than cocoyam leaves at MED. For the other locations, As levels in both cocoyam leaves and corms at KYE and AYE were significantly higher than As levels in both cocoyam leaves and corms at UEW and KNUST (Tables 4.13 and 4.14). Cadmium (Cd) levels in cocoyam leaves and corms sampled from KYE, SUA and AYE were generally significantly higher ($p = 0.01$) than examined Cd levels in cocoyam leaves and corms sampled from UEW, MED and KNUST (Tables 4.13 and 14). Mercury (Hg) levels were generally significantly higher in both cocoyam leaves and corms from KYE, SUA and AYE than Hg levels in cocoyam leaves and corms from UEW, MED and KNUST (Tables 4.13 and 14). Lead (Pb) levels were generally significantly higher ($p = 0.01$) in both cocoyam leaves and corms sampled from KYE, SUA and AYE than Hg levels in cocoyam leaves and corms sampled from UEW, MED and KNUST (Tables 4.13 and 14).

**Table 4.13 Heavy metals level in cocoyam leaves from selected dumpsites**

| | Metal level in cocoyam (mgkg$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| Location | leaf | leaf | leaf | leaf | leaf | leaf | leaf | leaf | leaf |
| KYE | 42.29 | 10925.38 | 14.59 | 9.31 | 44.92 | 4.85 | 5.06 | 4.66 | 2.99 |
| UEW | 19.35 | 8119.50 | 13.03 | 7.92 | 38.03 | 3.81 | 4.70 | 4.03 | 2.73 |
| SUA | 100.12 | 20442.75 | 21.93 | 67.75 | 186.5 | 8.30 | 6.41 | 7.41 | 36.15 |
| MED | 8.88 | 5986.56 | 10.6 | 6.31 | 17.43 | 1.74 | 3.63 | 3.27 | 2.18 |
| AYE | 81.30 | 15693.83 | 18.15 | 11.69 | 66.4 | 5.86 | 5.78 | 6.11 | 3.92 |
| KNUST | 19.35 | 8119.50 | 13.03 | 7.92 | 44.92 | 3.81 | 4.70 | 4.03 | 2.73 |
| P - value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 |
| LSD | 6.72 | 7017.70 | 7.43 | 7.43 | 16.14 | 1.49 | 1.49 | 1.68 | 0.43 |
| CV (%) | 8.20 | 33.40 | 28.80 | 22.10 | 13.40 | 17.79 | 16.20 | 18.60 | 2.80 |

*Locations: KYE - Kyeremfaso (dumpsite soil); UEW - Mampong Forest (background soil); SUAM - Suame Magazine (dumpsite soil); MED -Meduma Kumasi (background soil); AYE - Kumasi Ayeduase (dumpsite soil); KNUST Botanical gardens - Kumasi (backgroundsoil).*

**Table 4.14 Heavy metals level in cocoyam corms from selected dumpsites**

| | Metal level in cocoyam corms ($mgkg^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 85.77 | 21145.47 | 22.13 | 32.69 | 75.99 | 12.29 | 5.36 | 7.83 | 4.56 |
| UEW | 8.36 | 7700.83 | 11.92 | 7.15 | 48.36 | 2.75 | 4.28 | 3.82 | 2.50 |
| SUA | 29.07 | 10442.45 | 13.93 | 24.07 | 101.56 | 3.16 | 4.74 | 4.44 | 3.50 |
| MED | 14.00 | 8941.62 | 12.90 | 7.95 | 41.70 | 3.58 | 4.56 | 4.10 | 2.68 |
| AYE | 8.30 | 7884.00 | 12.21 | 7.43 | 83.29 | 3.18 | 4.45 | 3.89 | 2.65 |
| KNUST | 8.36 | 7700.83 | 11.92 | 7.15 | 48.36 | 2.75 | 4.28 | 3.82 | 2.50 |
| P - value | 0.01 | 0.01 | 0.08 | 0.01 | 0.01 | 0.01 | 0.26 | 0.01 | 0.01 |
| LSD | 0.07 | 6684.40 | 1.49 | 7.43 | 0.004 | 3.59 | 1.45 | 0.74 | 0.75 |
| CV (%) | 0.10 | 34.50 | 5.40 | 28.30 | 0.001 | 19.50 | 17.30 | 8.70 | 13.50 |

*Locations: KYE - Kyeremfaso (dumpsite soil); UEW - Mampong Forest (background soil); SUAM - Suame Magazine (dumpsite soil); MED -Meduma Kumasi (background soil); AYE - Kumasi Ayeduase (dumpsite soil); KNUST Botanical gardens - Kumasi (backgroundsoil).*

### 4.2.4 Relationships among heavy metals and other soil properties

#### 4.2.4.1 Correlation and linear regression

A Pearson's linear correlation relationship among Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb showed a significant association (Table 4.15). The soil total Cu concentrations correlated positively and highly significantly with Ni ($r = 0.96$; $p = 0.01$). The soil total Zn concentrations correlated negatively and significantly ($r = - 0.51$; $p = 0.04$) with total Fe concentration levels in the soil, and positively with Ni ($r = 0.95$; $p = 0.01$) and Cu ($r = 0.98$; $p = 0.01$) concentration in the soil (Table 4.15). Total soil As concentration correlated positively and significantly ($r = 0.53$; $p = 0.03$) with total soil Cu levels and with total soil Zn ($r = 0.48$; $p = 0.05$) levels (Table 4.12). Total soil Cd levels also correlated positively and significantly with Cr (r = 0.48; p = 0.04) and negatively with Fe (r = - 0.65; p = 0.01). Total soil Pb concentration correlated negatively and highly significantly with As (r = - 0.72; p = 0.01) and positively with Hg (r = 0.59; p = 0.01) (Table 4.15).

**Table 4.15 Pearson's correlation among the soil total heavy metals at the dumpsites**

| | Relationships among soil total heavy metals | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Correlation | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| Cr | 1.00 | | | | | | | | |
| Fe | -0.08 | 1.00 | | | | | | | |
| | (0.76) | | | | | | | | |
| Ni | 0.40 | -0.45 | 1.00 | | | | | | |
| | (0.11) | (0.06) | | | | | | | |
| Cu | 0.36 | -0.41 | **0.96**$^{**}$ | 1.00 | | | | | |
| | (0.14) | (0.09) | **(0.01)** | | | | | | |
| Zn | 0.35 | **-0.51**$^{*}$ | **0.95**$^{**}$ | **0.98**$^{**}$ | 1.00 | | | | |
| | (0.15) | **(0.04)** | **(0.01)** | **(0.01)** | | | | | |
| As | -0.17 | -0.22 | 0.32 | **0.53**$^{*}$ | **0.48**$^{*}$ | 1.00 | | | |
| | (0.50) | (0.39) | (0.21) | **(0.03)** | **(0.05)** | | | | |
| Cd | **0.47**$^{*}$ | -0.01 | -0.05 | -0.06 | -0.12 | 0.14 | 1.00 | | |
| | **(0.05)** | (0.98) | (0.85) | (0.85) | (0.63) | (0.57) | | | |
| Hg | 0.01 | -0.42 | 0.17 | -0.05 | 0.06 | -0.35 | 0.25 | 1.00 | |
| | (0.97) | (0.08) | (0.51) | (0.84) | (0.82) | (0.15) | (0.31) | | |
| Pb | 0.21 | -0.11 | 0.35 | 0.11 | 0.13 | **-0.72**$^{**}$ | -0.15 | **0.59**$^{**}$ | 1.00 |
| | (0.41) | (0.67) | (0.15) | (0.71) | (0.61) | **(0.01)** | (0.55) | **(0.01)** | |

$^{**}$*Correlation is significant at 0.01 level (2-tailed); *Correlation is significant at 0.05 level (2-tailed). P values are in parenthesis*

The results of linear regression analysis prediction showed the extent of relationship between soil pH, soil organic matter (SOM), cation exchange capacity (CEC), clay content, soil available P and selected heavy metals. Soil pH significantly (p = 0.02; $r^2$ = 0.26) influenced soil total Fe concentration and the prediction is that, under unfavourable soil pH condition, Fe level in the soil will be 9477 mgkg$^{-1}$ and for every unit increase in soil pH, total Fe level will increase by 2.66 mgkg$^{-1}$ in the soil. Also 26% of the variation in Fe level attributed to soil pH, the remaining 74% is due to other factors (Table 4.16).

**Table 4.16 Relationships between soil pH, soil organic matter, cation exchange capacity, clay, soil available phosphorus and selected heavy metals in dumpsites soil**

| Linear | Y- intercept | Slope | R | $R^2$ | P - value |
|---|---|---|---|---|---|
| (X) Soil pH – Fe (Y) | 9477 | 2.66 | $0.51^{*}$ | 0.26 | 0.02 |
| (X) SOM – Ni (Y) | 32.08 | 4.363 | $0.97^{**}$ | 0.94 | 0.01 |
| (X) SOM – Cu (Y) | 2.61 | 8.092 | $0.98^{**}$ | 0.96 | 0.01 |
| (X) SOM – Zn (Y) | -898 | 427.10 | $0.98^{**}$ | 0.96 | 0.01 |
| (X) CEC – Ni (Y) | 26.06 | 2.039 | $0.89^{**}$ | 0.79 | 0.01 |
| (X) CEC – Cu (Y) | -11.66 | 4.007 | $0.95^{**}$ | 0.90 | 0.01 |
| (X) CEC – Zn (Y) | -1481 | 199.10 | $0.89^{**}$ | 0.79 | 0.01 |
| (X) CEC – As (Y) | 12.03 | 0.1951 | $0.57^{**}$ | 0.32 | 0.01 |
| (X) CLAY – Cr (Y) | 54.15 | 1.457 | $-0.54^{*}$ | 0.29 | 0.02 |
| (X) CLAY – Fe (Y) | 12029 | 168.8 | $0.61^{**}$ | 0.37 | 0.01 |
| (X) Avail. P – Cd (Y) | 10.61 | 0.00663 | $-0.66^{**}$ | 0.44 | 0.01 |

*** Significant at 0.0l level; *Significant at 0.05 level.*

SOM highly and significantly influenced Ni (p = 0.01; $r^2$ = 0.94); Cu (p = 0.01; $r^2$ = 0.96) and Zn (p = 0.01; $r^2$ = 0.96). The prediction is that, under unfavourable SOM influence, total Ni level in the soil will be 32.08 mgkg$^{-1}$ and for every unit increase in SOM, total Ni level will increase by 4.36 mgkg$^{-1}$ in the soil. Also, unfavourable SOM influence, total Cu level in the soil will be 2.61 mgkg$^{-1}$ and for every unit increase in SOM, total Cu level will increase by 8.09 mgkg$^{2}$ in the soil. In addition, under unfavourable SOM influence, total Zn level in the soil will decrease by 898 mgkg$^{-1}$ and for every unit increase in SOM, total Zn level will increase by 427.10 mgkg$^{-1}$ in the soil. Also, SOM may also be attributed to 94 % variation in Fe levels while the remaining 6 % may be attributed to other factors in the dumpsite soil (Table 4.16).

CEC highly and significantly ($p = 0.01$; $r^2 = 0.79$) influenced Ni, Cu ($p = 0.01$; $r^2 = 0.90$), Zn ($p = 0.01$; $r^2 = 0.79$) and As ($p = 0.01$; $r^2 = 0.32$). The prediction is that, under unfavourable CEC influence, Ni level in the soil will be 26.06 mgkg$^{-1}$ and for every unit increase in CEC, total Ni level will increase by 2.04 mgkg$^{-1}$ in the soil. Also, under unfavourable CEC influence, Cu level in the soil will decrease by - 11.66 mgkg$^{-1}$ and for every unit increase in CEC, total Cu level will increase by 4.01 mgkg$^{-1}$ in the soil. Cu levels in the dumpsites soils may be attributed to 90 % variation in Cu levels while the remaining 10 % may be attributed to other factors in the dumpsites soils. In addition, under unfavourable CEC influence, Zn level in the soil will decrease by 1481 mgkg$^{-1}$ but for a unit increase in CEC, total Zn level will increase by 199.10 mgkg$^{-1}$ in the soil. Also, under unfavourable CEC effect, As level in the soil will be 12.03 mgkg$^{-1}$ but for a unit increase in CEC, total As in the soil level will increase by 199.10 mgkg$^{-1}$ in the soil. (Table 4.16).

Clay content significantly ($p = 0.02$; $r^2 = 0.29$) influenced Cr, and highly significantly influenced ($p = 0.01$; $r^2 = 0.37$) Fe. The prediction is that, clay variation in the soil are attributed to only 26 % of Cr levels in the soil while the remaining higher 76 % may attributed to other factors. Also, clay influenced, total Fe level in the soil will be 12029 mgkg$^2$ and for every unit increase in soil clay content, total Fe level will increase by 168.80 mgkg$^2$ in the soil (Table 4.16).

Soil available P highly and significantly ($p = 0.01$; $r^2 = 0.44$) influenced total Cd level in the soil. The prediction is that, under no available phosphorus influence, total Cd level in the soil will be 10.61 mgkg$^{-1}$ and for every unit increase in soil available phosphorus, total Cd level will increase by 0.01 mgkg$^{-1}$ in the soil. Also, soil available P influence might be attributed to 44 % variation in dumpsite soil Cd level while the remaining 56 % may be attributed to other factors in the soil (Table 4.16).

## 4.3 Study Three (Field Experimentation):- Evaluation of heavy metals contamination in dumpsite soils and selected plants under field conditions

### 4.3.1 Physicochemical properties of soils in pots under field conditions

Mampong Kyeremfaso dumpsite soil (KYE), Mampong UEW forest background soil (UEW), Kumasi Suame magazine dumpsite soil (SUA), Kumasi Meduma background soil (MED), Kumasi Ayeduase dumpsite soil (AYE) and Kumasi KNUST botanical gardens background soil (KNUST) generally recorded lower bulk densities in KYE, SUA and AYE (with no significant differences, $p = 0.64$) than in UEW, MED and KNUST (Table 4.17). Soil pH in SUA (6.51) was lower than in MED (8.03), KYE and AYE recorded higher soil pH than in UEW and KNUST with a significant difference ($p = 0.01$). Total organic carbon and organic matter were higher in KYE, SUA and AYE than in UEW, MED and KNUST with a significant difference ($p = 0.01$). Total N was higher in KYE (0.19 %) than UEW (0.18 %), total N levels in SUA and AYE were higher than in MED and KNUST with no significant differences ($p = 0.51$). Soil available P was higher in KYE, SUA and AYE than in UEW, MED and KNUST with significant differences ($p = 0.01$). The exchangeable cation K level in KYE (0.22 meq100g$^{-1}$) was lower than in UEW (0.24 meq100g$^{-1}$), SUA (0.18 meq100g$^{-1}$) recorded lower K levels than in MED (0.39 meq100g$^{-1}$), Na levels in SUA (0.12 meq100g$^{-1}$) was lower than in MED (0.17 meq100g$^{-1}$). Ca, Mg, and Na were higher in most dumpsites soils compared to background soils with significant differences ($p = 0.01$). Exchangeable acidity levels in KYE and AYE were higher than in UEW and KNUST with significant differences ($p = 0.03$). CEC and ECEC levels in KYE, SUA and AYE were higher than in UEW, MED and KNUST at a significant difference ($p = 0.01$). Base saturation levels in SUA (99.77 %) were lower than in MED (99.88 %). KYE, and AYE recorded higher exchangeable acid levels than in UEW and KNUST with a significant difference ($p = 0.01$). (Table 4.17).

Table 4.17 Physicochemical properties of soils in pots under field conditions

| | | | | | | | Exchangeable cations | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B.D ($gcm^{-3}$) | pH | T.O.C | T.O.M | Total N | Available P | Ca | Mg | K | Na | Exchangeable acidity | CEC | ECEC | Base saturation |
| | | | | (%) | | ($mgkg^{-1}$) | | | | ($meq100g^{-1}$) | | | | (%) |
| Soil source | | | | | | | | | | | | | | |
| KYE | 1.37 | 7.99 | 1.70 | 2.92 | 0.19 | 233.49 | 11.08 | 2.98 | 0.22 | 0.11 | 0.05 | 7.80 | 14.43 | 99.65 |
| UEW | 1.47 | 6.25 | 1.50 | 2.63 | 0.18 | 20.05 | 4.47 | 1.92 | 0.24 | 0.09 | 0.15 | 8.26 | 6.87 | 97.82 |
| SUA | 1.01 | 6.51 | 8.48 | 14.62 | 0.22 | 8.77 | 29.82 | 12.78 | 0.18 | 0.12 | 0.10 | 31.24 | 43.00 | 99.77 |
| MED | 1.57 | 8.03 | 1.78 | 3.07 | 0.15 | 36.22 | 9.16 | 1.92 | 0.39 | 0.17 | 0.02 | 17.14 | 11.66 | 99.88 |
| AYE | 1.26 | 8.77 | 2.54 | 4.38 | 0.16 | 9.11 | 26.84 | 1.49 | 0.30 | 0.15 | 0.02 | 10.76 | 28.80 | 99.93 |
| KNUST | 1.42 | 4.81 | 1.61 | 2.78 | 0.19 | 132.12 | 1.70 | 0.64 | 0.20 | 0.11 | 1.20 | 7.56 | 3.80 | 68.93 |
| P - value | 0.64**(NS)** | 0.01 | 0.01 | 0.01 | 0.51(NS) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.01 |
| LSD (0.05) | 0.74 | 1.29 | 0.74 | 0.04 | 0.58 | 1.49 | 0.94 | 1.52 | 0.01 | 0.02 | 0.73 | 1.79 | 2.87 | 2.05 |
| CV (%) | 30.00 | 4.00 | 13.80 | 0.01 | 0.53 | 1.10 | 3.70 | 23.10 | 2.80 | 10.50 | 0.79 | 7.10 | 8.70 | 1.20 |

*Treatments: KYE - Kyeremfaso Mampong dumpsite soil; UEW - UEW forest Mampong background soil; SUA - Suame Kumasi dumpsite soil; MED – Meduma Kumasi background soil; AYE - Ayeduase Kumasi dumpsite soil; KNUST – KNUST Kumasi botanical gardens background soil.*

### 4.3.2 Total metals levels in soils in pots under field conditions

Total heavy metals level in sampled soils before planting of lettuce in pots under field conditions showed that, Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb levels in KYE, SUA and AYE were generally higher than levels in UEW, MED and KNUST in pots before planting lettuce at significant differences (p = 0.01) (Table 4.18).

**Table 4.18 Total heavy metals levels in soils in pots under field conditions before planting**

| | Metal level ($mgkg^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Soil source | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 87.64 | 13421.3 | 63.41 | 36.21 | 291.14 | 15.36 | 47.31 | 36.52 | 43.77 |
| UEW | 69.07 | 12330.58 | 45.53 | 27.91 | 25.32 | 13.39 | 22.46 | 14.6 | 11.41 |
| SUA | 71.23 | 13673.42 | 82.74 | 78.64 | 5659.17 | 21.47 | 26.32 | 44.75 | 36.24 |
| MED | 40.85 | 13030.55 | 45.22 | 23.63 | 197.13 | 18.53 | 15.14 | 13.62 | 9.11 |
| AYE | 42.43 | 15942.39 | 69.15 | 36.55 | 931.02 | 20.74 | 23.97 | 19.79 | 75.32 |
| KNUST | 34.24 | 13397.55 | 39.53 | 33.70 | 752.25 | 16.39 | 14.57 | 17.87 | 10.46 |
| P - value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| LSD (0.05) | 1.11 | 1593.10 | 0.94 | 1.49 | 86.60 | 0.94 | 0.74 | 6.90 | 0.99 |
| CV (%) | 1.00 | 6.40 | 0.90 | 2.10 | 3.60 | 2.90 | 1.60 | 16.10 | 1.80 |

*Treatments: KYE - Kyeremfaso Mampong dumpsite soil; UEW - Mampong Forest background soil; SUA - Suame Magazine Kumasi dumpsite soil; MED - Meduma Kumasi background soil; AYE - Ayeduase Kumasi dumpsite soil; KNUST - KNUST Kumasi botanical gardens background soil.*

Total heavy metals level in sampled soils at harvest in pots under field conditions showed that, Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb levels in KYE, SUA and AYE were generally higher than levels in UEW, MED and KNUST in pots before planting lettuce with significant differences (P = 0.01) (Table 4.19)

**Table 4.19 Total heavy metals levels in soils in pots under field conditions at harvest**

| Soil source | Metal level (mgkg$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 61.13 | 15010.32 | 46.77 | 27.12 | 246.23 | 14.84 | 30.56 | 19.52 | 16.19 |
| UEW | 57.14 | 12644.48 | 38.14 | 22.19 | 197.46 | 13.15 | 11.64 | 12.20 | 9.36 |
| SUA | 59.67 | 15467.53 | 96.11 | 124.23 | 5464.62 | 17.92 | 14.35 | 16.79 | 24.33 |
| MED | 20.27 | 13384.51 | 44.59 | 35.74 | 229.23 | 17.06 | 13.58 | 12.91 | 7.71 |
| AYE | 43.46 | 12877.58 | 57.36 | 29.24 | 794.13 | 15.91 | 11.31 | 21.02 | 59.54 |
| KNUST | 19.13 | 10216.43 | 42.10 | 23.12 | 659.74 | 9.47 | 11.07 | 19.73 | 9.04 |
| P - value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| LSD (0.05) | 1.59 | 668.40 | 0.05 | 0.74 | 703.40 | 2.17 | 0.43 | 2.20 | 0.01 |
| CV (%) | 2.00 | 2.80 | 0.001 | 0.90 | 30.60 | 8.10 | 7.00 | 7.10 | 0.001 |

*Treatments: KYE - Kyeremfaso Mampong dumpsite soil; UEW - Mampong Forest background soil; SUA - Suame Magazine Kumasi dumpsite soil; MED - Meduma Kumasi background soil; AYE - Ayeduase Kumasi dumpsite soil; KNUST - KNUST Kumasi botanical gardens background soil.*

### 4.3.3 Heavy metals levels in lettuce shoots and roots at harvest under field conditions

Heavy metals (Fe, Ni, Cu, Zn, As, Cd, Hg and Pb) levels in lettuce shoots and roots in pots under field conditions showed that, on KYE soils, Chromium (Cr) levels in lettuce shoot (34.20 mgkg$^{-1}$) and root (23.56 mgkg$^{-1}$) were higher than Cr levels in lettuce shoot (14.64 mgkg$^{-1}$) and root (8.06 mgkg$^{-1}$) in UEW (Tables 4.20 and 4.21). On SUA, Cr in lettuce shoot (21.01 mgkg$^{-1}$) and root (19.24 mgkg$^{-1}$) were higher than MED Cr levels in lettuce shoot (15.25 mgkg$^{-1}$) and root (7.91 mgkg$^{-1}$). Cr level in lettuce shoots and roots in pots under field conditions showed that, on AYE, Cr levels in lettuce shoot (7.16 mgkg$^{-1}$) and root (6.90 mgkg$^{-1}$) were higher than Cr levels in lettuce shoot (7.05 mgkg$^{-1}$) and root (6.57 mgkg$^{-1}$) on

KNUST. Generally, Cr levels in lettuce on dumpsite soils were higher than on background soils and there were highly and significantly (p = 0.01) different from each other (Table 4.20 and 4.21).

**Table 4.20 Total metal levels in lettuce shoots in pots at harvest under field conditions**

| | Metal levels in lettuce shoots at harvest (mgkg$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Soil source | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 34.20 | 5126.48 | 15.91 | 10.12 | 69.50 | 6.12 | 5.25 | 5.95 | 3.75 |
| UEW | 14.64 | 6010.05 | 17.56 | 11.3 | 66.89 | 7.43 | 5.11 | 5.78 | 3.35 |
| SUA | 21.01 | 5563.51 | 17.24 | 47.70 | 2895.61 | 7.73 | 4.80 | 6.33 | 5.59 |
| MED | 15.25 | 6357.22 | 17.73 | 11.42 | 90.60 | 8.39 | 4.97 | 5.98 | 3.53 |
| AYE | 7.16 | 4671.34 | 15.89 | 13.34 | 131.74 | 4.88 | 4.72 | 5.29 | 3.90 |
| KNUST | 7.05 | 4113.63 | 14.00 | 8.77 | 210.47 | 5.75 | 4.54 | 4.55 | 3.09 |
| P – value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.89(NS) | 0.02 | 0.01 |
| LSD (0.05) | 1.55 | 742.80 | 1.99 | 0.83 | 742.00 | 0.95 | 1.47 | 0.91 | 0.43 |
| CV (%) | 5.10 | 7.70 | 6.70 | 2.70 | 7.70 | 7.80 | 16.50 | 8.90 | 6.00 |

*Treatments: KYE - Kyeremfaso Mampong dumpsite soil; UEW - Mampong background soil; SUA - Suame Kumasi dumpsite soil; MED - Meduma Kumasi background soil; AYE - Ayeduase Kumasi dumpsite soil; KNUST - KNUST Kumasi botanical gardens background soil.*

Iron (Fe) levels in lettuce shoots and roots in pots under field conditions showed that, on KYE, Fe levels in lettuce shoot (5126.48 mgkg$^{-1}$) and root (5011.23 mgkg$^{-1}$) was lower than Fe levels in lettuce shoot (6010.05 mgkg$^{-1}$) and lower Fe levels in lettuce root (4233.35 mgkg$^{-1}$) on UEW. On SUA, Fe levels in lettuce shoot (5563.51 mgkg$^{-1}$) and root (5121.46 mgkg$^{-1}$) were lower than Fe levels in MED lettuce shoot (6357.22 mgkg$^{-1}$) and root (5613.66 mgkg$^{-1}$). Fe levels in lettuce shoots (4671.34 mgkg$^{-1}$) and root (4511.22 mgkg$^{-1}$) on AYE were higher than Fe levels in lettuce shoot (4113.63 $mgkg^{-1}$) and root (3995.26 $mgkg^{-1}$) on KNUST. Fe levels in lettuce on most of dumpsites soils were higher in concentration than Fe levels in lettuce on background soils with highly significant diferences ($p = 0.01$) (Tables 4.20 and 4.21).

Nickel (Ni) levels in lettuce shoots (15.91 $mgkg^{-1}$) on KYE was lower than Ni levels in shoots (17.56 $mgkg^{-1}$) on UEW but Ni levels in roots (15.77 $mgkg^{-1}$) KYE was higher than Ni levels in lettuce root (14.82 $mgkg^{-1}$) on UEW. On SUA, Ni levels in lettuce shoot (17.24 $mgkg^{-1}$) was lower than Ni levels in lettuce shoot (17.73 $mgkg^{-1}$) on MED but lettuce root (16.39 $mgkg^{-1}$) on SUA recorded higher Ni levels than Ni levels in lettuce root (14.95 $mgkg^{-1}$) in MED. Ni levels in lettuce shoot (15.89 $mgkg^{-1}$) on AYE was higher than Ni levels in lettuce shoot (14.00 $mgkg^{-1}$) on KNUST. Ni levels in lettuce root (14.89 $mgkg^{-1}$) on AYE was lower than Ni levels in lettuce root (16.69 $mgkg^{-1}$) on KNUST. There was highly significant ($p = 0.01$) differences between Ni levels in dumpsites soil lettuce and background soils lettuce (Tables 4.20 and 4.21).

Copper (Cu) levels in lettuce shoots (10.12 $mgkg^{-1}$) on KYE was lower than Cu levels in lettuce shoots (11.30 $mgkg^{-1}$) on UEW but higher in roots (12.75 $mgkg^{-1}$) KYE than in root (10.39 $mgkg^{-1}$) UEW. On SUA, Cu levels in lettuce shoot (47.70 $mgkg^{-1}$) and root (28.88 $mgkg^{-1}$) was higher than Cu levels in lettuce shoot (11.42 $mgkg^{-1}$) and root (9.42 $mgkg^{-1}$) MED. Cu levels in AYE was higher in lettuce shoot (13.34 $mgkg^{-1}$) but lower Cu levels in lettuce root (9.54 $mgkg^{-1}$) on AYE as compare to Cu levels in lettuce shoot (8.77 $mgkg^{-1}$) and root (10.94 $mgkg^{-1}$) on KNUST. There was highly significant ($p = 0.01$) differences between all Cu levels in dumpsites soil lettuce and background soils lettuce (Tables 4.20 and 4.21).

Zinc (Zn) levels in lettuce shoots and roots in pots under field conditions showed that, on KYE, Zn levels in lettuce shoot (69.50 mgkg$^{-1}$) and root (110.11 mgkg$^{-1}$) were higher than Zn levels in lettuce shoot (66.89 mgkg$^{-1}$) and root (87.88 mgkg$^{-1}$) on UEW. Zn levels on SUA lettuce shoot (2895.61 mgkg$^{-1}$) and root (1698.12 mgkg$^{-1}$) showed higher concentration levels than in MED lettuce shoot (90.60 mgkg$^{-1}$) and root (71.05 mgkg$^{-1}$). On AYE, Zn levels in both lettuce shoot (131.74 mgkg$^{-1}$) and root (133.34 mgkg$^{-1}$) recorded lower Zn levels than in KNUST lettuce shoot (210.47 mgkg$^{-1}$) and root (146.43 mgkg$^{-1}$). There were highly and significant ($p = 0.01$) differences between Zn levels in dumpsite soils lettuce and their background soils lettuce studied (Tables 4.20 and 4.21).

Arsenic (As) levels in lettuce shoots (6.12 mgkg$^{-1}$) on KYE was lower than As levels in lettuce shoot (7.43 mgkg$^{-1}$) on UEW. As levels in lettuce root (6.31 mgkg$^{-1}$) on KYE recorded a higher As level than in lettuce root (4.42 mgkg$^{-1}$) on UEW. As levels in lettuce shoot (7.73 mgkg$^{-1}$) and root (7.09 mgkg$^{-1}$) on SUA recorded lower As levels in lettuce shoot (8.39 mgkg$^{-1}$) on MED. As levels in lettuce root (6.75 mgkg$^{-1}$) on MED was lower as compared with As levels in lettuce root on SUA. As levels in AYE dumpsite soil was lower in lettuce shoot (4.88 mgkg$^{-1}$) than As levels in lettuce shoot (5.75 mgkg$^{-1}$) on KNUST. As levels in lettuce root (9.05 mgkg$^{-1}$) on MED was higher than in lettuce root (3.90 mgkg$^{-1}$) on KNUST. There was a highly significant ($p = 0.01$) difference between As levels in lettuce plant shoots and roots in dumpsites soils and background soils (Tables 4.20 and 4.21).

Cadmium (Cd) levels in lettuce shoot (5.25 $mgkg^{-1}$) and root (4.64 $mgkg^{-1}$) were both higher on KYE dumpsite soil than Cd levels in lettuce shoot (5.11 $mgkg^{-1}$) and root (4.23 $mgkg^{-1}$) on UEW. Cd on SUA lettuce shoot (4.80 $mgkg^{-1}$) was lower than Cd levels in lettuce root (4.86 $mgkg^{-1}$) as compared with Cd levels in MED shoot (4.97 $mgkg^{-1}$) and root (4.47 $mgkg^{-1}$). Cd levels were higher in lettuce shoot (4.72 $mgkg^{-1}$) but lower in lettuce root (5.02 $mgkg^{-1}$) in AYE as compared with Cd concentration levels in KNUST lettuce shoot (4.54 $mgkg^{-1}$) and root (5.07 $mgkg^{-1}$). There was a highly significantly ($p = 0.01$) difference between Cd levels in dumpsite soils and their background soils studied (Tables 4.20 and 4.21).

Mercury (Hg) level in lettuce shoot (5.95 $mgkg^{-1}$) and root (5.12 $mgkg^{-1}$) were higher on KYE than in lettuce shoot (5.78 $mgkg^{-1}$) and root (4.82 $mgkg^{-1}$) in UEW. Hg in SUA lettuce shoot (6.33 $mgkg^{-1}$) and lettuce root (5.71 $mgkg^{-1}$) were higher than on lettuce shoot (5.98 $mgkg^{-1}$) and lettuce root (4.80 $mgkg^{-1}$) in KNUST. Hg level were both higher in lettuce shoot (5.29 $mgkg^{-1}$) and lettuce root (4.85 $mgkg^{-1}$) on AYE as compared to Hg concentration levels in KNUST lettuce shoot (4.55 $mgkg^{-1}$) and lettuce root (3.54 $mgkg^{-1}$). There was a significant ($p = 0.02$) difference between Hg levels in lettuce plant shoots parts in dumpsite soils and their background soils and a highly significantly ($p = 0.01$) difference between Hg levels in lettuce roots in dumpsites soils and their background soils (Tables 4.20 and 4.21).

Lead (Pb) level was lower in lettuce shoot (3.75 $mgkg^{-1}$) and higher in lettuce root (3.54 $mgkg^{-1}$) in KYE as compared with Hg in lettuce shoot (3.35 $mgkg^{-1}$) and root (3.23 $mgkg^{-1}$) in UEW. Pb in SUA lettuce shoot (5.59 $mgkg^{-1}$) and lettuce root (7.99 $mgkg^{-1}$) were both higher than Pb in lettuce shoot (3.53 $mgkg^{-1}$) and lettuce root (3.13 $mgkg^{-1}$) in MED. Pb levels were both higher in lettuce shoot (3.90 $mgkg^{-1}$) and lettuce root (35.76 $mgkg^{-1}$) in AYE than Pb concentration levels in KNUST lettuce shoot (3.09 $mgkg^{-1}$) and lettuce root (3.69 $mgkg^{-1}$). There was a higly significantly (p = 0.01) difference between Pb levels in lettuce shoots and roots in dumpsite soils and their background soils with a significant difference (p = 0.01) (Tables 4.20 and 4.21).

**Table 4.21 Total metal levels in lettuce roots in pots at harvest under field conditions**

| | Metal levels in lettuce roots at harvest ($mgkg^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Soil source | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 23.56 | 5011.23 | 15.77 | 12.75 | 110.11 | 6.31 | 4.64 | 5.12 | 3.54 |
| UEW | 8.06 | 4233.35 | 14.82 | 10.39 | 87.88 | 4.42 | 4.23 | 4.82 | 3.23 |
| SUA | 19.24 | 5121.46 | 16.39 | 28.88 | 1698.12 | 7.09 | 4.86 | 5.71 | 7.99 |
| MED | 7.91 | 5613.66 | 14.95 | 9.42 | 71.05 | 6.75 | 4.47 | 4.80 | 3.13 |
| AYE | 6.90 | 4511.22 | 14.89 | 9.54 | 133.34 | 9.05 | 5.02 | 4.85 | 35.76 |
| KNUST | 6.57 | 3995.26 | 16.69 | 10.94 | 146.43 | 3.90 | 5.07 | 3.54 | 3.69 |
| P - value | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.01 | 0.17 | 0.01 | 0.01 |
| LSD (0.05) | 1.10 | 939.40 | 0.70 | 6.91 | 79.60 | 0.13 | 0.74 | 0.07 | 7.67 |
| CV (%) | 5.00 | 10.90 | 2.60 | 27.90 | 11.70 | 1.10 | 8.70 | 0.80 | 1.37 |

*Treatments: KYE - Kyeremfaso Mampong dumpsite soil; UEW - Mampong background soil; SUA - Suame Kumasi dumpsite soil; MED - Meduma Kumasi background soil; AYE - Ayeduase Kumasi dumpsite soil; KNUST - KNUST Kumasi botanical gardens background soil.*

### 4.3.4 NPK levels in lettuce plant in pots at harvest

Primary nutrients Nitrogen (N), Phosphorus (P) and Potassium (K) in lettuce shoots and roots in pots at harvest showed a lower total nitrogen level in lettuce shoot (0.07 %) and root

(0.09 %) in KYE than the total nitrogen level in lettuce shoot (0.27 %) and root (0.16 %) on UEW at harvest. On SUA, there were higher total nitrogen in lettuce shoot (6.15 %) and root (3.01 %) as compare to lower total nitrogen in lettuce shoot (3.01 %) and root (2.38 %) in MED. In AYE, lettuce shoot (2.59 %) and root (1.61) were higher than the total nitrogen levels in lettuce shoot (0.31 %) and root (0.20 %) in KNUST. A highly significant difference (p = 0.01) was recorded between the total nitrogen levels in lettuce shoot and root in dumpsites soil and their background soils (Table 4.22).

Available phosphorus (P) in lettuce shoots and roots in pots at harvest showed higher available P in lettuce shoot (14.17 mgkg$^{-1}$) and root (12.46 mgkg$^{-1}$) in KYE as compared with available P in lettuce shoot (13.20 mgkg$^{-1}$) and root (11.28 mgkg$^{-1}$) on UEW at harvest. In SUA dumpsite soil, a higher available P in lettuce shoot (12.19 mgkg$^{-1}$) and root (14.07 mgkg$^{-1}$) as compare to lower available P in lettuce shoot (0.55 mgkg$^{-1}$) and root (1.02 mgkg$^{-1}$) in MED. In AYE, there were higher levels of available P in lettuce shoot (19.22 mgkg$^{-1}$) and root (15.35 mgkg$^{-1}$) than in lettuce shoot (0.79 mgkg$^{-1}$) and root (0.42 mgkg$^{-1}$) in KNUST in pots at harvest. There was a significant difference (p = 0.01) between lettuce shoot and root (Table 4.22).

Available potassium (K) in lettuce shoots and roots at harvest showed higher values in lettuce shoot (19.06 meq100$^{-1}$) and in root (14.13 meq100$^{-1}$) in KYE than the values in lettuce shoot (10.18 meq100$^{-1}$) and root (6.15 meq100$^{-1}$) in UEW at harvest. In SUA, there was a lower available K in lettuce shoot (4.79 meq100$^{-1}$) and root (5.10 meq100$^{-1}$) as compare to higher values in lettuce shoot (21.04 meq100$^{-1}$) and root (14.36 meq100$^{-1}$) in

MED at harvest. In AYE, at harvest, higher levels of available K in lettuce shoot (3.64 meq100$^{-1}$) and root (5.80 meq100$^{-1}$) were recorded than the levels in lettuce shoot (0.11 meq100$^{-1}$) and root (0.03 meq100$^{-1}$) in KNUST. There was a highly significant difference (p = 0.01) (Table 4.22).

**Table 4.22 Selected soil nutrients in lettuce plant in pots under field conditions at harvest**

| | Lettuce nutrient levels | | | | | |
|---|---|---|---|---|---|---|
| | Total Nitrogen (%) | | Available P (mgkg$^{-1}$) | | Available K (meq100g$^{-1}$) | |
| Soil Source | Shoot | Root | Shoot | Root | Shoot | Root |
| KYE | 0.07 | 0.09 | 14.17 | 12.46 | 19.06 | 14.13 |
| UEW | 0.27 | 0.16 | 13.20 | 11.28 | 10.18 | 6.15 |
| SUA | 3.01 | 2.38 | 12.19 | 14.07 | 4.79 | 5.10. |
| MED | 6.15 | 11.26 | 0.55 | 1.02 | 21.04 | 14.36 |
| AYE | 0.31 | 0.20 | 0.79 | 0.42 | 3.64 | 5.80 |
| KNUST | 2.59 | 1.61 | 19.22 | 15.35 | 0.11 | 0.03 |
| P - value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| LSD (0.05) | 0.96 | 0.99 | 0.94 | 0.74 | 0.74 | 0.74 |
| CV (%) | 25.60 | 20.90 | 5.10 | 4.50 | 4.10 | 5.30 |

*Treatments: KYE - Kyeremfaso Mampong dumpsite soil; UEW - Mampong Forest background soil; SUA - Suame Magazine Kumasi dumpsite soil; MED - Meduma Kumasi background soil; AYE - Ayeduase Kumasi dumpsite soil; KNUST - KNUST Kumasi botanical gardens background soil.*

## 4.4 Techniques to assess pollution of soils by heavy metals

### 4.4.1 Evaluation of heavy metals contamination on the field at 0 – 15 cm and 15 – 30 cm

#### 4.4.1.1 Geoaccumulation Index (Igeo) of dumpsite soils studied

The Geoaccumulation Index (Igeo) of classification by Forstner *et al.* (1993) and Buccolieri *et al.* (2006) was used to evaluate the contamination intensity of the plant metal elements (Cr, Fe, Ni, Cu and Zn) studied (Table 4.23). At 0 - 15 cm depth of soils sampled, Cr contamination was 'uncontaminated to moderate' (0.61) in KYE, 'Very strong' (15.75) contamination intensity in SUA and 'uncontaminated to moderate' (0.73) in AYE. Cr contamination was in an increasing order of KYE < AYE < SUA. Fe contamination in all the three dumpsites soil was 'uncontaminated to moderate' in KYE (0.64), SUA (0.83) and AYE (0.86). Ni was 'uncontaminated to moderate' in KYE (1.00) and AYE (0.69) but 'Strong to very strong' in SUA (4.35). Cu contamination intensity was 'uncontaminated to moderate' in KYE (0.72), 'Strong' in AYE (3.61), 'Very strong' in SUA (24.38). Zn intensity was 'Strong' in KYE (3.32), 'Very strong' in AYE (6.88) and SUA (7.97). (Table 4.24).

**Table 4.23 Geoaccumulation index classification criteria**

| $I_{geo}$ – Index | $I_{geo}$ - class | Contamination intensity |
|---|---|---|
| < 0 | 0 | practically uncontaminated |
| 0 - 1 | 1 | uncontaminated to moderate |
| 1 - 2 | 2 | moderate |
| 2 - 3 | 3 | moderate to strong |
| 3 - 4 | 4 | strong |
| 4 - 5 | 5 | Strong to very strong |
| > 5 | 6 | Very strong |

*Source: Forstener et al. (1993); Buccolieri et al. (2006).*

The Igeo was also used for the non - essential plant metal elements (As, Cd, Hg, and Pb). For As, the contamination intensity was classified as ‘uncontaminated to moderate’ with As in KYE (0.64), AYE (0.66) and SUA (0.67) in the order KYE < AYE < SUA. Cd was ‘uncontaminated to moderate’ in AYE (0.26), KYE (0.57) and SUA (0.71) in the order AYE < KYE < SUA. Hg was ‘uncontaminated to moderate’ in KYE (0.66) and AYE (0.72) but ‘Moderate’ in SUA (1.73). Pb was generally ‘uncontaminated to moderate’ in AYE (0.18), SUA (0.18) and KYE (0.69) (Table 4.24).

**Table 4.24 Geoaccumulation index ($I_{geo}$) and contamination intensity at a soil depth of 0 - 15 cm for selected dumpsites soil**

| | $I_{geo}$ and contamination intensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 0.61<br>Uncontaminated to moderate | 0.64<br>Uncontaminated to moderate | 1.00<br>Uncontaminated to moderate | 0.72<br>Uncontaminated to moderate | 3.32<br>Uncontaminated to moderate | 0.64<br>Uncontaminated to moderate | 0.57<br>Uncontaminated to moderate | 0.66<br>Uncontaminated to moderate | 0.69<br>Uncontaminated to moderate |
| SUA | 15.75<br>Very strong | 0.83<br>Uncontaminated to moderate | 4.35<br>Strong to very strong | 24.38<br>Very strong | 7.97<br>Very strong | 0.67<br>Uncontaminated to moderate | 0.71<br>Uncontaminated to moderate | 1.73<br>Moderate | 0.18<br>Uncontaminated to moderate |
| AYE | 0.73<br>Uncontaminated to moderate | 0.86<br>Uncontaminated to moderate | 0.69<br>Uncontaminated to moderate | 3.61<br>Strong | 6.88<br>Very strong | 0.66<br>Uncontaminated to moderate | 0.26<br>Uncontaminated to moderate | 0.72<br>Uncontaminated to moderate | 0.18<br>Uncontaminated to moderate |

*Location: KYE - Mampong Kyeremfaso dumpsite soil; SUA - Kumasi Suame dumpsite soil; AYE - Kumasi Ayeduase dumpsite soil.*

At soil depth between 15 - 30 cm, an essential element Cr contamination was ‘uncontaminated to moderate’ in KYE Mampong dumpsite soil (0.55), SUA (0.91) and AYE (0.65). Fe contamination in all the three dumpsites soil was ‘uncontaminated to moderate’ in KYE Mampong dumpsite soil (0.42), SUA Kumasi dumpsite soil (0.95) and AYE Kumasi dumpsite soil (0.51). Ni was ‘uncontaminated to moderate’ in KYE (0.64) and AYE (0.51) but ‘Very strong’ contamination intensity in SUA (8.82). Cu contamination intensity was ‘uncontaminated to moderate’ in KYE (0.79), ‘Very strong’ in AYE (38.06), ‘Strong to very strong’ in SUA (4.51). Zn intensity was ‘Moderate to strong’ in KYE (3.31), ‘Very strong’ in AYE (10.10) and SUA (66.69) (Table 4.25).

The $I_{geo}$ was also used for the non-essential plant metal elements (As, Cd, Hg and Pb) For As the contamination intensity was classified as ‘uncontaminated to moderate’ in KYE (0.57), AYE (0.55) and ‘Moderate’ in SUA (1.08). Cd was ‘uncontaminated to moderate’ in AYE (0.41), SUA (0.51) and KYE (0.71) in increasing order of AYE < SUA < KYE. Hg was ‘uncontaminated to moderate’ in KYE (0.64) and AYE (0.55) but ‘Moderate to strong’ in SUA (2.13) in increasing order AYE < KYE < SUA. Pb was ‘uncontaminated to moderate’ in intensity in KYE (0.71), ‘Very strong’ in AYE (5.06) and SUA (23.75) in increasing order of KYE < AYE < SUA (Table 4.25).

Table 4.25 Geoaccumulation index ($I_{geo}$) and contaminated intensity at a soil depth of 15 - 30 cm for selected dumpsites soil

| | $I_{geo}$ and contamination intensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 0.55<br>Uncontaminated to moderate | 0.42<br>Uncontaminated to moderate | 0.64<br>Uncontaminated to moderate | 0.79<br>Uncontaminated to moderate | 2.31<br>Moderate -to strong | 0.57<br>Uncontaminated to moderate | 0.63<br>Uncontaminated to moderate | 0.64<br>Uncontaminated to moderate | 0.71<br>Uncontaminated to moderate |
| SUA | 0.91<br>Uncontaminated to moderate | 0.95<br>Uncontaminated to moderate | 8.82<br>Very strong | 38.06<br>Very strong | 66.69<br>Very strong | 1.08<br>Moderate | 0.51<br>Uncontaminated to moderate | 2.13<br>Moderate to strong | 23.75<br>Very strong |
| AYE | 0.65<br>Uncontaminated to moderate | 0.51<br>Uncontaminated to moderate | 0.71<br>Uncontaminated to moderate | 4.51<br>Strong to very strong | 10.10<br>Very strong | 0.55<br>Uncontaminated to moderate | 0.41<br>Uncontaminated to moderate | 0.55<br>Uncontaminated to moderate | 5.06<br>Very strong |

*Location: KYE - Kyeremfaso Mampong dumpsite soil; SUA - Suame Kumasi dumpsite soil; AYE - Ayeduase Kumasi dumpsite soil.*

#### 4.4.1.2 Enrichment Factor (EF) of dumpsite soils studied

Enrichment Factor (EF) values for the studied soils at 0 - 15 cm depth for essential metal elements (Cr, Fe, Ni, Cu and Zn) was evaluated. There was ‘No human influence’ on Cr levels in KYE (0.96), Cr in SUA was exposed to ‘Very severe modification’ (19.05) while Cr in AYE was under ‘No human influence’ (0.85). Fe enrichment in the three dumpsites soils were under ‘No human influence’ in KYE (1.00), SUA (1.00) and AYE (1.00). Ni was under ‘No human influence’ in KYE (1.05), ‘Severe human influence’ in AYE (5.23) and ‘‘No human influence’ for Fe in SUA (0.81). Cu enrichment in KYE was under ‘No human influence’ for Cu (1.13), ‘Very severe modification’ on SUA (29.49) and ‘Moderate human influence’ for Cu in AYE (4.20). Zn contamination category was under ‘Severe human influence’ in KYE (5.19), SUA (9.64) and in AYE (8.11) (Table 4.27)

The EF for the non - essential plant metal elements (As, Cd, Hg and Pb) contamination category was under ‘No human influence’ with As in KYE (1.11), AYE (0.81) and in SUA (0.77). Cd was similarly under ‘No human influence’ in KYE (0.91), SUA (0.86) and in AYE (0.30). Hg was under ‘No human influence’ in KYE (1.03), AYE (0.84) but Hg was under ‘Minor human influence’ in SUA (2.09). Pb levels was under ‘No human influence’ in KYE (1.07), SUA (0.22) and in AYE (0.21) (Table 4.27).

**Table 4.26 Classification of pollution indices - Enrichment Factor (EF) and Relative Top soil Enrichment Factor (RTEF) criteria**

| EF | Category | RTEF | Interpretation |
|---|---|---|---|
| EF < 2 | no mineral enrichment | 1 ≤ RTEF < 2 | no contamination |
| 2 ≤ EF < 5 | moderate enrichment | RTEF > 2 | contamination |
| 5 ≤ EF < 20 | significant enrichment | RTEF > 2 | contamination |
| 20 ≤ EF < 40 | very high enrichment | RTEF > 2 | contamination |
| EF > 40 | extremely high enrichment | RTEF > 2 | contamination |

*Source: (Sutherland, 2000; Yongming et al., 2006; Ngange et al., 2013).*

**Table 4.27 Enrichment Factor (EF) values and Contamination categories for a soil depth at 0 - 15 cm**

| Location | Enrichment Factor (EF) and contamination category | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 0.96<br>No human influence | 1.00<br>No human influence | 1.05<br>No human influence | 1.13<br>No human influence | 5.19<br>Severe human influence | 1.11<br>No human influence | 0.91<br>No human influence | 1.03<br>No human influence | 1.07<br>No human influence |
| SUA | 19.05<br>Very severe modification | 1.00<br>No human influence | 5.23<br>Severe human influence | 29.49<br>Very severe modification | 9.64<br>Severe human influence | 0.81<br>No human influence | 0.86<br>No human influence | 2.09<br>Minor human influence | 0.22<br>No human influence |
| AYE | 0.85<br>No human influence | 1.00<br>No human influence | 0.81<br>No human influence | 4.20<br>Moderate human influence | 8.11<br>Severe human influence | 0.77<br>No human influence | 0.30<br>No human influence | 0.84<br>No human influence | 0.21<br>No human influence |

*Location: KYE - Kyeremfaso Mampong dumpsite soil; SUA - Suame Kumasi dumpsite soil; AYE - Ayeduase Kumasi dumpsite soil.*

Enrichment Factor (EF) at 15 - 30 cm depth for essential metal elements (Cr, Fe, Ni, Cu, Zn) was 'No human influence' for both Cr level in KYE (1.31) and Cr in SUA (0.96) but Cr in AYE was under 'Very severe modification' (98.21). Fe enrichment in the dumpsites soils were under 'No human influence' in KYE (1.00), SUA (1.00) and AYE (1.00). Ni was under 'No human influence' in AYE (0.95), 'Severe human influence' in SUA (9.31) and ''Minor human influence' for Fe in KYE (1.52). Ni enrichment in KYE was under 'Minor human influence' for Ni (1.52), 'Severe human influence' in SUA (9.31) and 'No human influence' for Ni in AYE (0.95). Cu enrichment in KYE was under 'Minor human influence' for Cu (1.88), 'Very severe modification' in SUA (40.20) and 'Severe human influence' for Cu in AYE (6.16). Zn contamination category was under 'Severe human influence' in KYE (5.49), under 'Very severe modification' in both SUA (40.20) and AYE (13.78) (Table 4.28).

The EF for the non-essential plant metal elements (As, Cd, Hg and Pb) contamination category were under 'No human influence' with As in KYE (1.35), AYE (1.141) and in SUA (0.75). Cd was under 'No human influence' in SUA (0.59), AYE (0.54) and in KYE (1.51). Hg was under 'No human influence' in AYE (0.74), but under 'Minor human influence' in KYE (1.53) and SUA (2.25). Pb level was under 'Minor human influence' in KYE (1.67), but was under 'Very severe modification' in both SUA (25.09) and AYE Kumasi dumpsite soil (70.17) (Table 4.28).

**Table 4.28 Enrichment Factor (EF) values and Contamination categories for a soil depth at 15 - 30 cm**

| | Enrichment Factor (EF) and Contamination category | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 1.31<br>No human influence | 1.00<br>No human influence | 1.52<br>Minor human influence | 1.88<br>Minor human influence | 5.49<br>Severe human influence | 1.35<br>No human influence | 1.51<br>Minor human influence | 1.53<br>Minor human influence | 1.67<br>Minor human influence |
| SUA | 0.96<br>No human influence | 1.00<br>No human influence | 9.31<br>Severe human influence | 40.20<br>Very severe modification | 70.45<br>Very severe modification | 1.14<br>No human influence | 0.59<br>No human influence | 2.25<br>Minor human influence | 25.09<br>Very severe modification |
| AYE | 98.21<br>Very severe modification | 1.00<br>No human influence | 0.95<br>No human influence | 6.16<br>Severe human influence | 13.78<br>Very severe modification | 0.75<br>No human influence | 0.54<br>No human influence | 0.74<br>No human influence | 70.17<br>Very severe modification |

*Location: KYE - Kyeremfaso Mampong dumpsite soil; SUA - Suame Kumasi dumpsite soil; AYE - Ayeduase Kumasi dumpsite soil*

### 4.4.1.3 Relative top soil enrichment factor (RTEF) of soils studied

A relative top soil enrichment factor (RTEF) was calculated for two soil depths between 0 - 15 cm and 15 - 30 cm. RTEF for Cr in KYE (0.65) was higher than Cr in UEW (0.62). In SUA, Cr RTEF (0.71) was higher than in MED (0.04). In AYE, Cr RTEF (1.07) was higher than in KNUST (0.95) (Table 4.29).

Fe RTEF in KYE (1.31) was higher than in UEW (0.85). In SUA, Fe RTEF (0.83) was lower than Fe in MED (0.96). In AYE, Fe RTEF (1.39) was higher than Fe in KNUST (1.18). Ni RTEF in KYE (1.00) was higher than in UEW (0.97). In SUA, Ni RTEF (0.51) was lower than Fe in MED (1.04). In AYE, Ni RTEF (1.04) was lower than Ni in KNUST (1.05) (Table 4.29).

Cu RTEF in KYE (0.84) was lower than in UEW (0.92). In SUA, Ni RTEF (0.67) was lower than in MED (1.05). In AYE, Cu RTEF (0.82) was lower than in KNUST (1.03) (Table 4.29).

Zn RTEF in KYE (1.23) was higher than Zn in UEW (0.86). In SUA, Zn RTEF (0.14) was lower than Zn in MED (1.19). In AYE, Zn RTEF (0.83) was lower than Zn in KNUST (1.22) (Table 4.29).

As RTEF in KYE (1.11) was higher than As in UEW (0.98). In SUA, As RTEF (0.83) was lower than As in MED (1.33). In AYE, As RTEF (0.98) was higher than As RTEF in KNUST (0.82) (Table 4.29).

Cd RTEF in KYE (0.76) was lower than Cd in UEW (0.83). In SUA, , Cd RTEF (0.83) was higher than Cd in MED (0.68). In AYE, Cd RTEF (0.54) was lower than Cd in KNUST (0.83) (Table 4.29).

Hg RTEF in KYE (0.97) was higher than Hg in UEW (0.94). In SUA, Hg RTEF (0.83) was lower than Hg in MED (1.02). In AYE, Hg RTEF (1.05) was higher than Hg in KNUST (0.79) (Table 4.29).

Pb RTEF in KYE (0.89) was lower than Pb in UEW (0.91). In SUA, Pb RTEF (0.02) was lower than Pb in MED (1.01). In AYE, Pb RTEF (1.05) was lower than Pb in KNUST (0.28) (Table 4.29).

**Table 4.29 Relative top soil Enrichment Factor (RTEF) values**

| | Relative Top soil Enrichment Factor | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 0.65 | 1.31 | 1.00 | 0.84 | 1.23 | 1.11 | 0.76 | 0.97 | 0.89 |
| UEW | 0.62 | 0.85 | 0.97 | 0.92 | 0.86 | 0.98 | 0.83 | 0.94 | 0.91 |
| SUA | 0.71 | 0.83 | 0.51 | 0.67 | 0.14 | 0.83 | 0.86 | 0.83 | 0.01 |
| MED | 0.04 | 0.96 | 1.04 | 1.05 | 1.19 | 1.33 | 0.68 | 1.02 | 1.01 |
| AYE | 1.07 | 1.39 | 1.04 | 0.82 | 0.83 | 0.98 | 0.54 | 1.05 | 0.00 |
| KNUST | 0.95 | 1.18 | 1.05 | 1.03 | 1.22 | 0.82 | 0.83 | 0.79 | 0.28 |

*Location: KYE - Mampong Kyeremfaso dumpsite soil; UEW - Mampong University of education Mampong background soil; SUA - Kumasi Suame magazine dumpsite soil; MED - Kumasi Meduma background soil; AYE - Kumasi Ayeduase dumpsite soil; KNUST - Kumasi KNUST botanical gardens background soil.*

### 4.4.2 Evaluation of heavy metals contamination in soils under field conditions

#### 4.4.2.1 Geoaccumulation Index ($I_{geo}$) of dumpsite soils in pots under field conditions

Soils in pots under field conditions contamination intensity for an essential element Cr was 'uncontaminated to moderate' in KYE (0.85), SUA was 'Moderate'(1.16) and AYE was 'uncontaminated to moderate' (0.83). Fe contamination in three dumpsites soil was 'uncontaminated to moderate' in KYE (0.73), SUA (0.71) and AYE (0.79). Ni was 'uncontaminated to moderate' in KYE (0.93), 'Moderate' in AYE (1.17) and 'Moderate' in SUA (1.22). Cu contamination intensity was 'uncontaminated to moderate' in KYE (0.80) and in AYE (0.61), 'Moderate to strong' in SUA (2.22). Zn intensity was 'Very strong' in KYE (7.70), 'Very strong' in AYE (19.14) and 'uncontaminated to moderate' in AYE (0.54) (Table 4.30)

The non - essential metal elements (As, Cd, Hg and Pb) contamination intensity studied was 'uncontaminated to moderate' with As in KYE (0.76), AYE (0.77) and in SUA (0.53). Cd was 'Moderate' in KYE (1.40), SUA (1.16) and in AYE (1.11). Hg was 'Moderate' in KYE (1.70), 'Moderate to strong' in SUA (2.19) but 'Uncontaminated to moderate' in AYE (0.60). Pb intensity was 'Moderate to strong' in KYE (2.55), 'Moderate to strong' in SUA (2.65) and 'Very strong' in AYE (15.69) (Table 4.30).

**Table 4.30 Geoaccumulation index ($I_{geo}$) and contamination intensity for soils in pots under field conditions**

| | $I_{geo}$ and contamination intensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 0.85<br>Uncontaminated to moderate | 0.73<br>Uncontaminated to moderate | 0.93<br>Uncontamiated to moderate | 0.80<br>Uncontamiat-ed to moderate | 7.70<br>Very strong | 0.76<br>Uncontaminated to moderate | 1.40<br>Moderate | 1.70<br>Moderate | 2.55<br>Moderate to strong |
| SUA | 1.16<br>Moderate | 0.71<br>Uncontaminated to moderate | 1.22<br>Moderate | 2.22<br>Moderate to strong | 19.14<br>Very strong | 0.77<br>Uncontaminated to moderate | 1.16<br>Moderate | 2.19<br>Moderate to strong | 2.65<br>Moderate to strong |
| AYE | 0.83<br>Uncontaminated to moderate | 0.79<br>Uncontaminated to moderate | 1.17<br>Moderate | 0.61<br>Uncontaminated to moderate | 0.54<br>Uncontaminated to moderate | 0.53<br>Uncontaminated to moderate | 1.11<br>Moderate | 0.60<br>Uncontaminated to moderate | 15.69<br>Very strong |

*Location: KYE - Mampong Kyeremfaso dumpsite soil; SUA - Kumasi Suame dumpsite soil; AYE - Kumasi Ayeduase dumpsite soil.*

#### 4.4.2.2 Enrichment factor (EF) of dumpsite soils in pots

Enrichment Factor (EF) categorized on soils in pots under field studies for selected essential plant metal elements (Cr, Fe, Ni, Cu, Zn) was under 'No human influence' for both Cr level in KYE (1.18) and Cr in SUA (1.04) but Cr in AYE was under 'Minor severe modification' (1.66). Fe enrichment in the three dumpsites soils was under 'No human influence' in KYE (1.00), SUA (1.00) and AYE (1.00). Ni was under 'No human influence' in both on KYE (1.28) and AYE (1.47) but under 'Minor human influence' in SUA (1.74). Cu enrichment in KYE was under 'No human influence' in both KYE (1.18) and AYE (0.77) but 'Moderate human influence' in SUA (3.17). Zn contamination category was under 'Very severe modification' in both KYE (10.45) and SUA (27.34) and under 'No human influence' in AYE (0.68) (Table 4.31).

The EF was also used on non - essential plant metal elements (As, Cd, Hg and Pb) in dumpsites soils in pots contamination was under 'No human influence' with As in KYE (1.10), AYE (1.10) and in SUA (0.66). Cd was under 'Minor human influence' in both KYE (1.93) and SUA (1.66) but 'No human influence' in AYE (1.38). Hg was under 'No human influence' in AYE (0.76), 'Minor human influence' in KYE (2.29) and 'Moderate human influence' in SUA (3.13). Pb level was under 'Moderate human influence' in both KYE (3.52) and SUA (3.79) but 'Severe human influence' in AYE (6.05) (Table 4.31).

**Table 4.31 Enrichment Factor (EF) values and Contamination categories for soils in pots under field conditions**

| | Enrichment Factor (EF) and Contamination category | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Soil Source | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 1.18<br>No human influence | 1.00<br>No human influence | 1.28<br>No human influence | 1.18<br>No human influence | 10.45<br>Very severe modification | 1.10<br>No human influence | 1.93<br>Minor human influence | 2.29<br>Minor human influence | 3.52<br>Moderate human influence |
| SUA | 1.66<br>Minor human influence | 1.00<br>No human influence | 1.74<br>Minor human influence | 3.17<br>Moderate human influence | 27.34<br>Very severe modification | 1.10<br>No human influence | 1.66<br>Minor human influence | 3.13<br>Moderate human influence | 3.79<br>Moderate human influence |
| AYE | 1.04<br>No human influence | 1.00<br>No human influence | 1.47<br>No human influence | 0.77<br>No human influence | 0.68<br>No human influence | 0.66<br>No human influence | 1.38<br>No human influence | 0.76<br>No human influence | 6.05<br>Severe human influence |

*Soil Source: KYE - Mampong Kyeremfaso dumpsite; SUE - Kumasi Suame dumpsite; AYE - Kumasi Ayeduase dumpsite*

#### 4.4.2.3 Transfer ratio (TR) of metals in dumpsite soils in pots under field conditions

The transfer ratio (TR) of Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb in dumpsites soils in pots for Cr in KYE (0.39) was higher than TR for UEW (0.21). In SUA, Cr TR (0.29) was lower than TR for Cr in MED (0.37). In AYE, Cr TR (0.17) was lower than TR for Cr in KNUST (0.21) (Table 4.32).

TR for Fe in KYE (0.38) was lower than TR for UEW (0.45). In SUA, Fe TR (0.0.41) was lower than TR for Fe in MED (0.49). In AYE, TR for Fe (0.29) was lower than TR for Fe in KNUST (0.31) (Table 4.32).

TR for Ni in KYE (0.25) was lower than TR for Ni in UEW (0.39). In SUA, Ni TR (0.21) was lower than TR for Ni in MED (039). In AYE, TR for Ni (0.23) was lower than TR for Ni in KNUST (0.35) (Table 4.32).

TR for Cu in KYE (0.28) was lower than TR for Cu in UEW (0.45). In SUA, Cu TR in SUA (0.61) was higher than TR for Cu in MED (0.48). In AYE, TR for Cu (0.41) was higher than TR for Cu in KNUST (0.24) (Table 4.32).

TR for Zn in KYE (0.24) was lower than TR for Zn in UEW (2.64). In SUA, Zn TR (0.51) was higher than TR for Zn in MED (0.46). In AYE, TR for Zn (0.18) was higher than TR for Zn in KNUST (0.23) (Table 4.32).

As TR level in KYE (0.41) was lower than the TR level for As in UEW (0.55). In SUA, As TR (0.36) was lower than TR of As in MED (0.46). In AYE, TR for As (0.31) was higher than TR for As in KNUST (0.28) (Table 4.32).

Cd recorded a TR level in KYE (0.11) and was lower than the TR level for Cd in UEW (0.23). In SUA, Cd TR (0.18) was lower than TR of Cd in MED (0.33). In AYE, TR for Cd (0.21) was higher than TR for Cd in KNUST (0.31) (Table 4.32).

TR for Hg in KYE (0.16) was lower than TR for Hg in UEW (0.41). In SUA, Hg TR (0.14) was higher than TR for Hg in MED (0.43). In AYE, TR for Hg (0.18) was higher than TR for Hg in KNUST (0.23) (Table 4.32).

TR for Pb in KYE (0.08) was lower than TR for Pb in UEW (0.33). In SUA, Pb TR (0.15) was lower than TR for Pb in MED (0.39). In AYE, TR for Pb (0.05) was lower than TR for Pb in KNUST (0.31) (Table 4.32).

**Table 4.32 Transfer ratio (TR) values of metals in lettuce in pots under field conditions**

| | Transfer ratio | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Soil Source | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 0.39 | 0.38 | 0.25 | 0.28 | 0.24 | 0.41 | 0.11 | 0.16 | 0.08 |
| UEW | 0.21 | 0.45 | 0.39 | 0.40 | 2.64 | 0.55 | 0.23 | 0.41 | 0.33 |
| SUA | 0.29 | 0.41 | 0.21 | 0.61 | 0.51 | 0.36 | 0.18 | 0.14 | 0.15 |
| MED | 0.37 | 0.49 | 0.39 | 0.48 | 0.46 | 0.45 | 0.33 | 0.43 | 0.39 |
| AYE | 0.17 | 0.29 | 0.23 | 0.41 | 0.18 | 0.31 | 0.21 | 0.31 | 0.05 |
| KNUST | 0.21 | 0.31 | 0.35 | 0.24 | 0.23 | 0.28 | 0.31 | 0.23 | 0.31 |

*Treatments: KYE - Mampong Kyeremfaso dumpsite; UEW - Mampong University of education background soil; SUA - Kumasi Suame magazine dumpsite soil; MED - Kumasi Meduma background soil; AYE - Kumasi Ayeduase dumpsite soil; KNUST - Kumasi KNUST botanical gardens background soil.*

#### 4.4.2.4 Translocation factor (TF) of metals in dumpsite soils in pots under field conditions

The translocation factor (TF) of Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb on the selected soils in pots under field conditions for Cr in KYE (1.45) was lower than TF for UEW (1.82). In SUA, Cr TF (1.09) was lower than TF for Cr in MED (1.92). In AYE, Cr TF (1.04) was lower than TF for Cr in KNUST (1.07) (Table 4.33).

TF for Fe in KYE (1.02) was lower than TF for UEW (1.42). In SUA, Fe TF (1.09) was lower than TF for Fe in MED (1.13). In AYE, TF for Fe (1.04) was higher than TF for Fe in KNUST (1.03) (Table 4.33).

TF for Ni in KYE (1.01) was lower than TF for Ni in UEW (1.18). In SUA Kumasi dumpsite soil, Ni TF (1.05) was lower than TF for Ni in MED (1.1.19). In AYE, TF for Ni (1.07) was higher than TF for Ni in KNUST (0.84) (Table 4.33).

TF for Cu in KYE (0.79) was lower than TF for Cu in UEW (1.09). In SUA, Cu TF (1.65) was higher than TF for Cu in MED (1.21). In AYE, TF for Cu (1.41) was higher than TF for Cu in KNUST (0.80) (Table 4.33).

TF for Zn in KYE (0.63) was lower than TF for Zn in UEW (0.76). In SUA Kumasi dumpsite soil, Zn TF (1.71) was higher than TF for Zn in MED (1.28). In AYE, TF for Zn (0.99) was lower than TF for Zn in KNUST (1.44) (Table 4.33).

As recorded a TF level in KYE (0.97) and was lower than the TF level for As in UEW (1.68). In SUA, As TF (1.09) was lower than TF of As in MED (1.24). In AYE, TF for As (0.54) was lower than TF for As in KNUST (1.47) (Table 4.33).

Cd recorded a TF level in KYE (1.13) and was lower than the TF level for Cd in UEW (1.21). In SUA, Cd TF (0.99) was lower than TF of Cd in MED (1.11). In AYE, TF for Cd (0.94) was higher than TF for Cd in KNUST (1.17) (Table 4.33).

TF for Hg in KYE (1.16) was lower than TF for Hg in UEW (1.21). In SUA, Hg TF (1.11) was lower than TF for Hg in MED (1.25). In AYE, TF for Hg (1.09) was lower than TF for Hg in KNUST (1.17) (Table 4.33).

TF for Pb in KYE (0.95) was lower than TF for Pb in UEW (1.16). In SUA, Pb TF (0.71) was lower than TF for Pb in MED (1.13). In AYE, TF for Pb (0.10) was lower than TF for Pb in KNUST (0.84) (Table 4.33).

**Table 4.33 Translocation factor (TF) values of lettuce in pots under field conditions**

| Soil Source | Translocation factor | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cr | Fe | Ni | Cu | Zn | As | Cd | Hg | Pb |
| KYE | 1.45 | 1.02 | 1.01 | 0.79 | 0.63 | 0.97 | 1.13 | 1.16 | 0.95 |
| UEW | 1.82 | 1.42 | 1.18 | 1.09 | 0.76 | 1.68 | 1.21 | 1.21 | 1.16 |
| SUA | 1.09 | 1.09 | 1.05 | 1.65 | 1.71 | 1.09 | 0.99 | 1.11 | 0.71 |
| MED | 1.92 | 1.13 | 1.19 | 1.21 | 1.28 | 1.24 | 1.11 | 1.25 | 1.13 |
| AYE | 1.04 | 1.04 | 1.07 | 1.41 | 0.99 | 0.54 | 0.94 | 1.09 | 0.10 |
| KNUST | 1.07 | 1.03 | 0.84 | 0.80 | 1.44 | 1.47 | 1.17 | 1.17 | 0.84 |

*Treatments: KYE - Kyeremfaso dumpsite soil; UEW - Unuversity of education Mampong background soil; SUA - Suame magazine Kumasi dumpsite soil; MED - Meduma Kumasi background soil; AYE -Ayeduase Kumasi dumpsite soil; KNUST - KNUST botanical gardens Kumasi background soil.*

# CHAPTER FIVE

## 5.0 DISCUSSION

### 5.1 Study One: - Dumpsite farmers' awareness of soil physicochemical propereties dumpsites

#### 5.1.1 Socio - demographic characteristics of dumpsite farmers in three communities

The socio-demographic studies of the dumpsites farmers interviewed showed that farming activities on the various dumpsites were dominated by males and were within an active age group (36 - 45 years) (Table 4.1) and these findings conform to an earlier work by Agyarko *et al.* (2011) who reported on a similar results that, farmers studied were dominated by males with an average age of 43 years.

Majority (57 %) of the farmers in the current studies had attained Middle / JHS education and farmers (19%) with a Primary school education (Table 4.1). This trend was similar to Dawoe *et al.* (2012) who reported that a majority (77.8%) of farmers whom they interviewed had primary school level of education.

#### 5.1.2 Reasons for farming on dumpsites

Most (63%) dumpsite farmers interviewed (Figure 3.1) farm on dumpsites because such soils are fertile (Table 4.2). The farmers' reason can be explain by the fact that organic wastes dumped on these sites decompose and add up to the soil nutrient pool. This finding agrees with work by Ahlijay *et al.* (2015). Other (20 %) farmers farm on dumpsites because it is the only available land, but the few (17 %) farmers said they do so because of the low cost of dumpsites farmlands. Dumpsites farmlands which according to the interviewed farmers are among the only available land very useful which doubles as plants nutrients rich soils and as such are used as compost for soil amendment in vegetable production as reported by Wunzani *et al.* (2019). Monohara and Belagali *et al.* (2014); Bamidele *et al.* (2014); Amadi *et al.* (2013) shared similar view.

### 5.1.3 Farmers awareness of dumpsites soil physicochemical properties

Dumpsites farmers (81%) interviewed responded that they are aware of their dumpsites soil physicochemical properties (Figure 4.1), an indication that, farmers' perception of soils are not only limited to soil nutrient status alone but also the soils' physical properties as reported earlier by Corbeels *et al.* (2000).

In addition, most farmers (66%) responded that, their soils have high nutrient content, while 28% said their soils contained some levels of heavy metals and the few (6%) said their soils had low nutrient content (Table 4.3). This is indicates that farmers are aware of the soil nutrient level such as, texture, moisture, temperature, soil organic matter, available nitrogen, phosphorus and potassium and these findings agrees with work by Tale and Ingole (2015). Furthermore, the result can also be explained by the fact that, dumpsite farmers have their own local knowledge that enables them to arrive at decisions in farming in order to maximize yield and profit to better their lot (Kolawole, 2002). Farmer's perceived knowledge of a fertile soil can be likened to a modern concept of a quality soil which is the soils' ability to sustain plant and animal productivity, to increase quality water and air and to contribute to plant and animal health (Doran and Zeiss, 2000). It is further affirmed that, Ghanaian farmers know indigenous soil science with sets of information about their farmlands especially their fertitlity status as shown by crops yield, colour of soil, vegetation cover, soil depth, soil organic matter and activities of soil organisms (Agyarko *et al.,* 2011). Farmers using indicators such as fertile (high soil nutrient) and infertile (low soil nutrient) about their soils' physicochemical properties awareness have also been reported by Dawoe *et al.* (2012), where farmers see dark soil colour, earthworms casts as fertile soil and slow plant growth, pale soil colour and few worms cast as infertile soil.

### 5.1.4 Sources of knowledge acquisition for soil physicochemical characteristic by dumpsite farmers

Majority (40%) of dumpsites farmers interviewed responded that, they accessed their soil physicochemical information from colleague farmers, extension officers (30%), the media (16%) and non-governmental organization (N.G.O) (14%). This finding can also be explained by the fact that, farmers have availability of sources with respect to their soils' information. of soil physicochemical knowledge information which doubles their efforts to maximize yield from their farmlands. Gupta and De (2011); Sakib *et al.* (2015) and Rahman *et al.* (2016) share similar findings about how farmers use of information sources contribute to the maximization of crop yield on their farmlands. The situation where farmers mostly found other farmers as their source of knowledge (Table 4.4) is supported by an earlier work by Farouque *et al.* (2019) that friends and neighbours play important roles in dissemination of farming information. Sumane *et al.* (2017) have found that farmers are from farming families, so they obtain their initial agricultural knowledge from their parents, grandparents and importantly other farmers because they see their colleague farmers as reputation experts, particularly due to their practical experience in similar conditions. De Souza *et al.* (2016) further explained that, soil properties information perceived by farmers are based on observation and life experiences over time, which is accumulatively transmitted over generations. Laekemariam *et al.* (2017) have affirmed that farmers acquired their soil knowledge from generations of experience and experimentation that fit local conditions. The print media and other social networks information sources to farmers have also been confirmed (Rahman *et al.,* 2013; Farouque *et al.,* 2019). Other source of information on soil properties to farmers are extension officers as earlier reported by Rydberg *et al.* (2008) with the reason that, farmers access information frequently when visit personal friends or agriculture office.

### 5.1.5 Farmers awareness of soil metals contamination on human and animal's health

Most farmers (94%) interviewed were aware of the effect of heavy metals contamination on man and animals' health while few (4%) were not aware (Table 4.5). This is an indication of dumpsites farmer's awareness of an environmentally friendly agriculture as confirmed by a 61.33 % of community members who showed an awareness of environmentally friendly agriculture and resulting into increasing growth, quality and productivity of agricultural land (Atmojo, 2010; Utari *et al.,* 2018). Also, dumpsites farmers' high awareness level of heavy metals contamination did not conform to an earlier report by Pradika *et al.* (2019) about low awareness level shown by people on heavy metals contamination on agricultural land and it does not promote environmentally friendly agriculture.

Dumpsites farmer’s awareness on ailments prevalent in the various dumpsites communities studied (Table 4.6) is similar to an earlier report by Coffie (2010) on a landfill site with a reported number of infectious diseases like malaria, cholera, diarrhea and typhoid fever. Owusu - Sekyere *et al.* (2013a) study at Dompoase, a community within the Kumasi metropolis in the Ashanti region of Ghana, similarly reported of an increased self - reported health symptoms such as fatigue and headaches among residents near landfill sites. Reported effects of heavy metals contamination on human and animals health as reported (Table 4.6) by the dumpsite farmers agrees with an assertion by Singh and Kalamdhad (2011) that heavy metals accumulated levels in plant parts are threat to human and animals’ health because utilized food crops contaminated with heavy metals like Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb are known major food chain route for human exposure especially concentration levels in plants which are above normal or permissible limits classified them as toxic due to the fact that, they are metabolized by the body and may subsequently accumulated in the soft tissues to affect human and animals’ health leading to conditions like cough, diarrhea, skin rashes and cholera (Table 4.6) is supported by Sobha *et al.* (2007) that, Cd toxicity in large organs like liver, placenta, kidney, lungs, brains and bones have been identified.

Clinical signs of Zn toxicosis have been reported as vomiting, diarrhea, bloody urine, yellow mucus membrane, liver failure, kidney failure and aneamia (Duruibe *et al.,* 2007). Moreover, excessive human intake of Cu may lead to severe mucosal irritation and corrosion, capillary damage, hepatic and renal damage and the central nervous irritation followed by depression (Singh and Kalamadhad, 2011). Ni exposure may vary from skin irritation to damage to the lungs (Argun *et al.,* 2007). In addition, dumpsite farmers are not only affected victims from heavy metals contamination but the people who live near dumpsite areas are also not spared of heavy metal toxicity (Abishek and Surrendra, 2016). Farmers (28%) description of their dumpsites soils indicated that their soils contain heavy metals (Table 4.3), an indication that of the use of dumpsites for direct vegetables production, because farmers have reported that dumpsites soils contain plant nutrients (Table 4.3). This results agree with a report dumpsite soils serve as compost for farmers in Ghana (Owusu-Sekyere *et al.,* 2013a) but are not without soil pollution problems (Nwaogu *et al.,* 2014; Stefang *et al.,* 2017).

### 5.1.6 Chi - square ($\chi^2$) test analysis of association between dumpsites farmers' physicochemical knowledge and other variables

The absence of (p = 0.21) significant influence or association between dumpsites farmers' soil physicochemical knowledge and these variables like dumpsites farmers' educational level, dumpsites farmers' reasons for farming on dumpsites (p = 0.55) and sources of dumpsites farmers' soil physicochemical knowledge (p = 0.17) (Table 4.7) might be due to either known or unknown factors other than these factors used in the analysis and is in agreement with earlier work by Sierra *et al.* (2016) who found no association between farmers' income, gender, educational level, age and knowledge on soil properties.

The significant association between dumpsites farmers' soil physicochemical knowledge and farmers' awareness that dumpsite soils contain toxic metal elements (p = 0.02) (Table 4.8) was expected because heavy metals are related to the farmers' soil physicochemical knowledge sourced from other farmers conforms to an earlier studies by Rydberg *et al.*

(2008) who found that farmers sourced agriculture information from localite (other friends or farmers and cosmolite (agriculture office). Moreover, an association found between farmers' soil physicochemical knowledge and the awareness that plants on dumpsites soil absorb toxic metal elements is expected as affirmed by Achazai *et al.* (2011) that plants have a natural propensity to take up metals.

## 5.2 Study Two: - Assessment of heavy metals level in selected dumpsite soils and their accumulation levels in plantain and cocoyam

### 5.2.1 Soil physicochemical properties of selected soils at Mampong and Kumasi

The soil physicochemical results showed an improved soil bulk density, soil pH, total organic matter, total nitrogen, and soil available phosphorus of dumpsite soils than background soils. These improved soil properties may be attributed to the materials emanating from the municipal and metropolis solid and liquid wastes deposited on dumpsites and this affirms the report by Krishna *et al.* (2016). Soil bulk density results were lower in the dumpsites soils than in background soils but with no significant ($p = 0.88$) difference. This may be due to the sand, sand clay loam and loamy sand textural class of the studied soils although was not significant, could have contributed to the improved soil property especially on the dumpsites and this results conform to a report by Tripathy and Misra (2012) that, soil texture plays a very important function by influencing other physical parameters of the soil.

The soil at SUA was slightly acidic as compared to slightly basic MED, which may be related to the textural differences between these two study soils (Table 4.8). Oyedele *et al.*

(2008) shared a similar finding by attributing such differences to differences in biological activity, temperature and disposal of municipal wastes on dumpsites. Slightly basic KYE and AYE as compare to slightly acidic UEW and KNUST shows an important quality feature of a natural soil as reported by Umar *et al.* (2016). Improved soil total organic carbon, total organic matter, total nitrogen, soil available phosphorus, exchangeable cations (Ca, Mg, K and Na), exchangeable acicdity, cation exchange capacity and base saturation on KYE, SUA and AYE than in UEW, MED and KNUST (Table 4.8) show a high nutrient rich property in dumpsite soils than background soils due to the presence of organic wastes dumped on dumpsites after decay might have contributed to the essential nutrients in the dumpsites soils. This finding conforms to an earlier report that dumpsite soils are known to be rich in soil nutrient for plant growth and development (Ogunmodede and Adewole, 2015) and that could be related to decayed and composted wastes found on dumpsite that enhance the fertility of dumpsites soils (Ogunyemi *et al.,* 2003). Such soils which support plant growth and production contain essential mineral materials (Uma *et al.,* 2016) and these essential plant nutrients might have been released from the wastes found on dumpsites after decomposition (Anikwe and Nwobodo, 2001). Also, the essential mineral materials from wastes help to increase nitrogen, pH, CEC, base saturation and organic matter. Higher soil organic matter levels in (Table 4.8) dumpsite soils may be as a result of continuous addition of high organic matter (Tripathi and Misra, 2012). Similarly, the high organic matter contents especially in dumpsite soils might have accumulated from subsequent decomposition of plant residue waste materials as reported by Gairola and Soni (2010).

### 5.2.2 Heavy metals level in selected dumpsites soil at different depths

#### 5.2.2.1 Chromium (Cr)

Chromium (Cr) is one of the metal nutrient elements required by plants in the soil in trace amounts for their physiological processes (Ehi and Uzu, 2011). Cr levels at both 0 - 15 cm and 15 - 30 cm depth (Table 4.9) were generally higher on dumpsite soils than on background soils and with a highly significant ($p = 0.01$) difference between Cr in dumpsite soils and background soils. Cr is a less mobile in soils, therefore Cr increased levels may be attributed to Cr containing compounds which might have been dumped on the dumpsites and might have accumulated in the soil. Wuana and Okieimen (2011) share a similar view that Cr does not occur naturally in elemental form but only in compounds. Cr higher levels in the different soil depths at 15 - 30 cm depth than at 0 - 15 cm could be due to the differences in soil properties with respect to depth with special reference to clay content and organic matter content (Table 4.8). This result conforms to a report by Engege and Lemoha (2012) that, dumpsite soils show variability in soil properties with depth.

The influence of slightly acidic soil have been reported by Adelekan and Alawode (2011) that, metal availability is relatively low when pH is around 6.5 - 7. However, with increasing soil pH, the solubility of most trace elements may decrease leading to low concentration in soil solution (Kabata - Pendias, 2011). Also, soil pH increases correlate with mineralogy changes in solution chemistry which in addition influences base cation concentration (Alamgir, 2017).

The soil textural class of the sampled soils might have contributed to the metals level in soils as reported by Sheoran *et al.* (2016) that, trace elements retainability is higher in fine - textured soils (clay and clay loam) compared with coarse - textured soils (sand). Gupta *et al.* (2019) shared similar view.

Chromium (Cr) levels in study soils were higher (Table 4.9) than the world's soil average level (59.50 mgkg$^{-1}$) as reported by Onyedika (2015). However, Cr levels recorded (Table 4.9) were in the range of 3.25 - 76.76 mgkg$^{-1}$ and 63.19 - 109.69 mgkg$^{-1}$ at both 0 - 15 cm and 15 - 30 cm depths respectively were above the critical concentration (Table 2.6) 5 - 30 mgkg$^{-1}$ but were within the 5 - 1500 mgkg$^{-1}$ by Radojevic and Baskin (2006). Cr levels at 0 - 15 and 15 - 30 cm depths were also found to be within (Table 2.4) 100 mgkg$^{-1}$ by Iniobong and Uduakobong (2017). This result show that Cr levels have no implication for soil toxicity in soils studied.

### 5.2.2.2 Iron (Fe)

Iron (Fe) as an essential and an abundant metal element (Onyedika, 2015) was generally higher in dumpsite soils than in background soils at both 0 - 15 cm and 15 - 30 cm depths (Tables 4.9 and 4.10). The higher Fe levels in KYE, SUA and AYE than in UEW, MED and KNUST might be due to the abundant nature of Fe in most soils as reported by Hameed *et al. (*2013). Higher Fe levels in dumpsites than in background soils could also be linked to Fe bearing compounds among wastes found on dumpsites which might have added up to the Fe levels in dumpsites. The higher Fe levels agrees with a report by Onyedika (2015) that major sources of Fe are the iron oxides such as minerals hematite, magnetite and taconite which are commonly found on dumpsites. Higher Fe levels in dumpsite soils at both 0 - 15 cm and 15 - 30 cm depths were due to the accumulation of heavy metals concentrations at the soil - surface than the sub-surface (Amadi *et al*., 2012; Olalode *et al*., 2014). Also, the higher Fe levels in dumpsites might have contributed significantly to the relatively higher soil pH (Table 4.8) in the study soils. Level of soil pH < 5 have been found to increase metals mobility as a result of increased proton concentration (Mclaughlin *et al*., 2000; Paulose *et al*., 2007). This report confirms the assertion that Fe is the most abundant and an essential constituent for all plants and animals (Shah *et al.,* 2013). Fe levels in KYE, SUA and AYE at both 0 - 15 cm and 15 - 30 cm depths were higher than Fe levels UEW, MED and KNUST. These results may be explained by the slightly higher soil pH values (Table 4.8) in KYE, SUA and AYE than in UEW, MED and KNUST. These results differ from an earlier report by Alamgir (2017) that, in acidic pH range, more protons ($H^+$) are available to saturate metal binding sites; therefore, metals are less likely to form insoluble precipitates. However, these results conform to report of possible combined effects of soil properties on metals sorption and desorption (Harter and Naidu, 2001; Appel and Ma, 2002; Dutta *et al*., 2011).

The differences in Fe levels at 0 - 15 cm and 15 - 30 cm depths in all the dumpsites as compared to the background site soils has also been reported by Olowookere *et al.* (2018). The Fe levels at 0 - 15 cm and 15 - 30 cm depths were generally above (Table 2.5) 48 mgkg$^{-1}$ (FAO/WHO, 2011), 10 - 100 mgkg$^{-1}$ (Table 2.7) by WHO/FAO (2001), but within the 5000 - 100 000 mgkg$^{-1}$ normal range of metals in soils (Table 2.6) reported by Radojevic and Baskin (2006)

### 5.2.2.3 Nickel (Ni)

Soil Ni recorded higher levels in KYE, SUA and AYE than in UEW, MED and KNUST at both 0 - 15 cm and 15 - 30 cm depths at a highly significant ($p = 0.01$) difference between them. This result may be attributed to an increased soil pH levels in dumpsite soils as compared to a weakly acidic soil pH of UEW (Tables 4.9 and 4.10). This report agrees with a report by Fine *et al.* (2005) with a report of an alkaline ($pH > 7$) conditions, where soil organic matter dissociates from heavy metals which finally may increase the bioavailability of heavy metals bound to organic matter. These results may also be linked to the widely distributed nature of Ni within the environment as released from both natural sources and anthropogenic activity with input from both stationary and mobile sources (Orji *et al.,* 2018).

The type of Ni bearing wastes found on municipal and metropolis dumpsites as reported by Alloway (1995) in a study might also have contributed as a result many domestic cleaning products such as soap (100 - 700 $mgkg^{-1}$) and powdered bleach (800 $mgkg^{-1}$) may prove to be important sources of Ni in urban soils. Also, other sources of Ni in dumpsites may include food stuffs such as chocolate, automobile batteries and various paint wastes (Onyedika, 2015) periodically dumped onto dumpsites. The concentration of Ni in dumpsites within metropolis were higher than Ni levels in the dumpsite studied in the rural community within a municipal. Such differences were observed as a result of the type of disposed material from mechanical shops and surrounding houses and are in agreement with the reason that Ni finds its way into the ambient air as a result of the combustion of coal, diesel oil, fuel oil and the incineration of waste and sewage (Cempel *et al*., 2006). Also, such differences may be due to higher population and industrial activities in cities which may lead to higher production of assorted waste than in the rural settlements. This result conforms to an earlier report by Agyarko *et al.* (2010). A major use of Ni as a raw material in steel and other metal products could have contributed to the high amount of Ni (Wuana and Raymond, 2011) in Metropolis dumpsite soil.

Nickel (Ni) concentration in SUA at 0 - 15 cm (113.08 mgkg$^{-1}$) and 15 - 30 cm (222.17 mgkg$^{-1}$) being the highest among all Ni levels was above 20 mgkg$^{-1}$ by Alloway (1995); 50 mgkg$^{-1}$ (Table 2.7) by WHO / FAO (2001); 16.52 - 17.24 mgkg$^{-1}$ in an automobile mechanic waste dump soil in Nigeria by Iwegbue *et al*. (2006); 89.76 - 118.35 mgkg$^{-1}$ on dumpsites soil and 20.08 mgkg$^{-1}$ on control soil by Ogunmodede *et al*. (2015); but was within a polluted soil range of 200 – 2600 mgkg$^{-1}$ and that of overall range of 10 - 1000 mgkg$^{-1}$ found in natural soil (Izosimora, 2005). High Ni levels in SUA was also within 2 - 750 mgkg$^{-1}$ (Table 2.6) by Radojevic and Baskin (2006), while all the remaining dumpsites and background soils Ni was within the allowable concentration levels. The background soils or the unpolluted soils were below the 34 mgkg$^{-1}$ of Ni reported by Kabata - Pendias and Pendias (2001) as the calculated world's mean Ni level in unpolluted soil. Ni is an essential trace element for human and animal health (Zighan Hassan *et al*., 2012), but a lower Ni concentrations in the selected studied sites might be toxic even at low concentrations (Aekola *et al*., 2012).

#### 5.2.2.4 Copper (Cu)

Copper (Cu) an essential metal element found in the soil was higher in KYE, SUA and AYE than in UEW, MED KNUST at both 0 - 15 cm and 15 - 30 cm depths (Tables 4.9 and 4.10).

Such Cu levels in KYE, SUA and AYE dumpsite soils might have been influenced by the natural occurrence of Cu in some soils which is derived from anthropogenic activities such as the use of copper containing fungicides, urban wastes management and industrial activity (Giovani *et al*., 2005). Higher Cu levels in SUA and AYE dumpsite soils within Kumasi metropolis comapare to KYE, a dumpsite within a rural community in Mampong metropolis may be attributed to higher population and industrial activities in cities and municipalities which could have led to higher production of assorted wastes than in the rural settlements (Agyarko *et al*., 2010). Some of the reasons might also be due to the differences in living standards, consumption patterns and level of industrial development between cities and rural communities (Ebong *et al*., 2008). Cu accumulation though high on dumpsite soils (Tables 4.9 and 4.10), is a necessity for many enzymes (Shah *et al.,* 2013; Ngange *et al.,* 2013), a macro nutrient for plants (Ngange *et al.,* 2013) in addition to its numerous applications as a result of its physical properties (Hameed *et al.,* 2013). Soil pH levels between the ranges of 6.07 - 9.04 (Table 4.8) is higher than pH 5.5 and that might have influenced the Cu lower levels in most studied soils with the exception of SUA and AYE (Tables 4.9 and 4.10). Such influence from low soil pH could be explained with the fact that, the solubility of Cu is drastically increased at pH 5.5 (Martinez and Motto, 2000).

The high Cu loads in especially SUA and AYE at both 0 - 15 cm and 15 - 30 cm depths was expected because, the two dumpsite soils were from Kumasi metropolis - a city, and due to the kind of waste disposed, most of the wastes may be mostly Cu bearing wastes as reported by Greany (2005), that, Cu is the third most used metal in the world, as a result accumulates in the surface horizons, a phenomenon explained by the bioaccumulation of the metal and recent anthropogenic sources (Hameed *et al*., 2013). In addition, anthropogenic activities on rural or sub-urban areas are lower with the disposal of wastes on dumpsites than on metropolitan dumpsites where more wastes are generated as reported by Charlesworth *et al*. (2013).

Cu levels in the soil which were in the range of (9.64 – 454.56 $\mathrm{mgkg^{-1}}$) at 0 – 15 cm depth and (9.38 – 674.19 $\mathrm{mgkg^{-1}}$) at 15 – 30 cm depth were, however, above the worlds' scale value of non – polluted soil of 24.00 $\mathrm{mgkg^{-1}}$ by Pendias and Pendias (2001); 30.00 $\mathrm{mgkg^{-1}}$ (WHO/FAO, 2011); 100.00 $\mathrm{mgkg^{-1}}$ (WHO/FAO, 2001; Shal *et al.,* 2011); 10 $\mathrm{mgkg^{-1}}$ by WHO/FAO (2007); 2 – 250 $\mathrm{mgkg^{-1}}$ by Radojevic and Bashkin (2006). This is an indication that, SUA dumpsite soil at 0 – 15 cm and 15 – 30 cm depths are contaminated with Cu.

#### 5.2.2.5 Zinc (Zn)

Zinc (Zn) levels in KYE, SUA and AYE (Tables 4.9 and 4.10) were generally higher in concentration than on UEW, MED and AYE. Such differences observed may be related to Zn accumulation from garden fertilizing activities, traffic and industrial input (Imperato *et al*., 2003). Also, Zn high concentrations level in KYE SUA, AYE than in UEW, MED KNUST could be due to anthropogenic additions as a result of industrial activities such as mining, waste combustion, steel processing couple with dumpsite plants and our inability to handle these Zn concentrations already in their system through accumulation (Wuana and Okieimen, 2010) might have contributed to the higher Zn values on dumpsite soils.

The mobility of Zn in soils is dependent on its speciation, the soil pH and high soil organic matter content (IPCS, 2001). The combined effect of soil pH (pH = 6.67) (Table 4.8) of

SUA, high soil organic matter, higher total nitrogen, high available phosphorus, high exchangeable cations and CEC (Table 4.8) might have contributed to a higher Zn levels. Alamgir (2017) similarly observed that, at acidic pH medium, more protons ($H^+$) are available to saturate metal binding sites; therefore, metals are less likely to form insoluble precipitates. Eze *et al.* (2018) have further reported that, heavy metals are generally more mobile at $pH < 7$ than $pH > 7$; Organic matter can reduce or increase the bioavailability of heavy metals in soil through immobilization or mobilization by forming various insoluble or soluble heavy metal organic complexes (Alamgir, 2017); The capacity of soils for adsorbing heavy metals is correlated with their CEC (Fontes *et al*., 2000; Harter and Naidu, 2001). The greater the CEC values, the more exchange sites of soil minerals will be available for metal retention (Alamgir, 2017). Several studies have indicated the possibility of the combined effects of soil properties on metals sorption and desorption (Harter and Naidu, 2001; Appel and Ma, 2002; Dutta *et al*., 2011).

The levels of Zn, as an essential mineral element to both plants and animals in all the soils studied at 0 – 15 cm depth was higher than Zn values in background soils at 15 – 30 cm depth (Tables 4.9 and 4.10). Olowookere *et al*. (2018) observed such differences when found a high concentration of 22.6 $mgkg^{-1}$ of zinc at 0 – 15 cm depth, as compare to a concentration of 21.0 $mgkg^{-1}$ at 15 – 30 cm depth and that of a control site at 21.1 $mgkg^{-1}$. Ngange *et al*. (2013) further reported that, the concentration of zinc at 0 – 15 cm depth ranged from 0.15 – 1.70 $mgkg^{-1}$ to 0.11 – 1.40 $mgkg^{-1}$ at 15 – 30 cm of soil depth. The concentration of Zn were in the range of 26.77 – 674.19 $mgkg^{-1}$ at 0 – 15 cm and 24.91 – 4749.72 $mgkg^{-1}$. Especially, Zn in SUA (4749.72 $mgkg^{-1}$) (Table 4.9) was above 60 $mgkg^{-1}$

(Table 2.5) by FAO/WHO (2011); 76.457 mgkg$^{-1}$ (Table 2.3) by Kabir *et al.* (2011); 300 mgkg$^{-1}$ (Table 2.7) by WHO/FAO (2001) and Shah *et al.* (2011); 1 – 900 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006). These results are indication that, SUA Kumasi dumpsite soil at 15 – 30 cm is contaminated with Zn though it is an essential plant nutrient.

### 5.2.2.6 Arsenic (As)

Arsenic (As) level in KNUST, a background soil was higher than As in AYE, a dumpsite soil at 15 - 30 cm (Tables 4.9 and 4.10). The difference in organic matter (Table 4.8) levels might have contributed to the lower As level in AYE (Tables 4.9 and 4.10) at 15 - 30 cm of soil sampling depth. Alamgir (2017) has similarly reported that, soil organic matter effects on metals can reduce or increase the bioavailability of heavy metals in soils through immobilization or mobilization by forming insoluble or soluble complexes and that depend on organic matter amount, composition and dynamics.

Arsenic (As) generally showed higher values of in KYE, SUA AYE than UEW, MED and KNUST at both 0 - 15 cm and 15 - 30 cm depths (Tables 4.9 and 4.10) and these difference may be related to higher organic matter contents (Table 4.8) contrary to a report by McBride *et al.* (2015) where no correlation between organic matter and specific metals like Pb and As. However, situations where As concentration in dumpsite soils have recorded higher levels than their adjoining background soils is in line with a report by Mensah *et al.* (2017), who found As levels in an e - waste dumpsite in Korle lagoon Accra comparatively recorded a higher As value although at a very close margin. A close margin of differences in As levels in dumpites soil and their background soils might be due to an increase soil pH recorded in the dumpsite soils (Table 4.8). This could have decreased the solubility of As in the dumpsite soils (Kabata - Pendias, 2011) but the reverse was the case in this study. The higher As levels in the dumpsite soils could also be explained by the use of As bearing heavy metals in several industries in agriculture, domestic and technological applications (Bradi, 2002). Also, metals like mercury, lead , cadmium, silver, chromium and many others are indirectly distributed as a result of human activities could be very toxic even at low concentrations and can undergo global ecological circles (Aekola *et al*., 2012). As is a non - essential metal element but when found in soils is not only carcinogenic but also has no nutritional value for plants and animals (Amadi *et al*., 2010; Ngange *et al*., 2013).

Arsenic (As) concentration levels at 0 - 15 cm (4.91 - 7.33 mgkg$^{-1}$) and at 15 - 30 cm (4.43 - 8.88 mgkg$^{-1}$) depth in the studied sites soil were below normal range in soils 0.1 - 40 mgkg$^{-1}$ (Table 2.6) by Radojevic and Baskin (2006) but this is not without any effect even at low concentrations in the soil because plants have a natural propensity to take up metals (Achazai *et al*., 2011) from the soil. All the As concentration levels recorded in the study sites were higher than the value reported in Accra city (3.67 mgkg$^{-1}$) by Mensah *et al*. (2017); 0.66 mgkg$^{-1}$ ; 0.55 mgkg$^{-1}$ by Opaluwa *et al*. (2012). Higher As levels recorded were lower than 17.08 mgkg$^{-1}$ in an e - waste dumpsite soil in China by Predhan and Kumar (2014); 30 mgkg$^{-1}$ (Table 2.5) by FAO/WHO (2011); 20 mgkg$^{-1}$ (Table 2.7) by WHO/FAO (2001). As values recorded at 0 - 15 cm and 15 - 30 cm depth (Table 4.11) were higher than 0.03 mgkg$^{-1}$ at 0 - 15 cm and 0.03 mgkg$^{-1}$ at 15 - 30 cm depth (Ngange *et al.* 2013).

#### 5.2.2.7 Cadmium (Cd)

Cadmium (Cd) was higher at 0 - 15 cm depth in KNUST soil than in AYE (Tables 4.9 and 4.10). This result may be due to the high soil organic matter (Table 4.8) in AYE. This result conforms to a report by Alamgir (2017) that, soil organic matter can influence metals levels in soils through the bioavailability of heavy metals in soils through immobilization or mobilization by forming insoluble or soluble complexes and that depend on organic matter amount, composition and dynamics.

Lower soil pH in KNUST (Table 4.8) could also be linked to the higher Cd level in KNUST than in AYE dumpsite soil. Eze *et al.* (2018) share a similar report to this difference by the fact that, heavy metals are generally mobile at pH < 7 than pH > 7. The lower Cd levels in AYE as compare to Cd in KNUST may be linked to the higher soil pH (Table 4.8) recorded in AYE. This result conforms to an earlier report by Kabata - Pandias (2011) that, with increasing soil pH the solubility of most trace elements decreases leading to low concentration in soil solution. Adelekan and Alawole (2011) further confirmed that, metal availability is relatively low when pH is around 6.5 - 7. This makes soil pH a master variable influencing the physical, chemical and biological properties of soil (Chakraborty, 2015; Neina, 2019).

Cadmium (Cd) levels in KYE, SUA and AYE dumpsite soils were higher than Cd levels in UEW, MED and KNUST at both 0 - 15 cm and 15 - 30 cm of soil sampling depths (Tables 4.9 and 4.10). These differences are expected because of the high soil organic matter and that might have influenced the high Cd levels. This high Cd levels might also be due to the possible disposal of Cd bearing wastes on dumpsites and that might have led to higher Cd levels in the dumpsite soils. Nurudeen and Aderibigbe (2013) share a similar report of highly contaminated value of Cd at 19.35 mgkg$^{-1}$ which was as a result of continuous dumping of refuse. Also higher levels of Cd in dumpsite soils may be linked to the age of dumpsites in addition to Cd bearing compounds which through atmospheric disposition and other related different sources of origin of inorganic waste exposed to the soils studied. Kisku *et al*. (2000) shared similar view that, the burning of fossil fuels and tyres, the use of lubrication oils, vehicles wheels, application of solid wastes from industries and home, sewage sludge waste water irrigation and phosphate fertilizer application also contributed to toxic Cd levels in soils.

Cadmium (Cd) levels in the range of (6.19 - 17.30 mgkg$^{-1}$) at 0 - 15 cm and (7.61 - 20.85 mgkg$^{-1}$) at 15 - 30 cm depth, were higher than normal range of Cd in soils (Table 2.6) at 0.01 - 2 mgkg$^{-1}$ by Radojevic and Baskin (2006), 3.00 mgkg$^{-1}$ (Table 2.4; 2.7) (WHO, 2007; Chiroma *et al.,* 2014), 5.633 mgkg$^{-1}$ (Table 2.3) by Kabir *et al.* (2011). The values recorded in this study need much attention although Cd levels recorded in the soils studied were lower than 103.70 mgkg$^{-1}$ (Mensah *et al.,* 2017), Cd is known to be extremely toxic even at low concentration (Shah *et al*., 2013). Cd is not known for any essential biological function (Wuana and Okieimen, 2011) and as a result Cd is not required for plants growth (Ngange *et al*., 2013).

### 5.2.2.8 Mercury (Hg)

Hg concentration level in KYE was lower than Hg level UEW at 0 - 15 cm and at 15 - 30 cm depths (Tables 4.9 and 4.10). This result may be due to the acidic pH medium in UEW as compare to higher soil pH recorded in KYE (Table 4.8). A similar result was found by

Alamgir (2017) that, at acidic pH medium, more protons ($H^+$) are available to saturate metal binding sites; therefore, metals are less likely to form insoluble precipitates. Sheoran *et al*. (2016) share a similar view that metal concentration decreases at high pH and increases at low pH values. Also, heavy metals become more mobile at pH < 7 than pH > 7 (Eze *et al.,* 2018).

Hg levels in KYE, SUA and AYE than in UEW, MED and KNUST at both 0 - 15 cm and 15 - 30 cm of soil sampling depths (Tables 4.9 and 4.10). This difference may be due to the combined effect of soil pH and organic matter dynamics which could also contribute to higher levels of Hg at both sampled depths at 0 - 15 cm and 15 - 30 cm of sampled soils (Table 4.8). Similarly, a report whereby a combined influence from soil physicochemical differences might have contributed to the mobility of positively charged heavy metals in soils as a result of proton competition with metals and a decreased in negative binding sites (Harckmans *et al*., 2007). Higher Hg levels in KYE, SUA and AYE may be related to Hg bearing wastes which might have been disposed on waste dumpsites through human activities from industries such as textiles tanning, petrochemicals from accidental oil spills or utilization of petroleum - based products and other pharmaceutical facilities. The dispose of such Hg bearing wastes and other metals which may be essential to plants have benefits to agriculture or forestry (Raymond and Okieimen, 2011). Also, higher Hg levels might be due the depth of soil sampling under this study as accumulation of heavy metals are concentrated at the soil - surface than in the sub - surface as reported by Amadi *et al*. (2012) and Ololade (2014) that, soils show remarkably high levels of metals which decrease with depth, and is the reason why surface soils have been found as better indicators for metabolic burdens (Anikwe and Nwobodo, 2002).

Mercury (Hg) concentrations were in the range of 5.12 - 13.47 mgkg$^{-1}$ at 0 - 15 cm and 15 - 30 cm (5.24 - 13.47 mgkg$^{-1}$) depths in all the study soils were higher than 2.00 mgkg$^{-1}$ (Table 2.7) by WHO/FAO (2001); Radojevic and Baskin (2006) reported Hg at a range of 0.01 - 0.50 mgkg$^{-1}$ (Table 2.6); Hg level in uncontaminated soils at 0.04 - 0.08 mgkg$^{-1}$ by Greany (2005). Hg levels at 15 - 30 cm depth in most of the studied soils were higher than in 0 - 15 cm soil depth of Hg concentration levels. This observation may be due to a number of combined effect of soil properties on metals absorption and adsorption (Harter and Naidu, 2001; Dutta *et al*., 2001; Appel and Ma, 2002).

### 5.2.2.9 Lead (Pb)

Lead (Pb) levels were higher in KYE, SUA and AYE than in UEW, MED and KNUST sampled at both 0 - 15 cm and 15 - 30 cm depths (Tables 4.9 and 4.10). These differences may be due to human wastes disposal activities and other Pb bearing wastes on dumpsites might have accumulated Pb leading to their increased levels in the dumpsite soils. This result is in line with the report by Poggio *et al.* (2009) who attributed the differences in Pb levels in the soil environment through numerous activities like mining, smelting, manufacturing and can be toxic to human health (Poggio *et al*., 2009). The high lead levels in dumpsites may also be linked to the soil type, moderately and high organic matter content of the dumpsite soils studied (Table 4.8). This difference agrees with a report by Hameed *et al*. (2013) that species of Pb vary considerably with soil type; it is mainly associated with clay minerals, magnesium oxides iron, aluminum hydroxides and organic matter.

High Pb levels recorded in SUA, AYE in Kumasi metropolis at 15 - 30 cm and 0 - 15 cm depth than in KYE, a rural community within Mampong municipal (Tables 4.9 and 4.10) may be linked to differences in waste generation between urban and rural population as found by Moller *et al*. (2000), that, Pb has shown to accumulate to high levels in urban environments from a range of sources including that derived from leaded petrol. Also, such differences are observed as a result of higher population and industrial activities in municipalities which may lead to higher production of assorted wastes than in the rural settlements (Agyarko *et al.,* 2010).

The concentration of Pb were in the range of 1.03 - 3.99 mgkg$^{-1}$ at 0 - 15 cm and 3.75 - 133.58 mgkg$^{-1}$ at 15 - 30 cm. Pb which was highest in AYE (3.99 mgkg$^{-1}$) at 0 - 15 cm and especially in SUA (133.58 mgkg$^{-1}$) at 15 - 30 cm depth, the highest among all Pb values was above the worlds' average Pb in unpolluted soil at 44.0 mgkg$^{-1}$ (Kabata - Pendias and Pendias, 2001); lower than Pb level in residential area (136.76 mgkg$^{-1}$) and at an industrial area (159.67 mgkg$^{-1}$) by Onyedika (2015) and also higher than Pb level in a dumpsite soil at 0 - 15 cm (1.3 mgkg$^{-1}$), at 15 - 30 cm soil depth (0.7 mgkg$^{-1}$) and on control or uncontaminated sites was 1.1 mgkg$^{-1}$ (Olowookere *et al*., 2018); 5.00 mgkg$^{-1}$ (Table 2.7) by WHO/FAO (2001); 2.00 mgkg$^{-1}$ (WHO, 2009). The remaining selected soils were within the permissible Pb level 40 mgkg$^{-1}$ by Kabata - Pendias and Pendias, (2001). This showed that, the highest Pb in SUA dumpsite soil at 15 - 30 cm was found to be within acceptable contamination level with Pb.

### 5.2.3 Heavy metals level in plants

#### 5.2.3.1 Cr levels in plantain and cocoyam

Chromium (Cr) in plantain leaves and fruits recorded higher Cr values from KYE, SUA and AYE than in UEW, MED and KNUST (Tables 4.11 and 4.12). The high Cr levels in plantain leaves and fruits from dumpsites than in their background sites were expected because plantain has a high demand for organic matter (Table 4.8) and as a result thrives well in wastes dumpsites (Iniobong and Uduakobong, 2017). Leachates from these dumpsites might have contributed to the high Cr levels in the dumpsites which subsequently ended up in the plantain leaves and fruits as reported by Ukpong *et al*. (2013). Also, higher Cr levels in plantain leaves than in fruits may be due to the fact that, there are differences in uptake and accumulation ability of different heavy metals in crops (Yadav *et al.,* 2018). The differences in physiology, morphology, anatomy, leaf inclination angle and density of each plant (Shahid *et al.,* 2016) also determine their metals accumulation levels. The level of Cr in plantain leaves confirm the assertion that, plantain has the ability to absorb metals and it has a good correlation with the concentration of metals in the soil (Bekteshi and Bora, 2013).

High Cr levels in plantain leaves and fruits (Tables 4.11 and 4.12) from dumpsites might be related to an increasing production and disposal of domestic, municipal and industrial wastes on dumpsites as reported by Agyarko *et al*. (2010). The differences in Cr levels in plantain leaves and fruits from dumpsites and background sites might be due to the differences in living standards, consumption patterns and level of industrial development between cities and rural communities dumpsites that receive different considerable waste proportions of product packaging, waste cloths, glass and bottles, newspapers, paints, batteries, industrial dust, ash, tyres, metal cans and containers, medicinal waste, abandoned vehicles and insulations which are known to be sources of metals (Zhang *et al*., 2002; Pasquini and Alexander, 2004; Woodbury, 2005). The high levels of Cr in plantain leaves and fruits might also be due to Cr mobility which depends on sorption characteristics, clay content and amount of organic matter (Table 4.8) as reported by Wuana and Okieimen (2011).

The levels of Cr recorded in plantain leaf was in the range of (8.30 - 98.08 mgkg$^{-1}$), plantain fruits (8.44 - 100.12 mgkg$^{-1}$) were higher than Cr levels in plants on dumpsites (6.59 - 7.33 mgkg$^{-1}$), control site fruits Cr levels (2.23 mgkg$^{-1}$) by Iniobong and Uduakobong (2017); 1.30 mgkg$^{-1}$ and 70.00 mgkg$^{-1}$ (Table 2.8) by WHO (2007; 2009); 0.3 - 14.00 mgkg$^{-1}$ as normal range in plants and 5.00 - 30.00 mgkg$^{-1}$ as a critical plant concentration (Table 2.6) as reported by Radojevic and Baskin (2006). Plantain is one of the common food tree crops found on dumpsites in Ghana (Iniobong and Uduakobong, 2017) and as a result are not fit to feed human and livestock especially plantain leaves from UEW (98.08 mgkg$^{-1}$) and plantain fruit from SUA (100.12 mgkg$^{-1}$).

Cocoyam corms sampled from AYE, recorded lower levels of Cr than in cocoyam corms sampled from KNUST, a background site (Tables 4.13 and 4.14). Such difference may be related to the lower and slightly soil acidic medium of KNUST as compare to a higher alkaline AYE soil pH medium (Table 4.8). This conforms to an earlier report by Eze *et al.* (2018) that, heavy metals are more mobile at pH < 7 than pH > 7. Higher CEC levels in KNUST than in AYE (Table 4.8) might have contributed to the higher Cr levels in KNUST (Table 4.9) and that resulted into higher Cr levels in cocoyam corms (Table 4.11) sampled from KNUST. This result is expected because; Gupta *et al.* (2019) have earlier explained that CEC is a factor that plays a vital role in the availability of metals in the soil to plants. Alamgir (2017) further explain that, the greater the CEC values, the more exchange sites of soil minerals will be available for metal retention.

Cr levels in the rest of cocoyam leaves and corms sampled from KYE, SUA and AYE were higher than Cr levels in UEW, MED and KNUST (Tables 4.13 and 4.14). These differences might be due to metal accumulated nature of soils (Tables 4.9 and 4.10) used for cocoyam cultivation and the cocoyam leaves and corms might have accumulated metals found in dumpsites. A similar report was found by Amusan *et al.* (2005) where dumpsites used as fertile grounds for the cultivation of crops results into increased uptake of heavy metals either as mobile ions or through foliar absorption. Leachates from dumpsites might have also contributed to the heavy metals absorbed by cocoyam leaves and corms (Ukpong *et al.*, 2013).

High Cr levels in cocoyam leaves and corms sampled from SUA AYE dumpsites in Kumasi metropolis as compared to cocoyam parts sampled from KYE, a rural dumpsite in Mampong municipal explains the situation in which the city dumpsites soil properties (Table 4.8) and quality are affected by the increasing number of human wastes dumped. Soffianian *et al.* (2014) share a similar report that, dumpsites soil properties and quality can be adversely affected by the over concentration of waste released from agriculture, industry, municipal and individual household. These heavy metal bearing wastes deteriorates the quality of dumpsites soil and negatively influence sustainable development (Getachew and Habtamu, 2015). The CEC levels (Table 4.8) of the dumpsite soils might have also influenced the metal levels (Tables 4.9 and 4.10) accumulated in the cocoyam leaves and corms. This finding conforms to a report by Gupta *et al*. (2019) that, cation exchange capacity (CEC) is a factor that plays a vital role in the availability of metals in soil.

Cr in cocoyam leaves and corms were in a range of 8.88 - 100.12 mgkg$^{-1}$, cocoyam corms (8.36 - 85.77 mgkg$^{-1}$) concentrations were above 1.00 mgkg$^{-1}$ of Cr (Table 2.2) in cocoyam leaves (Ogunmodede and Adewole, 2015); 0.03 - 14 mgkg$^{-1}$ as normal range in plants and 5 - 30 mgkg$^{-1}$ as critical plant concentration (Table 2.6) by Radojevic and Bashki (2006); 70 mgkg$^{-1}$ and 1.30 mgkg$^{-1}$ (Table 2.8) by WHO (2007; 2009). Cr levels were above the acceptable level at which plant toxicity is likely, however, cocoyam leaves and corms may be therefore toxic to grazing animals and human using cocoyam as food or for medicinal purposes.

#### 5.2.3.2 Fe levels in plantain and cocoyam

Fe levels were higher in plantain leaves and fruits sampled from KYE, SUA and AYE than in UEW, MED and KNUST (Tables 4.11 and 4.12). The Fe values obtained in this study is similar to a report by Iniobong and Udiokobong (2017) where dumpsites fruits studied in their work recorded significantly (p = 0.05) higher heavy metals content than those from the control site. The high Fe levels in plantain leaves and fruits (Tables 4.11 and 4.12) might be due to the Fe levels in the soils (Tables 4.9 and 4.10). This result is similar to a report by Bekteshi and Bora (2013) that plantain shows the ability to absorb metals and the concentrations in leaves correlate with metal levels in soil. Also, the higher concentration of Fe in especially plantain sampled from KYE, SUA and AYE as compared to plantain leaves and fruits sampled from UEW, MED and KNUST in relationship with Fe accumulation levels in plantain leaves and fruits (Tables 4.11 and 4.12) may be attributed to human wastes disposal activities on dumpsites in both rural and urban communities. Such reasons are similar to report by Iniobong and Udiokobong (2017) where due to the scarcity of arable lands in most urban areas, plantain is cultivated in most dumpsites in densely populated cities and rural communities, most especially in strategic locations where all sorts of solid waste material are dumped and these leached metals at times end up in plants.

Accumulation of Fe in plantain leaves and fruits from study sites soils may be related to plantain leaf uptake of Fe in smaller quantities in an accumulated manneras discussed by Gupta *et al.* (2019) that, root uptake and foliar uptake of trace elements occur in a dose dependent manner. These small metal particles might also diffuse through both the stomatal and cuticular path ways to enter plants (Xiong *et al.*, 2014). Leaf metal penetration through stomatal pathways is generally easier because the cuticle of the sub - stomatal cells is comparatively thinner compared to external one (Nebel, 2007). The high levels of Fe recorded in plantain leaves and fruits samples from dumpsites are expected because Fe is the most abundant element in the earth crust (Onyedijka, 2015) and as a result its abundance, it has no concentration limit in the soil (Hameed *et al.,* 2013). The higher Fe accumulation in plantain parts may be attributed to higher Fe concentrations at both 0 - 15 cm and 15 - 30 cm depths (Tables 4.9 and 4.10) which are within the active soil surface with higher Fe concentration. This assertion conforms to an earlier report by Olowookere *et al.* (2018).

Fe as an essential plant metal element was higher in plantain leaves than in plantain fruit. Fe in plantain leaves were in the range (7884.00 - 18712.58 mgkg$^{-1}$); plantain fruit (7663.66 -

20442.75 mgkg$^{-1}$) were higher than 48 mgkg$^{-1}$ as guideline for Fe in food and vegetables and normal range of Fe in plant at 400 - 500 mgkg$^{-1}$ (WHO / FAO, 2011); 40 - 500 mgkg$^{-1}$ as a critical range in plants (Stewart *et al.,* 1974); 20 mgkg$^{-1}$ (WHO, 2009). This is an indication that, Fe levels especially in plantain leaves (18712.58 mgkg$^{-1}$) from UEW and plantain fruits (20442.75 mgkg$^{-1}$) from SUA are toxic to grazing animals and human who use plantain fruit as food or for medicinal purposes.

Cocoyam corms sampled from AYE Fe levels were lower than Fe levels in cocoyam corms sampled from KNUST (Tables 4.13 and 4.14). Such differences observed may be as a result of the studied soils' pH (Table 4.8) conditions which might have increased Fe accumulation in cocoyam corms from KNUST, a background site more than in AYE, a dumpsite. Martinez and Motto (2000) earlier result have affirmed this assertion that the solubility of Fe may be drastically increased at pH 5.5. Also different Fe levels in different plant parts are expected and it agrees with Natasa *et al.* (2015) that, different plant parts contain different heavy metals, because heavy metals are absorb from the soil through the roots, and from the atmosphere through above ground vegetative organs (Mmolawa *et al.,* 2011). The presence of other metals (Tables 4.9 and 4.10) in the studied soils might have affected Fe levels in cocoyam corms (Tables 4.13 and 4.14). Abedin *et al.* (2002) shared similar report that, the presence of one trace element affects the presence of another different species of some metals.

Fe levels in cocoyam leaves and corms sampled from the remaining KYE, SUA and AYE dumpsite soils were higher than Fe levels in cocoyam leaves and corms sampled from UEW, MED and KNUST (Tables 4.13 and 4.14). This difference is expected because cocoyam plants sampled are commonly found on most dumpsites in the Ashanti region of Ghana (Asomani - Boateng and Murray, 1995) which might have absorbed toxic metal elements which may contain some Fe bearing wastes as a result of human activities. Some of these metals are non - biodegradable and may affect living organisms at high concentrations (Ogunmodede and Adewole, 2015). The high Fe levels in cocoyam leaves and corms may also be attributed to the fact that, organic wastes are converted into harmless substance while the inorganic substance which are also non - biodegradable, persisted and might have accumulated in soils and plants found on them as reported by Ukpong *et al.* (2013). The situation where dumpsites are commonly used as fertile grounds for the cultivation of crops like cocoyam may have served as another source of metals contamination contributes to the increased uptake of heavy metals either as mobile ions or through foliar absorption (Amusan *et al.,* 2005). Factors such as soil type, soluble contents of trace elements in soil, soil pH, organic matter, cation exchange capacity (Table 4.8), plant growth stages, crop type and fertilizers influence plant roots uptake of metals (Lente *et al.,* 2014; Yadav *et al.,* 2018).

Fe in cocoyam leaves from the study sites were in a range of 5986.56 - 20442.75 mgkg$^{-1}$ and cocoyam corms 7700.83 - 21145.47 mgkg$^{-1}$ were above 110.00 mgkg$^{-1}$ of Cr (Table 2.2) in cocoyam corm and 68.12 mgkg$^{-1}$ in cocoyam leaf (Ogunmodede and Adewole, 2015); normal range in plants at 40 - 500 mgkg$^{-1}$ (Table 2.6) by Stewart *et al.* (1974); 20 mgkg$^{-1}$ (Table 2.8) by WHO (2009). The highest Fe level was recorded in cocoyam leaf from SUA Kumasi dumpsite gives an indication that consumers of especially cocoyam leaves as food or for medicinal purposes faces a serious health threat if not attended to.

#### 5.2.3.3 Ni levels in plantain and cocoyam

The sampled plantain leaves and fruits from KYE, SUA and AYE recorded higher Ni levels than in UEW, MED and KNUST (Tables 4.11 and 4.10) and this could be attributed to the widely distributed nature of Ni in the environment as Ni is reported to be released through natural sources and anthropogenic activity with input from both stationary and mobile (Orji *et al.,* 2018). Other known reasons which might have contributed to high Ni levels in plantain leaves and fruits are wastes from food stuffs such as chocolate, automobile batteries and various paint wastes (Onyedjika, 2005) found on dumpsites. The presence of cleaning products like soaps dumped on waste sites are subsequently absorbed by plants and as a result ended up in plants. This result is supported by Alloway (1995) that, many domestic cleaning products such as soap (100 - 700 mgkg$^{-1}$) and powdered bleach (800 mgkg$^{-1}$) proofed to be an important sources of Ni levels in urban soil.

The levels of of Ni in plantain leaves in most of the study soils were higher in leaves than in fruits (Tables 4.11 and 4.12) is expected because, plant parts have differences in metals levels because heavy metals are also absorb from the soil through the roots, and from the atmosphere through above ground vegetative organs (Mmolawa *et al.,* 2011). This reason was reorted by Natasa *et al.* (2015) that, different plant parts contain different heavy metals. An effective transpiration may also be a reason behind the accumulation of higher Ni levels in plantain leaves than in fruits. A similar study is reported by Gupta *et al.* (2019) about the significant role transpiration play in trace elements accumulation. Hao *et al.* (2012) further discussed that, when transpiration is flourishing, plant accumulates more trace elements and its enrichment capability is also stronger.

Ni in plantain leaves were in the range of 12.21 - 20.82 mgkg$^{-1}$, plantain fruits in the range of 10.60 - 21.93 mgkg$^{-1}$ were found to be higher than Ni levels in dumpsites ( 2.66 - 3.36 mgkg$^{-1}$), Ni levels in control sites (1.14 mgkg$^{-1}$) by Iniobong and Uduakobong (2017); 0.02 - 5.00 mgkg$^{-1}$ as normal range in plants (Radojevic and Bashkin, 2006); 10 .00 mgkg$^{-1}$ (WHO, 2009); but were within 50 mgkg$^{-1}$ as permissible limits in plants (WHO, 2007); 0.02 - 50.00 mgkg$^{-1}$ (FAO / WHO, 2011); 67.00 mgkg$^{-1}$ (Chiroma *et al.,* 2014); 15 - 50 mgkg$^{-1}$ as critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006). This is an indication that although Ni levels were high in plantain leaves and fruits, Ni was within the permissible limits for human and farm animals consumption.

Cocoyam leaves and corms sampled generally recorded higher Ni in KYE, SUA and AYE than in UEW, MED and KNUST (Tables 4.13 and 4.14). The differences in Ni levels in cocoyam leaves and corms may be as a result of Ni bearing wastes found on dumpsites and when leached ended up in plants found on them. Alloway (1995) showed a similar observation that, many domestic cleaning products such as soap (100 - 700 mgkg$^{-1}$ Ni), powdered bleach (800 mgkg$^{-1}$ Ni) may prove to be important sources of Ni in urban soils. Foodstuffs such as chocolate, automobile batteries and various paint wastes (Onyedika, 2015) are also accumulated by the cocoyam grown. Other sources of Ni levels in sampled cocoyam leaves and corms are through the ambient air as a result of the combustion of coal, diesel oil and the incineration of wastes and sewage (Cempel *et al.,* 2006) in addition, Ni widely used in electroplating and in the manufacture of batteries (Hameed *et al.,* 2013) serves as an additional source of Ni, although Ni is an essential element for plants and animals (Hameed *et al.,* 2012).

Ni levels were also found higher in cocoyam leaves than in cocoyam corms (Tables 4.13 and 4.14). The enhanced levels of Ni in cocoyam leaves sampled from dumpsites may be due to transpiration effects because, when transpiration flourishes, plant accumulates more trace elements and its enrichment capacity is also stronger (Hao *et al.,* 2012). Gupta *et al.* (2019) further confirmed that, leafy vegetables accumulate much higher content of trace elements than other vegetables and crops due to higher translocation and transpiration rate. Other reports found that, the transfer of metals from root to stem and then to fruit during the transpiration and translocation process is longer in non - leafy vegetables and results in lower accumulation (Itanna, 2002; Khan *et al.,* 2009).

Ni in cocoyam leaves were in the range of 10.60 - 21.93 mgkg$^{-1}$ and cocoyam corms 11.92 - 22.13 mgkg$^{-1}$ (Table 4.11) were above cocoyam toxicity at 6.03 mgkg$^{-1}$ (Table 2.2) by Ogunmodede and Adewole (2015); 0.02 - 5 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006); 50 mgkg$^{-1}$ and 10 mgkg$^{-1}$ (Table 2.8) by WHO (2007; 2009). Also, recorded Ni levels in cocoyam plant parts were below FAO / WHO guidelines for metals in food and vegetables at 0.02 - 50 mgkg$^{-1}$ (Table 2.5) by FAO / WHO (2011); the normal range but were below the allowable concentration limit of 67 mgkg$^{-1}$ (Table 2.4) by Chiroma *et al.* (2014). The Ni levels in cocoyam leaves and corms indicate that, cocoyam leaves and fruits at the studied sites are safe for consumption by human and animals.

#### 5.2.3.4 Cu levels in plantain and cocoyam

Cu level in plantain leaves sampled from SUA was lower than Cu levels in plantain leaves from MED Also Cu level in plantain fruits sampled from AYE was lower than plantain fruits sampled from KNUST (Tables 4.11 and 4.12). Such differences observed may be as a result of the studied soils' pH (Table 4.8) conditions which might have influenced these differences of Cu accumulation in plantain leaves and fruits. Martinez and Motto (2000) earlier result has affirmed this assertion that the solubility of Cu is drastically increased at pH 5.5. Also different Cu levels in different plant parts are expected and it agrees with Natasa *et al.* (2015) that, different plant parts contain different heavy metals, because heavy metals are absorb from the soil through the roots, and from the atmosphere through above ground vegetative organs (Mmolawa *et al.,* 2011). The presence of other metals (Tables 4.9 and 4.10) in the studied soils might have affected Cu levels in plantain. Abedin *et al*. (2002) share a similar report that, the presence of one trace element affects the presence of another different species of some metals.

Cu in plantain leaves were in the range of (7.43 -24.07 mgkg$^{-1}$), plantain fruit (6.31 - 67.75 mgkg$^{-1}$) were higher than 8.00 mgkg$^{-1}$ $Cu^{2+}$ (Table 2.3) by Kabir *et al.* (2011); 30.00 mgkg$^{-1}$ as levels in plants and 2.5 mgkg$^{-1}$ as normal range in plants (FAO / WHO, 2011); 5 - 20 mgkg$^{-1}$ as normal range in plants and within 20 - 100 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006); 100.00 mgkg$^{-1}$ (Table 2.8) by WHO (2007). Cu levels in plantain leaves and fruits were within the permissible limit safe for human and farm animal's consumption.

Cu levels were generally higher in cocoyam leaves and corms sampled from KYE, SUA and AYE dumpsites than in UEW, MED KNUST background (Tables 4.13 and 4.14). This difference showed that the cocoyam parts sampled accumulated higher Cu levels. Olankule *et al.* (2018) share a similar finding that, the dumpsites soil studied contain Cu bearing wastes that might have accumulated in the dumpsite soil. Ogunmodede *et al.* (2015) similarly discussed that, heavy metals from refuse dump soils are higher in concentration than in the control or background values especially for Cu and that was attributed to the fact that, refuse dumps receive considerable waste proportions of product packaging, waste, cloths, glass and bottles, newspapers, paints, batteries, industrial dust, ash, car tyres, metal cans and containers, medical waste, abandoned vehicles and insulations. All these refuse dump wastes are known to be sources of metals (Woodburry, 2005). The Cu levels absorbed by cocoyam may be due to the available forms of Cu in the soils studied. This observation conforms to a report on the concentration of availability forms of metals in soil which is controlled by various physical and chemical processes such as cation exchange, adsorption and desorption, complexation, precipitation and dissolution, oxidation, reduction, sequestration and occlusion, diffusion and migration, metal competition, biological immobilization, mobilization and plant uptake (Kabata - Pendias, 2010; Wuana and Okieimen, 2011).

Cu levels were mostly higher in cocoyam leaves from most of the study sites than in cocoyam corms (Tables 4.13 and 4.14) and that may be related to the fact that, most Cu ions might have been transported from the roots to other parts of the cocoyam by factors like crop type and soil pH and resulted to higher levels of Cu in cocoyam leaves. Gupta *et al.* (2019) share a similar report that, vegetables take up metals from polluted soils and through atmospheric deposition of particulate matter from different sources are first absorbed in the apoplast of roots and transported further into other parts of the plant cells. Also, metals roots uptake of metals is controlled by many factors such as soluble contents of trace elements in soil, soil pH, organic matter, cation exchange capacity, plant growth stages, crop type, fertilizers and soil type (Lente *et al.,* 2014; Yadav *et al.,* 2018).

Cu in cocoyam leaves were in the range of 6.31 - 67.75 mgkg$^{-1}$ and cocoyam corms 7.15 - 32.69 mgkg$^{-1}$. The highest Cu level (22.13 mgkg$^{-1}$) recorded was found in cocoyam leaves (67.75 mgkg$^{-1}$) from SUA (Table 4.13) were above 11.05 mgkg$^{-1}$ in cocoyam corm; 5 - 20 mgkg$^{-1}$ as normal range in plants (Table 2.6) by Radojevic and Bashkin (2006); 22.00 mgkg$^{-1}$ in cocoyam leaf (Table 2.2) by Ogunmodede and Adewole (2015); 30 mgkg$^{-1}$ in food; 2.5 mgkg$^{-1}$ as normal range in plants (Table 2.5) by FAO / WHO (2011). On the contrary, Cu levels were generally below 20 - 100 mgkg$^{-1}$ as a critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006); 73.00 mgkg$^{-1}$ (Chiroma *et al.,* 2014). This finding show that, cocoyam leaves sampled from SUA recorded the highest Cu level in addition to cocoyam corms sampled are safe for human and animals as food or for medicinal purposes.

#### 5.2.3.5 Zn levels in plantain and cocoyam

Zn levels in dumpsites studied were higher than in background soils (Tables 4.9 and 4.10) so Zn higher levels in plantain parts sampled from KYE, SUA and AYE than in UEW, MED and KNUST is expected (Tables 4.11 and 4.12). Such differences may be due to the fact that, Zn is one of the most abundant element (second to Fe) so their higher levels in plantain sampled from dumpsites may be due to their high natural abundance or anthropogenic input (Onyedika, 2005) on wastes dumpsites. Other sources of Zn reported were manure, composted materials and agro chemicals like fertilizers and pesticides used in agriculture (Romi and Romic, 2003). Zn levels in plantain leaves and fruits sampled from SUA and

AYE within Kumasi metropolis recorded higher values than samples from a KYE, a rural community dumpsite within Mampong metropolis may be due to higher population and industrial activities in cities and metropolis which might have lead to higher production of Zn wastes in SUA and AYE than in rural settlements. Jiries *et al*. (2001) share a similar finding which attributed such differences to Zn bearing wastes like mechanical abrasion of vehicles used in the production of brass alloy itself, brake linings, oils leak dumps and cylinder head gaskets. Also, higher Zn levels in plantain leaves and fruits may also be linked to an antagonistic and synergistic behavior thus exists among trace elements (Chibuike and Obiora, 2014), a similar situation is reported under Cd by Salgare and Acharekar (1992), where Cd and Zn antagonize inhibitory effect had influence on the total amount of mineralised carbon. Cu and Zn as well as Ni and Cd have been reported to compete for the same membrane carrier in plants (Clarkson and Luttge, 1989).

Plantain leaves Zn levels were in the range of 56.46 - 126.19 mgkg$^{-1}$, plantain fruits in the range of 37.80 - 186.50 mgkg$^{-1}$ were above a permissible limit in plants (Table 2.8) at 50 mgkg$^{-1}$ (FAO/WHO, 2007); a reported level in plant at 60 mgkg$^{-1}$ (Table 2.5); a normal range in plants at 20 - 100 mgkg$^{-1}$ (FAO/WHO, 2011) but were within 1 - 900 mgkg$^{-1}$; normal range in plants at 1 - 400 mgkg$^{-1}$; critical plant concentration reported at 100 - 400 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006); 300 mgkg$^{-1}$ by Shal *et al.* (2011). These reported allowable Zn levels in plants show that, Zn levels reported in this study were within the acceptable limits in plantain for human and animal consumption.

Zn levels were generally higher in cocoyam leaves and corms sampled from KYE, SUA and AYE than cocoyam leaves and fruits sampled from UEW, MED and KNUST (Tables 4.13 and 4.14). This result is expected because all dumpsites soil recorded higher Zn levels than their background soils (Tables 4.9 and 4.10). The Zn values in the leaves and corms were expected to be higher in the dumpsite soils than their background samples. This finding is supported by a report that, dumpsites soils receive considerable waste proportions of product packaging, waste cloths, glass and bottles, newspapers, paints, batteries, industrial dusts, ash, tyres, metal cans and containers, medical waste, abandoned vehicles and insulations which are known to be sources of metals (Zhang *et al.,* 2002; Pasquini and Alexander, 2004; Woodbury, 2005). Zn levels were mostly higher in cocoyam corms than in cocoyam leaves with the exception of SUA (Tables 4.13 and 4.14) and this might be due to the fact that SUA dumpsite is at Kumasi an urban community as compare to KYE, a rural community within Mampong municipal. Such differences are observed as a result of higher population and industrial activities in cities and municipalities which lead to higher production of assorted wastes than in the rural settlements as found by Ebong *et al.* (2008).

Zn levels in cocoyam leaves were in the range of 17.43 - 186.50 mgkg$^{-1}$ and cocoyam corms 41.70 - 101.56 mgkg$^{-1}$. The highest Zn level recorded was found in cocoyam leaves (186.50 mgkg$^{-1}$) sampled from SUA (Table 4.11) was above 60 mgkg$^{-1}$ as normal Zn level in food; 50 mgkg$^{-1}$ (Table 2.8) by WHO (2009); 20 - 100 mgkg$^{-1}$ as normal range in plants (Table 2.5) by FAO / WHO (2011); 92.00 mgkg$^{-1}$ in cocoyam corms and 48.70 mgkg$^{-1}$ in cocoyam leaves (Table 2.2) by Ogunmodede and Adewole *et al.* (2015). However, the highest Zn levels recorded in cocoyam leaves and corms were within 1 - 400 mgkg$^{-1}$ as normal range in plants and 100 - 400 mgkg$^{-1}$ as a critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006); 300 mgkg$^{-1}$ (Table 2.8) by WHO (2009). This is an indication that, Zn levels in cocoyam leaves and corms sampled from KYE, SUA and AYE may not pose danger to grazing animals and humans using them as food or for medicinal purposes.

### 5.2.3.6 As levels in plantain and cocoyam

As levels in plantain leaves and fruits sampled from KYE, SUA and AYE were higher than As levels in UEW, MED and KNUST (Tables 4.11 and 4.12). This difference might have come about as a result of As bearing wastes (Tables 4.9 and 4.10) that might have ended up in the plantain leaves and fruits (Tables 4.11 and 4.12). These differences are similar to the report by Adebiyi *et al.* (2018) that, plants on polluted soils absorb heavy metals in the form of free moving ions in the soil through their xylem and phloem vessels where metals are bi-accumulated in their leaves, stems, fruits, grains and roots. These high concentrations of metals in dumpsite soils may also result in higher level of metal uptake by plants (Ebony *et al.,* 2008). A critical examination of metals level in dumpsites show the extinct to which plants found on them are exposed to these metals (Opaluwa *et al.,* 2012).

As was found to be high in lettuce leaves and fruits from SUA and AYE which are urban dumpsites than from KYE a rural dumpsites. As is not a plant nutrient (Ngange *et al.,* 2013) and as a result has no nutritional value for plants and animals (Amadi *et al.,* 2010), so their higher levels in urban dumpsites soil and subsequent absorption by plantain in urban dumpsite soils than found in rural dumpsite plantain is due to the fact that, inhabitants in the cities feeding habits and lifestyle conditions like disposal of As bearing wastes strongly contributes to higher As levels in urban dumpsites. As in plantain leaves were in the range of 3.16 - 8.29 mgkg$^{-1}$, plantain fruits ranged from 1.74 - 8.30 mgkg$^{-1}$ were below 0.5 - 20 mgkg$^{-1}$ (FAO/WHO, 2011); normal range in plants at 0.02 - 7 mgkg$^{-1}$ and critical plant concentration at 5 - 20 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006), an indication that, As in plantain leaves and fruits in the plantain samples were safe for human and animal consumption as food or as a drug.

Cocoyam corms sampled from SUA dumpsite recorded a lower As level than in cocoyam corms from MED a background sample (Tables 4.13 and 4.14). This difference may be explained by sandy clay loam texture of MED a dumpsite soil, as compare to the sandy texture of SUA a background soil (Table 4.8). The larger pore space and lower sorption capacity cause sandy soils to weakly absorb heavy metals unlike clay soils with high sorption capacities that play an important role in metals absorption by plants (Alamgir, 2017). Sheoran *et al.* (2010) further explained that, trace elements retainability is higher in fine - textured soils (clay and clay loam) as compare to coarse – textured soils (sand) due to the presence of more pore spaces in sand.

As levels were generally higher in the remaining cocoyam leaves and corms sampled from dumpsites, KYE, SUA and AYE than found in their background cocoyam parts sampled from UEW, MED and KNUST, (Tables 4.13 and 4.14). This observation may be explained with the reason that, most edible crops may not be selective in absorbing essential and non - essential plant nutrients. This finding is in line with a report that, most edible crops are indiscriminate in their extraction of both non - desirable and the required essential nutrients to man, which may cause blood and bone disorders, kidney damage, decreased mental capacity (NIEHS, 2004; Ogunmodede and Adewole, 2015). Also the use of dumpsites soil as fertile grounds for the cultivation of crops results in increased uptake of heavy metals either as mobile ions or through foliar absorption (Amusan *et al.,* 2005).

As levels were mostly higher in cocoyam leaves from most of the study sites than in cocoyam corms (Tables 4.13 and 4.14). Singh *et al.* (2013) attributed such differences to how most of the leafy vegetables used for cultivation especially on dumpsites soil are hyper accumulators of most of the non - essential heavy metals.

As in cocoyam leaves were in the range of (1.74 - 8.30 mgkg$^{-1}$), cocoyam corms (2.75 - 12.29 mgkg$^{-1}$) were however above the normal concentration levels in plants at 0.02 - 7 mgkg$^{-1}$ as normal range in plants (Table 2.6) by Radojevic and Bashkin (2006); 30 mgkg$^{-1}$ in food, 0.5 - 20 mgkg$^{-1}$ as normal As level in plants (Table 2.5) by FAO / WHO (2011).

The highest As level (12.29 mgkg$^{-1}$) recorded was found in cocoyam corm from SUA Kumasi dumpsite (Table 4.14) were within the acceptable toxic level of range 5 - 20 mgkg$^{-1}$ as critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006). This result shows that, cocoyam corms from SUA Kumasi dumpsite although recorded the highest As level, cocoyam part is safe for grazing animals and human consumption.

### 5.2.3.7 Cd levels in plantain and cocoyam

The sampled plantain leaves and fruits from KYE, SUA and AYE recorded higher Cd levels than in UEW, MED and KNUST (Tables 4.11 and 4.12) are some distances away from their dumpsites (Ukpong *et al.,* 2013; Amos - Tautau *et al.,* 2014; Olufunmilayo *et al.,* 2014; Tanee and Eshami - Mario, 2015) showed that, plantain leaves and fruits sampled have the ability to absorb heavy metals from dumpsite soils than from background soils and they correlated with the metals in the soil (Tables 4.9 and 4.10) (Iniobong and Uduakobong, 2017).

Higher levels of Cd were recorded plantain leaves than in fruits and such difference may be attributed to the different parts of a plant which may contain different levels of heavy metals. Natasa *et al.* (2015) share a similar report that, different plant parts may contain different heavy metals, and their distribution in plants is quite heterogenous and is controlled by genetic environment and toxic factors. Guala *et al.* (2001) have also attributed the Cd levels in plantain parts as a result of the dynamics of heavy metals in plant - soil interactions which depend mainly on the level of soil contamination and plant species.

Cd levels in plantain leaves were in the range of 4.45 - 6.43 mgkg$^{-1}$, plantain fruits range (3.63 - 6.41 mgkg$^{-1}$) were above 0.10 mgkg$^{-1}$ (Table 2.4) by Chiroma *et al.* (2014); 2.4 mgkg$^{-1}$ (Table 2.5) by FAO / WHO (2011); 0.1 - 2.4 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006); 0.02 mgkg$^{-1}$ (Shal *et al.,* 2011); 0.35 mgkg$^{-1}$ (WHO, 2007) but were within a critical plant concentration range of 5 - 30 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006) an indication that plantain leaves and fruits are safe for human and animal consumption.

Cd levels were generally higher in cocoyam leaves and corms sampled from KYE, SUA and AYE dumpsites than in UEW, MED and KNUST background sites (Tables 4.13 and 4.14). Such observation may be as a result of higher metal levels in dumpsites soil (Tables 4.9 and 4.10) which might have accumulated Cd in the cocoyam leaves corms. A similar finding was reported with an increased uptake of metals either as mobile ions or through foliar absorption (Amusa *et al.,* 2005) of metals in plants sampled from dumpsites. Also dumpsites are known to contain heavy metals and they are brought about as a result of disposal of Cd bearing wastes and when leached, end up in plants through absorption without discrimination. This result is in line with a report that, most edible crops are indiscriminate in their extraction of essential and non - essential nutrients which may cause bone and blood and bone disorders (NIEHS, 2004; Ogunmodede and Adewole, 2015).

Cd in cocoyam leaves were in the range of 3.63 - 6.41 mgkg$^{-1}$ and cocoyam corms 4.28 - 5.36 mgkg$^{-1}$ were above 0.1 - 2.4 mgkg$^{-1}$ as normal range in plants (Table 2.6) by Radojevic and Bashkin (2006); 0.35 mgkg$^{-1}$ (WHO, 2007); 0.02 mgkg$^{-1}$ (Table 2.8) by WHO (2009); 1 - 2.4 mgkg$^{-1}$ as normal range in food and plants (Table 2.5) FAO / WHO (2011); 0.1 mgkg$^{-1}$ (Table 2.4) by Chiroma *et al.* (2014). The highest Cd level (6.41 mgkg$^{-1}$) recorded was found in cocoyam leaves sampled from SUA (Table 4.11) were within the critical plant concentration range of 5 - 30 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006); 5.20 mgkg$^{-1}$ in cocoyam corms and 7.30 mgkg$^{-1}$ in cocoyam leaves (Table 2.2) by Ogunmodede and Adewole (2015). This result shows that, cocoyam leaves even from SUA is still safe for animal and human consumption.

### 5.2.3.8 Hg levels in plantain and cocoyam

Hg levels in sampled plantain leaves and fruits from KYE, SUA and AYE recorded higher values than in UEW, MED and KNUST (Tables 4.11 and 4.12). This is in agreement with the findings of Ebong *et al.* (2008) who attributed such differences to the high metal contents in dumpsite soils (Tables 4.9 and 4.10) which are eventually accumulated by the plants grown on them. The high Hg levels in plantain leaves and fruits from the dumpsite soils may be linked to the absorbed plantain nutrients in response to concentration gradient and selective uptake of ions by diffusion (Peralta - Videa *et al.,* 2009). The higher levels of Hg in plantain may also be linked to transpiration process, which plays a significant role in trace elements accumulation in plants (Gupta *et al.,* 2019), and this conforms to the finding by Hao *et al.* (2012) that, when transpiration flourishes, plant accumulates more trace elements and its enrichment capacity is also stronger. In addition, higher Hg levels in plantain leaves and fruits may also be attributed to the soluble nature of Hg species present in the soil environment and it agrees with finding by Ukpong *et al.* (2013) that, for plant root uptake of heavy metals to occur, soluble species must exist adjacent to the root membrane for some finite period.

Plantain leaves in Hg levels were in the range of 3.89 - 6.95 $mgkg^{-1}$, plantain fruits (3.83 - 7.41 $mgkg^{-1}$) were above 0.005 - 0.17 $mgkg^{-1}$; 1 - 3 $mgkg^{-1}$ (Table 2.6) as the normal range in plants and critical plant concentration respectively by Radojevic and Bashkin (2006). This is a matter of concern because Hg has been reported to be toxic in all life forms even at low concentrations because it causes anomalies in functions of the living organism especially in greater quantities (Manahan, 2001). These plantain leaves and fruits sampled from the refuse dumpsites may be toxic to grazing animals and human using plantain leaves and fruit as food and for medicinal purposes.

Cocoyam leaves and corms sampled from KYE, SUA and AYE dumpsites recorded higher Hg levels than in samples from UEW, MED and KNUST background sites (Tables 4.13 and 4.14). This bears a resemblance of plants with a natural taste for metals which also has toxic effects on plants, human and grazing animals due to metals non - biodegradable nature. Achazai *et al.* (2011) have similarly attributed such differences in Hg accumution in cocoyam plant parts by the fact that, plants have natural propensity to take up metals. In addition, the levels of Hg found in cocoyam corms and leaves sampled from dumpsites compared with background's samples might be due to certain soil physicochemical factors. Amusan and Olawale (2005) share a similar finding that, the rate of metal uptake by plants could be influenced by metal species, plant species, soil pH, CEC, organic matter, soil texture (Table 4.8) and interaction among the target elements. Also, plants absorption of both essential and non - essential elements from the soil is may be in respond to concentration gradient and selective uptake of ions or by diffusion (Peralta - Videa *et al.,* 2009).

Hg levels were mostly higher in cocoyam leaves from most of the study sites than in cocoyam corms (Tables 4.13 and 4.14). This observation may be explain by the fact that, different plant parts contain different heavy metals (Natasa *et al.,* 2015) because plants absorb heavy metals from the soil through the root and from the atmosphere through above ground vegetative organs (Mmolowa *et al.,* 2011).

Hg levels in cocoyam leaves were in the range of 3.27 - 7.41 mgkg$^{-1}$ and cocoyam corms 3.82 - 7.83 mgkg$^{-1}$ were above 0.005 - 0.17 mgkg$^{-1}$ as normal range of Hg in plants; 1 - 3 mgkg$^{-1}$ as critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006). The highest Hg level (7.83 mgkg$^{-1}$) was recorded in cocoyam corms sampled from KYE (Table 4.13). As a non -essential metal element, Hg uptake and subsequent accumulation along the food chain is a potential threat to animal and human health (Sprynskyy *et al.,* 2007). This result shows that, cocoyam leaves samples from SUA, cocoyam corms from KYE are not fit for human and farm animals consumption as food or for medicinal purposes due to Hg contamination.

#### 5.2.3.9 Pb levels in plantain and cocoyam

Pb levels were in higher in plantain leaves and fruits from KYE, SUA and AYE dumpsites than plantain samples from UEW, MED and KNUST (Tables 4.11 and 4.12). This may be explain by the fact that, the absorption of heavy metals in plants differs from one metal to other. This report conforms to a finding by Yadav *et al.* (2018) that, an uptake and accumulation ability of different trace elements is dissimilar in different vegetables. As a result, crops generally accumulate trace metals due to differences in physiology, morphology and anatomy of each plant, leaf inclination angle and branch density (Shahid *et al.,* 2016).

Pb levels differences between dumpsites and background sampled plantain parts may be due to easier foliar accumulation of metal ions in plants. Roth - Nebel (2014) attributed such differences to the fact that, penetration of metals in leaf through stomata pathway is generally easier because the cuticle of the sub - stomata cells is comparatively thinner as compare to external one. These differences in Pb levels may be due to small metal particles that can diffuse through both the stomata and cuticle pathways to enter a plant (Xiong *et al.,* 2014).

Pb level in plantain leaves were in the range of 2.65 - 4.55 mgkg$^{-1}$ and plantain fruits (2.18 - 36.15 mgkg$^{-1}$) were above the normal range of Pb in food at 2 mgkg$^{-1}$ (WHO, 2009; FAO / WHO, 2011); control site fruits Pb level (1.13 mgkg$^{-1}$) by Iniobong and Uduakobong (2017). The highest Pb (36.15 mgkg$^{-1}$) level recorded in plantain fruit from SUA Kumasi dumpsite (Table 4.12) was above the normal range in plants at 0.2 - 20 by Radojevic and Bashkin (2006); 0.50 - 30 mgkg$^{-1}$ (FAO / WHO, 2011); dumpsite fruits Pb range ( 7.63 - 8.67 mgkg$^{-1}$) by Iniobong and Uduakobong (2017). The Pb concentrations were within critical plant concentration range of 30 - 300 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006); 100 mgkg$^{-1}$ (WHO, 2007) above which plant toxicity is likely, however, the concentrations of Pb in plantain leaves and fruits make it safe for human and animal consumption.

Cocoyam leaves and corms sampled from KYE, SUA and AYE dumpsites were generally higher in Pb than in UEW, MED and KNUST background sites (Tables 4.13 and 4.14). Such a difference was expected because dumpsites soil receives considerable wastes and as a result may be accumulated in plants found on them. Zhang *et al.* (2002) affirms this assertion. Pb is not biodegradable and as a result, even at low concentrations, Pb may have toxic effects on living organisms at certain level of concentration (Ogunmodede and Adewole, 2015). This level of Pb in cocoyam plants parts as recorded confirm that, there is a very narrow range between Pb concentrations which are beneficial or toxic with respect to the effects of metals (Tchounwou *et al*., 2008). Pb levels were found to be mostly higher in cocoyam leaves from most of the study sites than in cocoyam corms (Tables 4.13 and 4.14). This finding supports an earlier report by Natasa *et al.* (2015) that, different plant parts contain different heavy metals.

Pb level in cocoyam leaves were in the range of 2.18 - 36.15 mgkg$^{-1}$ and cocoyam corms (2.50 -3.50 mgkg$^{-1}$) were above 2.00 mgkg$^{-1}$ in food (Table 2.5) by FAO / WHO (2011). Also, the highest Pb level (36.15 mgkg$^{-1}$) recorded was found in cocoyam leaf from SUA Kumasi dumpsite (Table 4.13) were within 46.04 mgkg$^{-1}$ in cocoyam corms; 30.01 mgkg$^{-1}$ in cocoyam leaves (Table 2.2) by Ogunmodede and Adewole (2015); 0.5 - 30 mgkg$^{-1}$ as normal range in plant (Table 2.5) by FAO / WHO (2011); 0.5 - 20 mgkg$^{-1}$ as normal range in plants and 30 - 300 mgkg$^{-1}$ as critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006). This result is an indication that, cocoyam corms and leaves especially sampled from SUA Kumasi dumpsite is safe for humans and animal consumption as food or medicinal purposes.

### 5.2.4 Relationship between soil physicochemical properties and soil total heavy metals at the studied sites

#### 5.2.4.1 Relationships among the selected soil heavy metals

A correlation analysis studies among the soil metals in the selected studied soils showed a positive relationships among some metals (Table 4.15). The presence of certain trace elements affects the total metals level of other metals in the soil (Gupta *et al*., 2019). Cu and Ni positively and highly significantly (r = 0.96, p = 0.01) correlated well though they may compete for the same membrane carriers in plants (Clarkson and Luttge, 1989) an indication that, Cu and Ni might have come from the same source of contamination. Similarly, Zn and Ni positively and highly significantly (r = 0.95, p = 0.01) correlated well. Similarly, Zn and Cu (r = 0.98, p = 0.01), Zn and Fe (r = 0.51, p = 0.04), As and Cu (r = 0.53, p = 0.03), Cr and Cd (r = 0.47, p = 0.05), Pb and As (r = - 0.72, p = 0.01), Pb and Hg (r = 0.59, p = 0.01).

The general significant relationships among Zn and Ni, Zn and Cu, Zn and Fe, As and Cu, Cr and Cd, Pb and As are expected although, the presence of certain trace elements affect the availability of other metals in the soil (Table 4.18) as reported by Gupta *et al.* (2019). Zn correlated with Ni, Cu, Fe, and As but not Pb. This finding might be due to how these metals compete for the same membrane carriers in plants (Clarkson and Luttge, 1989). Also, Cr and Cd did not correlate with Pb and this might be due to their antagonistic effect on the availability of Pb (Orronoa et al., 2012) in soils. Pb significant relationship with As and Hg in this study is expected and might be due to an interaction between Pb and other metals availability which might prevented that significant relationship. This result might have resulted in a reduced form of these metals especially with Cd, Cr, Cu, Ni and Zn (Table

4.15) was due to antagonistic effect (Orronoa *et al., 2002*), thus exist among trace elements (Chibuike and Obiora, 2014) because, the presence of one trace element may affect the presence of another, and even different species of some metals may also affect each other (Abedin *et al.,* 2002).

Metals like Cr and Fe, and Cu, Cr and Zn, and others were not significantly correlated (Table 4.15) may be due to antagonistic and synergistic behavior that exists among trace elements (Chibuike and Obiora, 2014). These results showed that the correlated soil heavy metals (Cr and Cd, Fe and Zn, Ni and Cu, Cu and As, Zn and As, As and Pb, Hg and Pb) among themselves is an indication that, these metals might have come from the same sources of soil contanmination with special reference to their enrichment factor (Tables 4.27 and 4.28) and how the availability of one of them might affect the availability of another (Chibuike and Obiora, 2014).

### 5.2.4.2 Relationships between soil pH, SOM, CEC, soil clay content, soil available P and selected soil heavy metals

### 5.2.4.1 Relationship between soil pH and selected heavy metals

Results on the extent of relationship from a linear regression analysis prediction showed that soil pH positively and significantly ($r^2 = 0.26$, $p = 0.02$) influenced soil Fe levels in the studied soils (Table 4.16). The soil pH influence may be attributed to the fact that, soil pH (Table 4.8) affects metals level in soil. This result conforms to report that, soil pH is considered as a great effect of any single factor on solubility or retention of metals in soils (Ghosh and Singh, 2005; Alloway, 2012). Soil pH is found as one of the most considered and an influencing factor that affect soil metals availability (Aduani, 2001; Bolon *et al*., 2013; Selim, 2013). The weakly basic soil pH conditions (Table 4.8) might have enabled functional groups present in soil organic matter to dissociate thereby increasing the bioavailability of Fe in the soil. Fine *et al*. (2005) affirm this result in their earlier studies. The soil pH conditions in KYE, UEW, SUA and KNUST (Table 4.8) might have also accounted for the increased mobility of a positively charged heavy metals like Fe as a result of proton competition causing decreases in the negative binding sites (Horckmans *et al*., 2007). Proshad *et al*. (2018) shared a similar view that at low soil pH (< 5), solubility of hazardous elements are soil pH (pH < 5), solubility of hazardous elements are increased.

#### 5.2.4.2 Relationship between soil organic matter and selected heavy metals

Total soil organic matter (SOM) positively and significantly influenced soil Ni level ($r^2 = 0.94$, $p = 0.01$); soil Cu level ($r^2 = 0.96$, $p = 0.01$) and soil Zn level ($r^2 = 0.94$, $p = 0.01$) (Table 4.16). This relationships were expected because, soil organic matter contains a humid substance or humus which comprised of humic and fulvic acids (Gupta *et al*., 2019) and as a result may reduce or increase the bioavailability of heavy metals in soil through immobilization or mobilization by forming various insoluble heavy metal organic complexes (Alamgir, 2017) to influence the concentration levels of Ni, Cu and Zn in the studied soils. The organic matter of the studied soils (Table 4.8) ranged from values above critical limit as medium (2.1 - 3.0%) to > 3.1% (high) (Enzezer *et al*., 1988) as a result of organic wastes mostly found in dumpsite soils (Odai *et al*., 2008). On the contrary, soil organic matter did not significantly correlate well with some of the heavy metals and this conforms to an earlier work by McBride *et al.* (2015) who had earlier recorded lower correlation of soil organic matter with metals like Pb and As.

#### 5.2.4.3 Relationship between soil cation exchange capacity and selected heavy metals

Cation exchange capacity (CEC) is a factor that plays a vital role in the availability of metals in soil (Gupta *et al*., 2019). CEC positively and significantly influenced soil total Ni level ($r^2 = 0.79$, $p = 0.01$); soil total Cu level ($r^2 = 0.90$, $p = 0.01$); soil total Zn level ($r^2 = 0.79$, $p = 0.01$) and soil total As level ($r^2 = 0.26$, $p = 0.01$). The significant influence of CEC on Ni, Cu, Zn and As (Table 4.16) might be linked to the sand fractions in KYE, UEW and SUA and sand clay loam in MED which recorded comparatively higher CEC in studied site soils as compare to lower CEC loamy sands in AYE and KNUST (Table 4.8), might have contributed in making the metals bonded to the soils studied. Bhargava *et al.* (2012) share a similar view that, soils with low CEC such as sand has less binding power to metals and other cations as compare to soils with high CEC such as clay. Gupta *et al*. (2019) also reported that, CEC levels increase concomitantly with increasing soil clay content (Table 4.8), while the soil metal ions decrease as in the case of Cu and As levels (Tables 4.9 and 4.10). The comparative lower levels of soil Cu and As could also be explain by the soils' lower capacity to absorb heavy metals and that, CEC (Fontes *et al*., 2000; Harter and Naidu, 2001) if higher, could have also contributed for more exchange sites of soil minerals which as a result was present without necessary being available in soil solution.

#### 5.2.4.4 Relationship between soil clay content and selected heavy metals

Soil texture and mineral types play an important role in mobility of metals in soil and it reflects the relative amounts of sand, silt and clay particles in a soil (Alamgir, 2017). Clay content positively and significantly influenced soil total Cr ($r^2 = 0.29$, $p = 0.02$) and Fe levels ($r^2 = 0.37$, $p = 0.01$) (Table 4.16). This observation is due to the fact that, clay influenced soil Cr and Fe levels in studied soils because, a high sand textured soil has been found to contain less metal binding sites as compare to clay with high CEC and high metal binding sites (Bhargava *et al*., 2012). These results confirm why soil Cr and Fe levels were influenced due to the low clay fractions in the soils studied (Table 4.8). This reason is similar to a report by Gupta *et al*. (2019) that, metals availability may be influenced by clay content as the solubility and availability of trace elements is highest in loam sand followed by clay loam and lastly fine - textured clay soils. The higher correlation between metals (Table 4.16) and high metals level in the studied soils (Tables 4.9 and 4.10) may be linked to a report by Sheoran *et al.* (2010) that, trace elements retainability is highest in fine - textured soils (clay and clay loam) as compared with coarse - textured soils (sand) due to the presence of more pore spaces in sand.

#### 5.2.4.4 Relationship between soil available P and selected heavy metals

Soil available P positively and significantly influenced soil Cd levels ($r^2 = 0.44$, $p = 0.01$) (Table 4.16). This result indicated that, soil available levels contributed to 44 % of variations in Cd levels while the remaining 56 % might have been caused by other factors. This result is similar to an earlier studies that indicated the possibility of combined effects of soil properties on metals sorption and desorption (Harter and Naidu, 2001; Appel and Ma, 2002; Dutta *et al*., 2011).

## 5.3 Study Three: - Evaluation of heavy metals contamination in dumpsite soils and accumulation in selected plants under field conditions in a pot experiment

### 5.3.1 Physicochemical properties of soils in pots under field conditions

The soil physicochemical analytical results generally had improved soil properties on dumpsite soils than on background soils with bulk density, soil pH, total organic matter, total nitrogen, and soil available phosphorus (Table 4.17) and this could be attributed to the materials emanating from the municipal and metropolis solid and liquid wastes deposited on the soil and it affirms to a report by Krishna *et al.* (2016). Soil bulk density results (Table 4.17) were lower in the dumpsites soils than in background soils with no significant ($p = 0.88$; $p = 0.64$) difference and may be attributed to the textural class of the studied soils. This result conforms to an earlier report by Tripathy and Misra (2012) that, soil texture plays a very important function by influencing other physical parameters of the soil.

The lowest soil pH of SUA was slightly acidic as compare to slightly basic MED may be related to the textural differences between these two study soils (Table 4.8). Oyedele *et al.* (2008) share a similar finding by attributing such soil pH differences to differences in biological activity, temperature and disposal of municipal wastes on dumpsites. Slightly basic KYE and AYE as compare to slightly acidic UEW and KNUST shows an important quality feature of a natural soil as reported by Umar *et al.* (2016). Improved soil total organic carbon, total organic matter, total nitrogen, soil available phosphorus, exchangeable cations (Ca, Mg, K and Na), exchangeable acicdity, cation exchange capacity and base saturation on KYE, SUA and AYE than in UEW, MED and KNUST (Table 4.8) show a high nutrient rich property in dumpsite soils than background soils due to the presence of organic wastes dumped on dumpsites after decay might have contributed to the essential nutrients in the dumpsites soils. This finding conforms to an earlier report that dumpsite soils are known to be rich in soil nutrient for plant growth and development (Ogunmodede and Adewole, 2015) and that could be related to decayed and composted wastes found on dumpsite that enhance the fertility (Ogunyemi *et al.,* 2003) of dumpsites soils. Such soils which support plant growth and production contain essential mineral materials (Uma *et al.,* 2016) and these essential plant nutrients might have been released from the wastes found on dumpsites after decomposition (Anikwe and Nwobodo, 2001). Also, the essential mineral materials from wastes help to increase nitrogen, pH, CEC, base saturation and organic matter. Higher soil organic matter levels in (Table 4.8) dumpsite soils may be as a result of high organic matter added after decay of organic wastes (Tripathi and Misra, 2012). The high organic matter contents especially in dumpsite soils might have accumulated from subsequent decomposition of plant residue waste materials as reported by Gairola and Soni (2010).

### 5.3.2 Heavy metals level in soils in pots under field conditions

#### 5.3.2.1 Cr levels in soils in pots under field conditions

Cr levels before planting and after planting of lettuce in pots were generally higher in dumpsite soils than in background soils under field conditions (Table 4.18). Chromium (Cr) levels were generally higher in KYE, SUA and AYE dumpsite soils than in UEW, MED and KNUST background soils (Table 4.18). This observation could be explain with the fact that, although Cr is less mobile, it may become mobile in a compound form through environmental disposition or human waste disposal on dumpsites at Mampong municipal and Kumasi metropolis. This may have contributed to the differences in contamination even on background soils. Wuana and Okieimen (2011) shared a similar report that, Cr is one of the less mobile elements which does not occur naturally in elemental form but only in compounds, also, Cr mobility may also depend on sorption characteristics of the soil, including clay content, iron oxide content and organic matter. Comparatively higher metal contamination in dumpsites soil than in background soils in pots could be due to variability in soil properties on dumpsites which conforms to a report by Engege and Lemoha (2012) that, dumpsite soils show variability in soil properties.

Soil pH values (Table 4.17) recorded in the soils studied were mostly higher in dumpsite soils than in their background soils might have influenced Cr levels (Table 4.19). This result is supported by a report by Horckmans *et al.* (2007) that, under alkaline (high pH) conditions, functional groups present in soil organic matter dissociate, and according to Fine *et al.* (2005), this increases the bioavailability of heavy metals bound to organic matter. This finding did not conform to a report that, with an increasing soil pH, the solubility of most trace elements will decrease leading to low concentration in soil solution (Kabata - Pendias, 2011). However, metal availability is relatively low when pH is around 6.5 - 7 (Adelekan and Alawode, 2011). Cr is one of the metal nutrient element required by plants in the soil in trace amounts for their physiological processes (Ehi and Uzu, 2011) but Cr levels in most dumpsites and background sites were higher (Tabls 4.19) than the world's soil average level (59.50 mgkg$^{-1}$) as reported by Onyedika (2015) and this suggest a possible anthropogenic source of chromium in the study sites.

The textural class for KYE, UEW and SUA were sandy, MED is sandy clay loam, while AYE and KNUST are loamy sand and that may have influenced the metals level in soils as explained by Sheoran *et al.* (2016) that, trace elements retainability is higher in fine - textured soils (clay and clay loam) as compared with coarse - textured soils (sand). Gupta *et al.* (2019) shared a similar view. High Cr levels in the dumpsite soils might be explain by the fact that, under increased pH conditions, functional groups present in the soil organic matter dissociates thereby increasing the bioavailability of heavy metals that are bound to organic matter (Fine *et al.,* 2005).

The highest Cr level recorded (87.64 mgkg$^{-1}$) in KYE before planting (Table 4.16) and at harvest (61.13 mgkg$^{-1}$) in KYE (Table 4.17) were above the critical concentration (Table 2.6) 5 - 30 mgkg$^{-1}$ but were within the 5 - 1500 mgkg$^{-1}$ by Radojevic and Baskin (2006). Cr general mobility were above (Table 2.8) 70 mgkg$^{-1}$ (2007); 1.30 mgkg$^{-1}$ (WHO (2009). This is an indication that, as an essential element Cr levels recorded is within the acceptable level of toxicity.

### 5.3.2.2 Fe levels in soils in pots under field conditions

Fe levels were generally higher in KYE, SUA and AYE than Fe levels in UEW, MED and KNUST before and after planting lettuce in pots (Table 4.18). Fe is an essential and an abundant metal elements (Onyedika, 2015) was generally higher in dumpsite soils than in background soils in a highly significant ($p = 0.01$) difference from each other. The higher Fe levels in the dumpsites than in the background soils might be due to the abundant nature of Fe in soils in addition to its concentration which has no limit conform to a report by Hameed *et al.* (2013) that, Fe is abundance in soils so it has no concentration limit in soils. Higher Fe levels in dumpsites than in background soils could also be linked to iron compounds among wastes found on dumpsites might have added up to Fe levels, leading to higher Fe levels in the dumpsite soils. This result agrees with a report by Onyedika (2015) that, major sources of Fe are the iron oxides such as minerals hematite, magnetite and taconite which are commonly found on dumpsites. Furthermore, higher Fe levels in dumpsite soils than in background soils could be attributed to the fact that, the accumulation of higher Fe levels on dumpsite soils may be due to the presence of metallic substance in the earth crust, as well as Fe bearing wastes (Olayiwola *et al.,* 2017). Also, the higher Fe levels in dumpsite soils conforms to a similar study where accumulation of heavy metals are concentrated at the soil - surface than the sub - surface (Amadi *et al*., 2012; Olalode *et al*., 2014).

The difference between Fe levels in dumpsite soils and their background (Table 4.18) soils may be linked to the relatively high soil pH (Table 4.17) levels in the background soils and that might have increased metal sorption rates. This difference agrees with the fact that, when pH falls below 5, metals mobility is enhanced as a result of the increased proton concentration (Mclaughlin *et al*., 2000; Paulose *et al*., 2007). Shah *et al.* (2013) have also explained that, Fe is the most abundant and an essential constituent for all plants and animals. However, higher Fe levels in KYE (9661.97 mgkg$^{-1}$) than in UEW (9661.97 mgkg$^{-1}$) may further be explained by the fact that, soil pH (Table 4.14) in especially SUA was acidic as compared to an alkaline pH medium in the dumpsite soils and Alamgir (2017) has described such differences by the fact that, at acidic pH medium, more protons ($H^+$) are available to saturate metal binding sites; therefore, metals are less likely to form insoluble precipitates. On ther hand, Fine *et al.* (2005) have described a situation where under alkaline (increase pH) conditions functional groups present in soil organic matter, dissociate, thereby increasing the bioavailability of metals bound to organic matter, an evidence that there is a possible combined effects of soil properties on metals sorption and desorption (Harter and Naidu, 2001; Appel and Ma, 2002; Dutta *et al*., 2011).

Lower Fe levels before planting in UEW (12330.58 mgkg$^{-1}$) (Table 4.15) and at harvest (12644.48 mgkg$^{-1}$) (Table 4.19) were higher than Fe levels recorded in UEW, MED and KNUST as similarly reported by Olowookere *et al.* (2018). Fe levels recorded before planting lettuce in pots and at harvest (Table 4.18) were above (Table 2.5) 48 mgkg$^{-1}$ (FAO/WHO, 2011); 10 - 100 mgkg$^{-1}$ (Table 2.7) by WHO/FAO (2001) but within the 5000 - 100 000 mgkg$^{-1}$ normal range of metals in soils by Radojevic and Baskin (2006) (Table 2.6).

#### 5.3.2.3 Ni levels in soils in pots under field conditions

Ni levels were generally higher KYE, SUA and AYE than in UEW, MED and KNUST in studied soils in pots before planting and after planting (Table 4.18). These differences in Ni levels are expected due to an increased soil pH in KYE as compare to soil pH in UEW (Table 4.17). A similar report by Fine *et al.* (2005) explained that, under alkaline (increased soil pH) conditions, functional groups present in soil organic matter, dissociate, thereby increasing the bioavailability of heavy metals that are bound to organic matter. Higher Ni levels in dumpsites soil than in background soils may also be due to the widely distributed nature of Ni in the environment andas a result may be released from both natural sources and anthropogenic activity with input from both stationary and mobile sources (Orji *et al.,* 2018). Furthermore, higher Ni levels recorded in dumpsite soils may also be linked to the type of Ni bearing wastes found on dumpites within municipal and metropolis studied.This observation is confirmed by Alloway (1995) who discussed that, many domestic cleaning products such as soap (100 - 700 mgkg$^{-1}$) and powdered bleach (800 mgkg$^{-1}$) may prove to be important sources of nickel in urban soil. Also, other sources of nickel may include food stuffs such as chocolate, automobile batteries and various paint wastes (Onyedika, 2015) periodically dumped on these sites. The concentration of Ni in SUA and AYE, all within a metropolis, recorded higher Ni levels than in KYE - a rural community within Mampong municipal. Such differences are expected because of the type of disposed material from mechanical shops and surrounding houses. This result agrees with a reason that Ni finds its way into the ambient air as a result of the combustion of coal, diesel oil and fuel oil and the incineration of waste and sewage (Cempel *et al*., 2006). Also, higher Ni levels in the dumpsites as compare to background soils could be linked to higher population and industrial activities in cities which most often lead to higher production of assorted waste than in the rural settlements. Agyarko *et al.* (2010) share a similar report. Also, a major use of Ni as a raw material in steel and other metal products could also have contributed to the high amount of Ni (Wuana and Raymond, 2011) bearing products which might have translated into high Ni levels in SUA.

The Ni concentration in SUA before planting (82.74 mgkg$^{-1}$) (Table 4.18) and at harvest (96.11 mgkg$^{-1}$) (Table 4.19) with the highest Ni levels were above 20 mgkg$^{-1}$ by Alloway (1995); 50 mgkg$^{-1}$ (Table 2.7) by WHO/FAO (2001); 16.52 - 17.24 mgkg$^{-1}$ in an automobile mechanic waste dump soil in Nigeria by Iwegbue *et al*. (2006); 10.00 mgkg$^{-1}$ (Table 2.8) by

WHO/FAO ( 2007) and 50.00 mgkg$^{-1}$ by WHA/FAO (2009); 89.76 - 118.35 mgkg$^{-1}$ on dumpsites soil and 20.08 mgkg$^{-1}$ on control soil by Ogunmodede *et al*. (2015); but was within a polluted soil range of 200 - 2600 mgkg$^{-1}$ and that of overall range of 10 - 1000 mgkg$^{-1}$ found in natural soil (Izosimora, 2005); High Ni levels in SUA was also within 2 - 750 mgkg$^{-1}$ (Table 2.6) by Radojevic and Baskin (2006), while the remaining Ni levels in the dumpsites and background soils were within the allowable concentration levels especially Ni levels in UEW, MED and KNUST, as in unpolluted soils but were above (Table 4.18) 34 mgkg$^{-1}$ of Ni reported by Kabata - Pendias and Pendias (2001) as the calculated world's mean Ni level in unpolluted soil. Ni is an essential trace element for human and animal health (Zighan Hassan *et al*., 2012), so Ni concentrations in the selected studied sites might be toxic even at low concentrations (Aekola *et al*., 2012).

#### 5.3.2.4 Cu levels in soils in pots under field conditions

Cu levels recorded before planting and after planting in pots were highest in most dumpsites soil than background soils in pots under field conditions (Table 4.18). Cu, an essential metal element was generally higher in dumpsite soils than in their background soils (Table 4.18) especially in SUA before planting (5659.17 mgkg$^{-1}$), at harvest (96.11 mgkg$^{-1}$). Such Cu levels in dumpsite soils might have been influenced by the natural occurrence of Cu in some soils which is derived from anthropogenic activities such as the use of copper containing fungicides, urban wastes management and industrial activity (Giovani *et al*., 2005). Also, higher Cu concentrations in SUA and AYE within a metropolitan may be attributed to higher population and industrial activities in cities and municipalities which could have led to higher production of assorted wastes than in the rural settlements (Agyarko *et al*., 2010).

Some of the reasons might also be due to the differences in living standards, consumption patterns and level of industrial development between cities and rural communities (Ebong *et al*., 2008). Cu accumulation though high on dumpsite soils (Table 4.18), is a necessity for many enzymes (Shah *et al.,* 2013; Ngange *et al.,* 2013) and also doubles as a macro nutrient for plants (Ngange *et al.,* 2013) in addition to its numerous applications due to its physical properties (Hameed *et al.,* 2013). Soil pH recorded between 6.07 - 9.04 (Table 4.17) was higher than pH 5.5 and might have influenced Cu lower levels in most soils with the exception of SUA and AYE (Table 4.18). Such influence from low soil pH could be linked to a situation where the solubility of Cu is drastically increased at pH 5.5 (Martinez and Motto, 2000).

The high Cu loads in especially SUA and AYE before planting and at harvest was expected because, two dumpsite soils studied were sampled from Kumasi metropolis - a city, and due to the kind of waste disposed, most of the wastes may be mostly Cu bearing wastes as reported by Greany (2005), that, Cu is the third most used metal in the world, as a result accumulates in the surface horizons, a phenomenon explained by the bioaccumulation of the metal and recent anthropogenic sources (Hameed *et al*., 2013). In addition, anthropogenic activities on rural or sub - urban areas are lower with the disposal of wastes on dumpsites than at metropolitan dumpsites where more wastes are generated as affirmed by Charlesworth *et al*. (2013).

Cu levels before planting were highest (78.64 mgkg$^{-1}$) in SUA (Table 4.18) and at harvest (124.23 mgkg$^{-1}$) in SUA (Table 4.19) were, however, above the worlds' scale value of non -

polluted soil of 24.00 mgkg$^{-1}$ by Pendias and Pendias (2001); 10 mgkg$^{-1}$ by WHO/FAO (2007); 30.00 mgkg$^{-1}$ (WHO/FAO, 2011). The highest Cu level although above 100.00 mgkg$^{-1}$ (WHO/FAO, 2001; Shah *et al.,* 2011) was found below 2 - 250 mgkg$^{-1}$ by Radojevic and Bashkin (2006). This is an indication that, SUA used to cultivate lettuce in pots under field conditions was within the acceptable limits safe for human health.

#### 5.3.2.5 Zn levels in soils in pots under field conditions

Zn levels recorded were highest in KYE, SUA and AYE in pots under field conditions both before planting and at harvest in pots (Table 4.18) than Zn levels in UEW, MED and KNUST. Such differences observed may be related to Zn accumulation from garden fertilizing activities, traffic and industrial input (Imperato *et al*., 2003). Furthermore, Zn high concentrations level on dumpsite soils as compared to the background soils could be due to anthropogenic additions on the dumpsites studied as a result of industrial activities such as mining, waste combustion, steel processing couple with dumpsite plants inability to handle these Zn concentrations already in their system through accumulation (Wuana and Okieimen, 2010) might have contributed to the higher Zn values in dumpsite soils.

A comparatively high soil pH (Table 4.17) values recorded on the dumpsite soils might have contributed to the increase in Zn levels because under increased (alkaline) conditions, functional groups present in soil organic matter dissociate, thereby increasing the bioavailability of heavy metals bound to organic matter (Fine *et al*., 2005). Also, the mobility of Zn in soils is dependent on its speciation, the soil pH and high soil of organic matter content (IPCS, 2001). The combined effect of lower soil pH in SUA as compare to

MED, higher soil organic matter, higher total nitrogen, high exchangeable cations and CEC (Table 4.17) of the dumpsite soils might have contributed to a higher Zn levels. Alamgir (2017) observed that, at acidic pH medium, more protons ($H^+$) are available to saturate metal binding sites; therefore, metals are less likely to form insoluble precipitates. Alamgir (2017) and Eze *et al.* (2018) have also reported that, heavy metals are generally more mobile at pH $< 7$ than pH $> 7$. Also, the higher Organic matter in dumpsite soils is reported for reducing or increasing the bioavailability of heavy metals in soil through immobilization or mobilization by forming various insoluble or soluble heavy metal organic complexes (Alamgir, 2017) while the capacity of soils for adsorbing heavy metals is correlated with their CEC (Fontes *et al*., 2000; Harter and Naidu, 2001). The greater the CEC values, the more exchange sites of soil minerals will be available for metal retention (Alamgir, 2017). These reasons agree with an assertion where several studies have showed the possibility of the combined effects of soil properties on metals sorption and desorption (Harter and Naidu, 2001; Appel and Ma, 2002; Dutta *et al*., 2011). Zn as an essential plant mineral element for animals too was higher in dumpsite soils than in background soils (Table 4.18). Olowookere *et al*. (2018) observed a similar difference after recording a higher concentration of Zn at the top soil in a dumpsite soil. Ngange *et al*. (2013) also recorded Zn concentration ranged from 0.15 - 1.70 $mgkg^{-1}$ and 0.11 - 1.40 $mgkg^{-1}$ at the upper part of the soil studied.

Zn levels were highest (5659.17 $mgkg^{-1}$) in SUA before planting (Table 4.18) and after planting (5464.62 $mgkg^{-1}$) in SUA (Table 4.19). The values were above 50 $mgkg^{-1}$ (Table 2.8) by WHO (2009); 60 $mgkg^{-1}$ (Table 2.5) by FAO/WHO (2011); 76.457 $mgkg^{-1}$ (Table 2.3) by Kabir *et al.* (2011); 300 $mgkg^{-1}$ (Table 2.7; 2.8) by WHO/FAO (2001) and Shah *et* *al.* (2011); 1 - 900 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006). These results are indication that, SUA is contaminated with Zn though it is an essential nutrient metal element.

### 5.3.2.6 As levels in soils in pots under field conditions

As levels recorded were highest KYE, SUA and AYE than in UEW, MED and KNUST soils in pots under field conditions (Table 4.18). Such situations conforms to an earlier report by Mensah *et al*. (2017), with a reported higher As levels in an e - waste dumpsite in Korle lagoon Accra although at a very close margin as compare to anbackground site. Also such close margin of differences in As levels in dumpites and their background soils might be due to an increase dumpsite soil pH (Table 4.17). This might have decreased the solubility of As in the dumpsite soils (Kabata - Pendias, 2011). The higher As levels in the dumpsite soils than in their background soils could be linked to the use of As bearing heavy metals in several industries in agriculture, domestic and technological applications (Bradi, 2002). The levels of As although very low as compare to metals like mercury, lead, cadmium, silver, chromium and many others. These metals are indirectly distributed as a result of human activities and could be very toxic even at low concentrations and can undergo global ecological circles (Aekola *et al*., 2012). The higher levels of soil organic matter content in dumpsite soils (Table 4.17) as compare to the background soils could not transmit into higher As levels in dumpsite soils under this condition as expected. This result is similar to a report where no correlation between soil organic matter, As and Pb were established by McBride *et al*. (2015).

As is a non - essential metal element but when found in soils is not only carcinogenic but has no nutritional value for plants and animals (Amadi *et al*., 2010; Ngange *et al*., 2013). As concentration were in the range of 13.39 - 21.47 mgkg$^{-1}$ before planting and at harvest of 9.47 - 17.92 mgkg$^{-1}$ (Tables 4.15 and 4.16) were within the normal range in soils 0.1 - 40 mgkg$^{-1}$ (Table 2.6) by Radojevic and Baskin (2006). This is not without any effect even at low concentrations in the soil because plants have a natural propensity to take up metals (Achazai *et al*., 2011) from the soil. The As levels recorded were above 20 mgkg$^{-1}$ (Table 2.7) by WHO / FAO (2001); 0.03 mgkg$^{-1}$ (Ngange *et al.* 2013); 3.67 mgkg$^{-1}$ in Accra city by Mensah *et al*. (2017); 0.66 mgkg$^{-1}$ and 0.55 mgkg$^{-1}$ by Opaluwa *et al*. (2012). The highest As levels before planting (21.47 mgkg$^{-1}$) in SUA (Table 4.18) and at harvest (17.92 mgkg$^{-1}$) in SUA (Table 4.19) were higher than 17.08 mgkg$^{-1}$ in an e - waste dumpsite soil in China by Predhan and Kumar (2014) but below 30 mgkg$^{-1}$ (Table 2.5) by FAO/WHO (2011). This is an indication that, As levels were within the acceptable limit in soils studied.

#### 5.3.2.7 Cd levels in soils in pots under field conditions

Cd levels recorded were higher in KYE, SUA and AYE than in UEW, MED and KNUST in pots under field conditions (Table 4.18). The Cd levels in dumpsite soils although higher than in background soils may be linked to the comparatively higher soil pH values (Table 4.17). Kabata - Pandias (2011) similarly explained that, with increasing soil pH the solubility of most trace elements will decrease leading to low concentration in soil solution. Adelekan and Alawole (2011) also reported that, metal availability is relatively low when pH is around 6.5 - 7. This makes soil pH a master variable influencing the physical, chemical and biological properties of soil (Chakraborty, 2015; Neina, 2019). Also, Cd higher levels in dumpsite soils are expected and may be linked to the disposal of Cd bearing wastes on dumpsites. Nurudeen and Aderibigbe (2013) have confirmed this result with their highly contaminated reported value of Cd at 19.35 mgkg$^{-1}$ as a result of Cd bearing continuous refuse dumping. The higher Cd levels in the dumpsite soils may also be linked to the age of dumpsites opened for use in the community with the presence of Cd bearing compounds, atmospheric disposition and other related different sources and origin of inorganic waste exposed to the soils. Kisku *et al*. (2000) shared a similar view that, the burning of fossil fuels and tyres, the use of lubrication oils, vehicles wheels, application of solid wastes from industries and home, sewage sludge waste water irrigation and phosphate fertilizer application have also contributed to Cd toxic levels in soils.

Cd levels were highest at 47.31 mgkg$^{-1}$ in KYE (Table 4.18) and at 30.56 mgkg$^{-1}$ in SUA (Table 4.19) were higher than normal range of Cd in soils (Table 2.6) at 0.01 - 2 mgkg$^{-1}$ by Radojevic and Baskin (2006), 3.00 mgkg$^{-1}$ (Table 2.4; 2.7) (WHO, 2007; Chiroma *et al.,* 2014), 5.633 mgkg$^{-1}$ (Table 2.3) by Kabir *et al.* (2011). The values recorded in this study need much attention although Cd levels recorded in the soils studied were lower than 103.70 mgkg$^{-1}$ (Mensah *et al.,* 2017), Cd is extremely toxic even at low concentration (Shah *et al*., 2013), because Cd is also not known for any essential biological function (Wuana and Okieimen, 2011) and as a result Cd is not required for plants growth (Ngange *et al*., 2013).

### 5.3.2.8 Hg levels in soils in pots under field conditions

Hg levels recorded were highest in KYE, SUA and AYE than in UEW, MED and KNUST background soils in pots under field conditions (Table 4.18). Such higher Hg levels in dumpsite soils in pots before planting and at harvest is expected due to the differences in soil pH values recorded in the study soils (Table 4.17). Sheoran *et al*. (2016) have found that, metal concentration decreases at high pH and increases at low pH values. In addition, heavy metals become more mobile at pH < 7 than pH > 7 (Eze *et al.,* 2018). The combined effect of soil pH and organic matter dynamics could also be linked to higher levels of Hg in dumpsite soils than in background. The soil pH (Table 4.17) differences might have contributed to the mobility of positively charged heavy metals as a result of proton competition with metals and decreased negative binding sites (Harckmans *et al*., 2007). However, under alkaline (increase pH) conditions, functional groups present in soil organic matter dissociate, thereby increasing the bioavailability of heavy metals that are bound to organic matter (Fine *et al*., 2005).

Higher Hg levels in dumpsite soils than in the background soils may be explained with the reason that, Hg bearing wastes disposed on waste sites through human activities from industries such as textiles tanning, petrochemicals from accidental oil spills or utilization of petroleum - based products and other pharmaceutical facilities, are highly variable in composition although some are disposed on land, and few of these plant essential metals have benefits to agriculture or forestry (Raymond and Okieimen, 2011). Also, higher Hg levels are expected at top soil. This finding is in line with a report in which accumulation of heavy metals are concentrated at the soil - surface than in the sub - surface is reported by Amadi *et al*. (2012) and Ololade (2014) in that, soils show remarkably high levels of metals such as copper, iron, and zinc which decrease with depth, and is the reason why surface soils have been found as better indicators for metabolic burdens (Anikwe and Nwobodo, 2002).

Hg levels before planting were highest at 44.75 mgkg$^{-1}$ in SUA (Table 4.18) and at harvest highest in AYE at 21.02 mgkg$^{-1}$ (Table 4.19) were higher than 2.00 mgkg$^{-1}$ (Table 2.7) by WHO/FAO (2001); Radojevic and Baskin (2006) reported Hg at a range of 0.01 - 0.50 mgkg$^{-1}$ (Table 2.6); Hg level in uncontaminated soils at 0.04 - 0.08 mgkg$^{-1}$ by Greany (2005). Hg levels in most of the studied soils were higher in dumpsites in metropolis than dumpsites in the rural communities within a municipal with low Hg concentration levels. This observation may be due to a number of combined effect of soil properties on metals absorption and adsorption (Harter and Naidu, 2001; Dutta *et al*., 2001; Appel and Ma, 2002). This result show that Hg levels in SUA was above the allowable limit in agricultural soils

#### 5.3.2.9 Pb levels in soils in pots under field conditions

Pb levels recorded were higher in KYE, SUA and AYE than in UEW, MED and KNUST in pots under field conditions (Table 4.18). This observation is expected because of human wastes disposal activities and other Pb sources on dumpsites might have accumulated Pb leading to increased levels in the dumpsite soils. This pattern bears a resemblance of a Pb concentration trend as observed by Poggio *et al.* (2009) who attributed such differences in Pb levels through numerous human activities like mining, smelting, manufacturing which can be toxic to human health (Poggio *et al*., 2009). The high Pb levels in dumpsites may also be linked to the soil type, moderately and high organic matter content of the dumpsite soils studied (Table 4.17). This difference agrees with a report by Hameed *et al*. (2013) that species of lead vary considerably with soil type; it is mainly associated with clay minerals, magnesium oxides iron, aluminum hydroxides and organic matter.

High Pb levels recorded in dumpsite soils may also be linked to differences in waste generation between urban and rural population as found by Moller *et al*. (2000), that, soils accumulated high levels of Pb in urban environments from a range of sources including that derived from leaded petrol. Such differences might also be due to higher population and industrial activities in municipalities which may lead to higher production of assorted wastes than in the rural settlements (Agyarko *et al.,* 2010).

Pb levels were highest in AYE (75.32 mgkg$^{-1}$) before planting (Table 4.18) and at harvest (59.54 mgkg$^{-1}$) in AYE (Table 4.19) and were above the worlds' average Pb in unpolluted soil at 44.0 mgkg$^{-1}$ (Kabata - Pendias and Pendias, 2001); lower than Pb level in residential area (136.76 mgkg$^{-1}$) and at an industrial area (159.67 mgkg$^{-1}$) by Onyedika (2015); higher than Pb in a dumpsite soil (0.7 - 1.3 mgkg$^{-1}$) and on control or uncontaminated sites was 1.1 mgkg$^{-1}$ (Olowookere *et al*., 2018); 5.00 mgkg$^{-1}$ (Table 2.7) by WHO/FAO (2001); 2.00 mgkg$^{-1}$ (WHO, 2009). The remaining selected soils were within the permissible Pb level at 40 mgkg$^{-1}$ by Kabata - Pendias and Pendias, (2001. This result gives an indivation that, the highest Pb recorded in AYE was found to be within acceptable contamination level with Pb.

### 5.3.3 Heavy metals level in lettuce shoots and roots in pots at harvest under field conditions

#### 5.3.3.1 Cr levels in lettuce in pots under field conditions

Concentration of Cr in lettuce shoots and roots were higher on dumpsites soil than on backgrounds soil at harvest (Tables 4.20 and 4.21). The high Cr levels in lettuce shoot and roots planted on dumpsites may be due to metal contaminated dumpsites commonly used as agricultural lands in especially cities where arable land for crop production are inadequate. This observation is similar to earlier report by Amusan *et al.* (2005) that, dumpsites used as fertile grounds for the cultivation of crops results in increased uptake of heavy metals either as mobile ions or through foliar absorption. Fuge (2013); Wuana and Okieimen (2011) share a common report that, dumpsites used for agriculture are important sources of dangerous heavy metals derived from components of industrial products. Also, higher Cr levels in lettuce shoost than in roots (Tables 4.20 and 4.21) may be explain with the fact that, crop production on dumpsites though fertile also provides an environment for metals absorption by edible parts of plants. Such similar observations have been that, agricultural activities on such lands provide entry route for heavy metals in the food chain (Twumasi *et al*., 2016) and most of these vegetables used for cultivation are hyper accumulators of most of the essential heavy metals (Singh *et al.,* 2012). Cr level which was highest in lettuce shoots (34.20 $mgkg^{-1}$) and roots (23.56 $mgkg^{-1}$) in KYE in pot (Tables 4.20 and 4.21) were above 0.03 - 14 $mgkg^{-1}$ as normal range in plants; 5 - 30 $mgkg^{-1}$ as critical plant concentration (Table 2.6)

#### 5.3.3.2 Fe levels in lettuce in pots under field conditions

Fe was generally high in lettuce shoots than in lettuce roots on KYE, SUA and AYE than on UEW, MED and KNUST (Tables 4.20 and 4.21). The differences in Fe levels may be due to high organic and inorganic waste which might have contributed to higher Fe levels in lettuce shoots and roots harvested from dumpsites soils in pots than from background soils. The high Fe levels in lettuce shoots and roots from dumpsites may also be attributed to the fact that, organic wastes in dumpsites soil are easily converted into harmless substance but inorganic substance which are non - biodegradable, persisted and may have accumulated in the soil and plants found on them as reported by Ukpong *et al.* (2013). Furthermore, the situation where dumpsites are commonly used as a fertile grounds for the cultivation of crops might have contributed to the increased uptake of heavy metals either as mobile ions or through foliar absorption (Amusan *et al.,* 2005).

Plant roots uptake of metals is controlled by many factors such as soluble contents of trace elements in soil, soil pH, organic matter, cation exchange capacity, plant growth stages, crop type, fertilizers and soil type (Lente *et al.,* 2014; Yadav *et al.,* 2018).

Fe level was highest in lettuce shoot (6357.22 mgkg$^{-1}$) and root (5613.66 mgkg$^{-1}$) on SUA Kumasi dumpsite soil (Table 4.18) were above 384.412 mgkg$^{-1}$ of Cr (Table 2.3) lettuce plant at harvest (Kabir *et al.,* 2011); normal range in plants at 40 - 500 mgkg$^{-1}$ (Table 2.6) by Stewart *et al.* (1974); 20 mgkg$^{-1}$ (Table 2.8) by WHO (2009). The highest Fe level was recorded in lettuce shoot and root harvested from SUA in pots give an indication that consumers of especially lettuce shoots as food or for medicinal purposes faces a serious health threat if not attended to.

### 5.3.3.3 Ni levels in lettuce in pots under field conditions

Ni was generally high in lettuce shoots than in lettuce roots especially on dumpsites than on background sites (Tables 4.20 and 4.21). Differences in Ni levels in lettuce cultivated on dumpsites soil and background soils in pots may be due to common use of dumpsites soil for agriculture are important sources of dangerous heavy metals derived from components of industrial products as reported by Fuge (2013); Wuana and Okieimen (2011) and thus agricultural activities on such lands provide entry route for heavy metals in the food chain (Twumasi *et al*., 2016). Also, most leafy vegetables have been found to be hyper accumulators of most of the non - essential heavy metals (Singh *et al*., 2012).

Differences in Ni levels in lettuce shoot and root sampled from dumpsites soils as compared with lettuce shoot and roots in background soils in pots might be due to various Ni bearing wastes found on dumpsites and when leached might end up in plants found on them. Alloway (1995) showed a similar observation that, many domestic cleaning products such as soap (100 - 700 mgkg$^{-1}$ Ni), powdered bleach (800 mgkg$^{-1}$ Ni) have proven to be important sources of Ni in urban soils. Also, foodstuffs such as chocolate, automobile batteries and various paint wastes (Onyedika, 2015) might have eventually accumulated by the lettuce cultivated on dumpsites soils in pots. Other sources of Ni levels in sampled lettuce shoots and roots are through the ambient air as a result of the combustion of coal, diesel oil and the incineration of wastes and sewage (Cempel *et al.,* 2006) in addition, Ni widely used in electroplating and in the manufacture of batteries serves as an additional source of Ni, although Ni is an essential element for plants and animals (Hameed *et al.,* 2013),

The enhanced levels of Ni in cultivated lettuce on dumpsites soils in pots may be due to transpiration effects because, when transpiration flourishes, plant accumulates more trace elements and its enrichment capacity is also stronger (Hao *et al.,* 2012). Gupta *et al.* (2019) also confirmed that, leafy vegetables accumulate much higher content of trace elements than other vegetables and crops due to higher translocation and transpiration rate. In addition, mostly higher concentrations of heavy metals have earlier been detected in fruits and vegetables harvested from waste dumpsites (Imasueb Omorogiera, 2013; Cortez and Ching, 2014; Tanee and Eshalomi - Mario, 2015). Other reports have found that, the transfer of metals from root to stem and then to fruit during the transpiration and translocation process is longer in non - leafy vegetables and may result in lower accumulation (Itanna, 2002; Khan *et al.,* 2009).

Ni level was highest in lettuce shoot (17.73 mgkg$^{-1}$) on SUA in pots than lettuce root background soil (16.69 mgkg$^{-1}$) on KNUST (Tables 4.20 and 4.21) were above 3.083mgkg$^{-1}$ (Table 2.3) by Kabir *et al.* (2011); 0.02 - 5 mgkg$^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006); was within 50 mgkg$^{-1}$ and 10 mgkg$^{-1}$ (Table 2.8) by WHO (2007; 2009); 02 - 50 mgkg$^{-1}$ (Table 2.5) by FAO / WHO (2011); 67 mgkg$^{-1}$ (Table 2.4) by Chiroma *et al.* (2014). The Ni levels in lettuce shoots and roots indicate that, lettuce shoots and roots harvested from all study sites are safe for consumption by human and animals.

#### 5.3.3.4 Cu levels in lettuce in pots under field conditions

Cu was generally high in lettuce shoots than in roots on KYE, SUA and AYE than on UEW, MED and KNUST (Tables 4.20 and 4.21). This observation may be due to the fact that wastes dump on dumpsites might be Cu bearing wastes and as a result plants found on them may accumulate higher metal levels than plants found on background soils. A similar results was reported where higher concentrations of heavy metals were detected in fruits and vegetables harvested from waste dumpsites (Imasueb Omorogiera, 2013; Cortez and Ching, 2014; Tanee and Eshalomi - Mario, 2015) because dumpsites mostly used for agriculture are important sources of dangerous heavy metals derived from components of industrial products (Fuge, 2013; Wuana and Okieimen, 2011). Also, lettuce shoots and roots sampled from the studied dumpsites might have been composed of Cu bearing wastes and which might have accumulated in lettuce shoots and roots.

Olankule *et al.* (2018) share a common report that, dumpsites soil may comprise of other materials that contain heavy metals and as a result are of great concern to farmers and consumers in Ghana. Ogunmodede *et al.* (2015) discussed that, heavy metals from refuse dump soils were in higher levels than in the control or background values especially for Cu and that was attributed to the fact that, refuse dumps receive considerable waste proportions of product packaging, waste, cloths, glass and bottles, newspapers, paints, batteries, industrial dust, ash, car tyres, metal cans and containers, medical waste, abandoned vehicles and insulations. All these refuse dump wastes are known to be sources of metals (Woodbury, 2005). The Cu levels absorbed by lettuce may be due to the available forms of Cu in the soils studied. This observation conforms to a report that, concentration of availability forms of metals in soil is controlled by various physical and chemical processes such as exchange, adsorption and desorption, complexation, precipitation and dissolution, oxidation, reduction, sequestration and occlusion, diffusion and migration, metal competition, biological immobilization, mobilization and plant uptake (Kabata – Pendias, 2010; Wuana and Okieimen, 2011).

Cu levels were mostly higher in lettuce shoots than in roots from most of the study dumpsites than in background sites (Tables 4.20 and 4.21). This observation may be related to the fact that, most Cu ions might have been transported from the roots to other parts of lettuce through factors like crop type and soil pH which might have resulted to higher levels of Cu in lettuce shoots. Gupta *et al.* (2019) share a similar report that, vegetables take up metals from polluted soils and through atmospheric deposition of particulate matter from different sources are first absorbed in the apoplast of roots and transported further into other parts of the plant cells. Also, metals roots uptake of metals is controlled by many factors such as soluble contents of trace elements in soil, soil pH, organic matter, cation exchange capacity, plant growth stages, crop type, fertilizers and soil type (Lente *et al.,* 2014; Yadav *et al.,* 2018).

Cu level was highest in lettuce shoots (47.70 mgkg$^{-1}$) and roots (28.88 mgkg$^{-1}$) on SUA (Tables 4.20 and 4.21) were above 11.05 mgkg$^{-1}$ in cocoyam corm; 5 - 20 mgkg$^{-1}$ as normal range in plants (Table 2.6) by Radojevic and Bashkin (2006); 8.00 mgkg$^{-1}$ in lettuce (Table 2.3) by Kabir *et al.* (2011); 30 mgkg$^{-1}$ in food; 2.5 mgkg$^{-1}$ as normal range in plants (Table 2.5) by FAO / WHO (2011). On the contrary, Cu levels were within 20 - 100 mgkg$^{-1}$ as a critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006) and below 73.00 mgkg$^{-1}$ (Chiroma *et al.,* 2014). These results show that, lettuce shoots and roots cultivated in SUA in pots recorded the highest Cu level and are safe for human and animals as food or for medicinal purposes.

### 5.3.3.5 Zn levels in lettuce in pots under field conditions

Zn was generally high in both lettuce shoots and roots (Tables 4.20 and 4.21) on dumpsite soils than on background soils in pots. This result may be due to the absorption of Zn by lettuce on Zn bearing wastes found on dumpsites soil in pots. This observation is in line with the fact that, when plants are cultivated on dumpsites soils, they absorb some heavy metals and bioaccumulate them in their roots, stems, fruits, grains and leaves (Fatoki, 2000). The highest Zn level was recorded in lettuce shoot on a dumpsite soils in pots than from background soils (Tables 4.20 and 4.21). This difference is expected because refuse dumpsites soil receive considerable waste proportions of product packaging, waste cloths, glass and bottles, newspapers, paints, batteries, industrial dusts, ash, car tyres, metal cans and containers, medical waste, abandoned vehicles and insulations which are known to be sources of metals (Zhang *et al.,* 2002; Pasquini and Alexander, 2004; Woodbury, 2005). Zn levels were mostly higher in lettuce shoots and roots cultivated (Tables 4.20 and 4.21) in urban dumpsites soil wthint Kumasi than in Kyeremfaso Mampong, a rural community within Mampong municipal. Such differences are observed as a result of higher population and industrial activities in cities and municipalities which lead to higher production of assorted wastes than in the rural settlements (Ebong *et al.*, 2008).

Zn levels recorded among all studied soils in pots was highest in lettuce shoots (2895.61 mgkg$^{-1}$) and roots (1698.12 mgkg$^{-1}$) on SUA (Tables 4.20 and 4.21) were above 76.457 mgkg$^{-1}$ (Table 2.3) as normal metal concentration levels in cultivated lettuce by Kabir *et al.* (2011); 60 mgkg$^{-1}$ as normal Zn level in food; 50 mgkg$^{-1}$ (Table 2.8) by WHO (2009); 20 - 100 mgkg$^{-1}$ as normal range in plants (Table 2.5) by FAO / WHO (2011); 1 - 400 mgkg$^{-1}$ as normal range in plants and 100 - 400 mgkg$^{-1}$ as a critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006); 300 mgkg$^{-1}$ (Table 2.8) by WHO (2009). This result shows that, Zn levels in lettuce shoot and root cultivated on SUA and the remaining lettuce parts from the other urban dumpsites and background soils lettuce shoots and roots were above the allowable Zn levels in plants. Lettuce shoots and roots harvested from SUA may pose danger to humans and grazing animals using them as food or for medicinal purposes.

### 5.3.3.6 As levels in lettuce in pots under field conditions

As was generally high in lettuce shoots than in roots on dumpsites than in background soils in pots (Tables 4.20 and 4.21). This observation may be related to the situation where most edible crops may not be selective in absorbing essential and non - essential plant nutrients. This observation is comparable to report where most edible crops show their indiscriminate activities in their extraction of both non - desirable and the required essential nutrients to man, which may cause blood and bone disorders, kidney damage, decreased mental capacity (NIEHS, 2004; Ogunmodede and Adewole, 2015). Also the use of dumpsites soil as fertile grounds for crop cultivation has resulted to an increased uptake of heavy metals either as mobile ions or through foliar absorption (Amusan *et al.,* 2005). Cultivated plants on dumpsites may absorb some of these heavy metals and bioaccumulate them in their roots, stems, fruits, grains and leaves (Fatoki, 2000). Singh *et al.* (2013) have attributed higher As levels in lettuce shoots to how leafy vegetables found on dumpsites are hyper accumulators of most non - essential heavy metals

Higher As levels in SUA and AYE lettuce shoots than As levels in lettuce shoots on KYE dumpsite soil may be linked to higher living standards in SUA and AYE within a metropolis against a rural KYE dumpsite in a municipal might have contributed to the differences in As levels in lettuce shoots and roots in pots (Tables 4.20 and 4.21). This result may be explain by the fact that, high living standards in urban resulting to different metal species wastes differs from that of the rural metal bearing wastes agrees with a report by Amusan and Olawale (2005) that, the rate of metal uptake by plants could be influenced by factors such as metal species, plant species, soil pH, CEC, organic matter, soil texture and interaction among the target elements.

The highest As level in lettuce shoot (8.39 mgkg$^{-1}$) on MED and lettuce root (9.05 mgkg$^{-1}$) on AYE in pots (Tables 4.20 and 4.21) were however within the normal concentration levels in plants at 0.02 - 7 mgkg$^{-1}$; 5 - 20 mgkg$^{-1}$ range as a critical plant concentration As level (Table 2.6) by Radojevic and Bashkin (2006); 30 mgkg$^{-1}$ in food, 0.5 - 20 mgkg$^{-1}$ as normal As level in plants (Table 2.5) by FAO / WHO (2011). This result shows that, lettuce shoots from SUA Kumasi dumpsite which recorded the highest As level is safe for human and grazing animals as food and medicinal purposes.

#### 5.3.3.7 Cd levels in lettuce in pots under field conditions

Cd levels were equally high in both lettuce shoots and roots on dumpsites soil than on background soils (Table 4.18). This observation is linked to metals contaminant sources which are mostly dumped on waste dumpsites and that might have affected the Cd levels in dumpsite soils. This result is in line with the explanation that Cd contamination sources like dumping of inorganic wastes, burning of refuse at dumpsites from time to time (Nurudeen and Aderibigbe, 2013), burning of fossil fuels, car tyres, the use of lubrication oils, vehicle wheels, application of solid wastes from industries and homes, sewage sludge waste, water irrigation and phosphate fertilizer application (Kisku *et al*., 2000) might have contributed to Cd levels accumulated in lettuce shoots and roots found on dumpsites. Also, such observation may be as a result of higher metal levels in dumpsites soil (Tables 4.18) which might have resulted in Cd accumulation in lettuce.

A similar finding was reported with an increased uptake of metals either as mobile ions or through foliar absorption (Amusa *et al.,* 2005) of metals in plants cultivated in dumpsites soil in pots. Also dumpsites soil which are known to contain heavy metals might have come from the disposal of Cd bearing wastes and when leached, end up in plants through absorption without discrimination. Such observation is confirmed by an earlier work where lettuce found on dumpsites recorded Cd in a range of 90.13 - 0.67 mgkg$^{-1}$ higher than lettuce on control site at 0.010 mgkg$^{-1}$ (Twumasi *et al.,* 2016). In addition, a similar study have found that, most edible crops are indiscriminate in their extraction of essential and non - essential nutrients and that may cause blood and bone disorders (NIEHS, 2004; Ogunmodede and Adewole, 2015).

Cd level was highest in lettuce shoot (5.25 $mgkg^{-1}$) on KYE Mampong dumpsite soil and lettuce root (5.07 $mgkg^{-1}$) on KNUST Kumasi background soil in pots (Table 4.18) were above 0.1 - 2.4 $mgkg^{-1}$ as normal range in plants (Table 2.6) by Radojevic and Bashkin (2006); 0.35 $mgkg^{-1}$ (WHO, 2007); 0.02 $mgkg^{-1}$ (Table 2.8) by WHO (2009); 1 - 2.4 $mgkg^{-1}$ as normal range in food and plants (Table 2.5) by FAO / WHO (2011); 0.1 $mgkg^{-1}$ (Table 2.4) by Chiroma *et al.* (2014); 0.02 $mgkg^{-1}$ as maximum allowable limit in lettuce and 0.05 $mgkg^{-1}$ in fruit vegetable by Twumasi *et al.* (2016). Cd values recorded were within 5.633 $mgkg^{-1}$ as a concentration in lettuce by Kabir *et al.* (2011); the critical plant concentration range of 5 - 30 $mgkg^{-1}$ (Table 2.6) by Radojevic and Bashkin (2006). This result show that, lettuce leaves from SUA Kumasi dumpsite soil is still safe for animal and human consumption.

### 5.3.3.8 Hg levels in lettuce in pots under field conditions

Hg levels were generally higher especially in lettuce shoots and roots planted on KYE, SUA and AYE than lettuce planted on UEW, MED and KNUST soils in pots (Tables 4.20 and 4.21). Hg levels in lettuce shoots and roots bear a resemblance of leafy plants which has a natural affinity for metals and with their non - biodegradable toxic nature, affect plants, human and grazing animals. Achazai *et al.* (2011) have similarly attributed such differences in Hg absorption by lettuce as a plant with a natural propensity to take up metals. Also, the higher levels of Hg found in lettuce shoots and roots than lettuce shoots and roots in pots might be due to the rate of Hg uptake by lettuce plant as influence by Hg specie present in the soil. Amusan and Olawale (2005) similarly attributed Hg levels in lettuce, to the rate of metal uptake by plants due to influences by metal species, plant species, soil pH, CEC, organic matter, soil texture (Table 4.17) and interaction among the target elements. However, plants absorption of essential and non - essential elements from the soil is in respond to concentration gradient and selective uptake of ions or by diffusion (Peralta - Videa *et al.,* 2009).

Higher Hg levels in lettuce shoots than in roots (Tables 4.20 and 4.21) may be explain with the reason that, different plant parts contain different heavy metals (Natasa *et al.,* 2015) and plants absorb heavy metals from the soil through the root and from the atmosphere through above ground vegetative organs (Mmolowa *et al.,* 2011).

Hg levels recorded were highest in lettuce shoot (6.33 $mgkg^{-1}$) and lettuce root (5.71 $mgkg^{-1}$) planted on SUA in pots under field conditions(Tables 4.20 and 4.21) were found to be above 0.005 - 0.17 $mgkg^{-1}$ as normal range of Hg in plants and 1 - 3 $mgkg^{-1}$ as critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006). Hg is a non - essential plant metal element, so Hg uptake and subsequent accumulation along the food chain is a potential threat to animal and human health (Sprynskyy *et al.,* 2007). This result shows that, lettuce shoot from SUA may not be safe for human and grazing animal's consumption due to Hg contamination.

#### 5.3.3.9 Pb levels in lettuce in pots under field conditions

Pb was mostly high in lettuce shoots and roots on KYE, SUA AYE dumpsite soils than on UEW, MED and KNUST background soils (Tables 4.20 and 4.21). This result is expected because dumpsites receive considerable wastes and as a result accumulated in plants found on them. Zhang *et al.* (2002) affirms this assertion. Hg is not biodegradable so even at low concentrations; Pb may have toxic effects on living organisms at certain level of concentration (Ogunmodede and Adewole, 2015). Pb levels in lettuce shoots and roots confirm the very narrow range of concentrations between beneficial and toxic effects of metals (Tchounwou *et al*., 2008). Such Pb differences in lettuce shoots and roots in the soils studied is similar to an earlier report by Natasa *et al.* (2015) that, different plant parts contain different levels of heavy metals.

Pb levels in SUA was lower in lettuce shoot at 5.59 mgkg$^{-1}$ and higher AYE in lettuce root at 35.76 mgkg$^{-1}$ (Tables 4.20 and 4.21) were above 2.00 mgkg$^{-1}$ in food (Table 2.5) by FAO / WHO (2011); 5.942 mgkg$^{-1}$ in lettuce (Table 2.3) by Kabir *et al.* (2011); 0.5 - 30 mgkg$^{-1}$ as normal range in plant (Table 2.5) by FAO / WHO (2011); 0.5 - 20 mgkg$^{-1}$ as normal range in plants but were within the 30 - 300 mgkg$^{-1}$ as critical plant concentration (Table 2.6) by Radojevic and Bashkin (2006). This result is an indication that, cocoyam corms and leaves especially sampled from SUA Kumasi dumpsite is safe for humans and animal consumption as food or medicinal purposes.

### 5.3.4 NPK levels in lettuce plant at harvest

Nitrogen levels were lower in lettuce shoots and roots on KYE, SUA and AYE than on UEW, MED and KNUST in pots under field conditions (Table 4.22). Available P levels were lower in lettuce shoots and roots on AYE than on KNUST. Available K level was lower in lettuce shoots and roots on SUA than on MED. The higher levels of especially N in all the background lettuce shoots and roots, higher P and K in KNUST and MED background soils than in their dumpsite soils can be related to the moderate levels of organic matter in their soils (Table 4.17). This finding is in agreement with Ideriah *et al*. (2010) who found that, organic matter is one of the sources of most N and P which enhance and promote plants growth. Also, this difference could have resulted from the organic materials from organic wastes which when decayed helped to increase N, pH, CEC, base saturation and organic matter (Anikwe and Nwobodo, 2001). N in organic matter in dumpsites (Table 4.14) although lower than in background soils in pots was enough to support lettuce growth as described by Obianefo *et al*. (2017) that, N in dumpsite soils produced yield better than their control locations an assertion that confirms the level of N in lettuce shoot and root (Table 4.22).

Available P levels were higher in lettuce shoots and roots on KYE and SUA than on UEW and MED in pots under field conditions (Tables 4.22). Available K levels were higher in lettuce shoots and roots on KYE and AYE than on UEW and KNUST (Table 4.22). Higher levels of phosphorus and potassium in lettuce shoots and roots on the dumpsites than on their background sites can be related to the studied soils organic matter content, pH and CEC (Table 4.17) might have contributed to the accumulation of the soil nutrients (NPK) by lettuce shoots and roots in pots. Ogunyemi *et al*. (2003) share a similar report that, an improved soil physicochemical properties (Table 4.17) of the studied dumpsite soils might have resulted from the decayed and composted wastes that enhance soil fertility. Ogunmodede *et al*. (2005) share a similar report. Also Aydenalp and Marinova (2003) similarly share a common reason to the effect that, the concentrations levels of CEC and organic matter (Table 4.17) might have improved lettuce nutrient (NPK) accumulation in pots more easily by conditioning the soil for crop growth.

### 5.4 Techniques to assess pollution of soils by heavy metals

### 5.4.1 Evaluation of heavy metals contamination on the field

### 5.4.1.1 Geoaccumulation Index ($I_{geo}$) of dumpsite soils studied

The $I_{geo}$ contamination intensity of Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb in Kyeremfaso Mampong dumpsite soil (KYE); Ayeduase Kumasi dumpsite soil (AYE) and Suame Kumasi dumpsite soil (SUA) at 0 - 15 cm depth showed contamination intensity of Cr, Cu, Zn, As, Hg follow the order of (KYE < AYE < SUA) Ni, Fe and Cd (AYE < KYE < SUA) with the most contaminated soil in SUA at 0 - 15 cm of soil depth (Table 4.23). Pb (AYE < SUA < KYE) was least contaminated in AYE and most contaminated in SUA (Table 4.23). Similarly, at 15 - 30 cm depth, Cr, Fe, Ni, Cu, Zn, Pb (KYE < AYE < SUA) As and Hg (AYE < KYE < SUA) were most contaminated in SUA. Cd (AYE < SUA < KYE) was least contaminated in AYE and most contaminated in KYE (Table 4.24). This result showed that a rural community within a Municipal KYE was the least contaminated with metals as compared to an urban Metropolis SUA and AYE, which may be due to the low population and industrial activities in the area compared to the order studied sites. Agyarko *et al*. (2010) shared similar results. Also, the differences in $I_{geo}$ pollution values among the studied dumpsites soil might have contributed to differences in soil pollution levels in the various dumpsites which may be related to soil physicochemical properties like soil texture and organic matter contents (Table 4.8) which are important to the forms of heavy metals in their available forms. Aydinalp and Cresse (2009) shared a similar view that soil physicochemical parameters like texture and organic matter are important with regards to the forms of heavy metals present and their bioavailability. The various different industrial activities coupled with varying living standards might have contributed to the heavy metals load pollution in the metropolitan dumpsites than in rural set up within a municipal and this results is affirm by Olankule *et al.* (2018) that, dumpsite soils may also comprise of other materials that contain heavy metals.

### 5.4.1.2 Enrichment Factor (EF) of dumpsite soils studied

Contamination categories of Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb in an increasing contamination category order under KYE, SUA and AYE soils showed that, at 0 - 15 cm depth, Cr, Fe, Ni and As, Cd were in the increasing order of AYE < KYE < SUA. Cu, Zn and Hg increased in the order of KYE < AYE < SUA. SUA soil were highly enriched through human influence (Table 4.27). Pb (KYE < SUA < AYE) was highly enriched through human influence on AYE Kumasi dumpsite soil (Table 4.23). A similar pattern at 15 - 30 cm depth, was observed when Cr (SUA < KYE < AYE) and Pb (KYE < SUA < AYE) were highly enriched through human influence in AYE Kumasi dumpsite soil than in other dumpsite soil (Table 4.24). Fe, Ni, Hg (AYE < KYE < SUA) Cu and Zn (KYE < AYE < SUA) were highly enriched through human influence in SUA Kumasi dumpsite soil than in AYE Kumasi dumpsite soil (Table 4.28). As and Cd were highly enriched through human influence (AYE < SUA < KYE) in KYE Mampong dumpsite soil than in other dumpsite soils (Table 4.28). Similarly, These similar observations may be explain by the fact that, a soil contamination evaluation technique, an enrichment factor (EF) is an effective tool used to evaluate the magnitude of metal contamination in soil (Franco - Uria *et al.*, 2009). EF classification by Birch and Olmos (2008), showed that, most EF values for 0 - 15 cm and 15 - 30 cm of soil sample depths were above 1.5 are consistent with an earlier results which showed that, a significant portion of the metals source is from human influence due to the fact that, waste materials dumped on these sites coupled with their higher concentrations in soils (Tables 4.8) and plants (Tables 4.11, 4.12, 4.13 and 4.1) confirm that major pollutants exist in all the dumpsites soil studied with EF values more than two (Sutherland, 2000; Yonming *et al*., 2016).

#### 5.4.1.3 Relative top soil enrichment factor (RTEF) of dumpsite soils studied

The relative top soil enrichment factor (RTEF) of the selected metals studied found Cr, Fe and Hg with the highest RTEF in AYE through human influence on the top soil (Table 4.29). Ni recorded high human influence on the top soil of KNUST (Table 4.29). Cu, As and Pb recorded high human influence on the top soil of MED (Table 4.29). Zn recorded a high human influence on the top soil of KYE (Table 4.29). Cd recorded a high human influence on the top soil of SUA (Table 4.29). The RTEF values recorded showed 'no contamination'. All the RTEF values in studied sites soil had a RTEF < 2 (Table 4.26) as found by Ngange *et al*. (2013). Such observation may be attributed to trace elements or heavy metals recycling by plant and retention by organic matter (Siegel, 2002). However, the low (RTEF < 2) values by extension 'no contamination' interpretation might be related to the organic matter content (Table 4.8) recorded in the soils might have played a major role in the RTEF values due to metal complexation and adsorption, their sphere and ion exchange reaction (Evans, 1989). In addition, the bioavailability of heavy metals in soils through immobilization or mobilization through various insoluble or soluble heavy metal complexes (Alamgir *et al*., 2017) might have contributed to the low (RTEF < 2) values.

### 5.4.2 Evaluation of heavy metals contamination in soils under field conditions

#### 5.4.2.1 Geoaccumulation Index ($I_{geo}$) of dumpsite soils in pots under field conditions

The $I_{geo}$ contamination intensity of Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb in KYE, SUA and AYE dumpsite soils in pots under field conditions found Cr, Cu, Zn, As and Hg in the order of (AYE < KYE < SUA) with the most contaminated soil in SUA (Table 4.30). Fe and Cd (AYE < SUA < KYE) were most contaminated soil in KYE. Ni and Pb (KYE < SUA < AYE) were least contaminated in KYE and mostly contaminated in AYE (Table 4.30) showed that KYE was the least polluted with the metals. This may be due to the low population and industrial activities in the rural area compared to the Urban municipal studied sites. Agyarko *et al*. (2010) share a similar result. Also, the differences in $I_{geo}$ pollution values among the studied dumpsites soil might have contributed to differences in soil pollution levels in the various dumpsites which may be related to soil physicochemical properties like soil texture and organic matter contents (Table 4.17) which are important to the forms of heavy metals in their available forms. Aydinalp and Cresse (2009) share a similar view that soil physicochemical parameters like texture and organic matter are important with regards to the forms of heavy metals present and their bioavailability. The various different industrial activities coupled with varying living standards might have contributed to the heavy metals load pollution in the metropolitan dumpsites than in rural set up within a municipal and this results is affirm by Olankule *et al.* (2018) that, dumpsite soils may also comprise of other materials that contain heavy metals.

### 5.4.2.2 Enrichment Factor (EF) of dumpsite soils in pots under field conditions

Contamination categories of Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb under KYE, SUA and AYE dumpsite soils in pots under field conditions, found Cr, Ni, Zn, Hg (AYE < KYE < SUA) and Fe (KYE < AYE < SUA) were highly influenced by human in SUA (Table 4.31). As and Cd were highly enriched (AYE < SUA < KYE) in KYE through human influence. Pb was highly enriched (KYE < SUA < AYE) in AYE Kumasi dumpsite soil through human influence (Table 4.31). These observations may be explain by the fact that, a soil contamination evaluation technique, an enrichment factor (EF), , is an effective tool used to evaluate the magnitude of metal contamination in soil (Franco - Uria *et al*., 2009). EF classification by Birch and Olmos (2008), showed that, soils in pots were above 1.5 and are consistent with an earlier results found that, a significant portion of the metals source is through human influence, because waste materials dumped on these sites coupled with their higher concentrations in soils (Table 4.18) and in plants (Tables 4.20 and 4.21) confirm that major pollutants exist in all the dumpsites soil studied with EF values more than two (Sutherland, 2000; Yonming *et al*., 2016).

### 5.4.2.3 Transfer Ratio (TR) of metals in dumpsite soils in pots under field conditions

In pots study under field conditions, Cr was the most transferred heavy metal in lettuce on KYE (Table 4.28). Fe, Ni, Cd, Hg and Pb were the most transferred heavy metals in lettuce on MED in pots (Table 4.32). Cu was the most transferred heavy metal in lettuce on SUA in pots (Table 4.32). Zn and As were the most transferred heavy metals in lettuce on UEW in pots (Table 4.32). The transfer ratio (TR) which is the ratio of the concentration of metals in plants to the total concentration of that metal in soil (Hammed *et al*., 2017) were generally higher in lettuce plants on background soils than lettuce plants on dumpsite soils in pots under field conditions. This differences with the exception of Zn may be due to some other soil factors apart from the total soil metal content which also affect the rate of metals uptake by plants specifically the available phosphorus (phosphates), organic matter and exchangeable cations such as Ca and Mg (Table 4.17) might have affected the metals level and subsequently leading to lower transfer ratios of metals in the dumpsite soils than in background soils in pots. This result conforms to earlier studies by Agyarko *et al*. (2010). However, Zn which otherwise recorded the highest transfer ratios in UEW than in KYE and the entire study soils in pots may be attributed to soil pH, exchangeable cations and cation exchange capacities (Table 4.17), climatic change and morphology of the plant. Jolly *et al*. (2013) and Chindo *et al*. (2016) share a common view.

In addition, the differences in transfer ratio of metals on the study sites was earlier explained by Cui *et al*. (2004) that, plants species, plants physiological stage, plants metals uptake capacity and growth rates are among the major determinants of metal transfer from soil to the crop, and subsequently might have contributed to the lower transfer ratios of the metals in the dumpsite soils than in background soils. Heavy metals load which were higher in dumpsite soils (Tables 4.18) than in background soils in pots might have contributed to lower transfer ratios (Table 4.32) of metals in lettuce plants cultivated on dumpsites soils than on background soils in pots(Tables 4.20 and 4.21). This observation conforms to a report that, transfer ratio or factor decreases when plants are grown in soils with higher levels of heavy metals (Natasa *et al*., 2015). Soil pH levels in most dumpsite soils as compare to background soils (Table 4.17) have also contributed to lower transfer ratio of metals in lettuce on dumpsite soils than on background soils because, high soil pH levels in soils have been found to decrease metals mobility in soils. Sheoran *et al*. (2006) confirms this result due to the fact that metal levels decreases at high pH and increases at low pH levels.

Most transfer ratio levels of metals in lettuce plant on soils from both Mampong Municipal and Kumasi Metropolis calculated were lower (TR < I) and it is an indication that, lettuce plants cultivated had a poor response towards metal adsorption and the lettuce can be consumed. However, transfer ratio of Zn (2.64) in UEW was higher (TR > 1), an indication of a higher adsorption of Zn metal by lettuce plant at harvest and so lettuce plant may not be safe for human (Rangmaeker *et al*., 2013b) and grazing animals consumption.

### 5.4.2.4 Translocation Factor (TF) of metals in dumpsite soils in pots under field conditions

Cr, Ni and Hg were highly conducted in lettuce on MED in pots (Table 4.33) Fe, As, Cd and Pb were highly conducted in lettuce on UEW in pots (Table 4.33). Cu and Zn were highly conducted in lettuce on SUA in pots (Table 4.33). The translocation factor (TF) of a plant which is a function of root shoot metal transport is expressed as a TF (Gosh and Singh, 2005) were generally lower on dumpsite soils than on background soils (Table 4.33), a similar pattern was found using transfer ratio. The translocation factors were generally lower on dumpsite soils and could be due to the high lettuce shoot metal concentration levels than metals level in lettuce roots (Tables 4.20 and 4.21). This result agrees with Nafiu (2010), who found that, plants with high above ground plant part metals concentration than the below ground plant part metals level have high capacity to transport elements from root to shoot. This results confirms the assertion that, lettuce plants have high capacity to transport heavy metals from root to shoot and as a result is a heavy feeder and may be due to trace elements factor at soluble content, soil pH, soil organic matter, soil cation exchange capacity (Table 4.14), plant growth stages, crop type, fertilisers and soil type (Lente *et al*., 2014; Yadav *et al*., 2018).

Lettuce ability to accumulate high levels of metals in shoot than in root could also be attributed to effective transpiration within the plants environment. This result is supported by Hao *et al*. (2012), who found that, under effective transpiration, plants accumulates more trace elements and its enrichment capacity is also strong.

The low TF values recorded on dumpsite soil plants as compare to background plants in pots might also be due to high soil pH values found on dumpsite soils (Tables 4.17) that could have led to a decreasing solubility with low metals concentration in soil solution (Kabata - Pendias, 2011). Soil pH which is a master soil variable influences the chemical, physical and biological properties of soil (Chakrabortey, 2019) with low cation exchange capacity (Table 4.17) such as sand has less binding power to metals and other cations as compared to clay soil with high cation exchange capacity (Bhargava *et al*., 2012). This observation might have contributed to higher translocation factors in background soils than in dumpsite soils in pots under field conditions. These soil physicochemical properties confirm a report by Kirmanni *et al.* (2011) that, large number of factors control metals accumulation and bioavailability associated with soil climatic conditions, plant genotypes and agronomic management might have accounted for the differences in translocation factors found on both dumpsite and background soils. The lower TF in dumpsites soil than in background soils might have been caused by the transpiration and translocation process which is longer in non - leafy vegetable and may results in lower accumulation especially during the transfer of metals from root to stem and then to fruit (Itanna, 2002; Khan *et al*., 2009). Gupta *et al*. (2009) have also found that, leafy vegetables accumulate much higher trace elements than other vegetable crops due to leafy vegetables higher translocation and transpiration rate. Other studies have further reported of a significant impact of carbonates on sorption and retention of metals (Shirvani *et al*., 2006; Ahmed *et al*., 2008, Irha *et al*., 2009) and these metals retention if absorbed into above ground plant parts and in concentrations higher than below ground levels affect plant metal translocation factor. All these reported soil physicochemical properties influence metals sorption and desorption and their subsequent absorption by plants. This result agrees with an earlier report by Harter and Naidu (2001); Appel and M. (2002) and Dutta *et al*. (2011). Although heavy metal loads on background soils were very low, the background soils recorded higher TF than on dumpsite soils. This results is in line by the fact that, plants uptake and accumulation ability of different trace elements is dissimilar in different vegetables (Yadav *et al*., 2018) and other crops in general due to the differences in physiology, morphology and anatomy of each plant leaf, inclination angle and branch density (Shahid *et al*., 2016). In addition, plants with numerous thin roots like lettuce has high accumulation capacity of trace elements than one with few thick roots (Chandran *et al*., 2012). The high background soil translocation factor might have caused by this plant property.

# CHAPTER SIX

## 6.0 CONCLUSION AND RECOMMENDATION

### 6.1 Conclusion

Dumpsite farmers' soil physicochemical knowledge made up of experiences acquired especially from colleague farmers, extension officers, research scientists and the media should be intensified to reduce farming activities on dumpsites especially at Kumasi Suame Magazine dumpsite. Dumpsite farmers soil physicochemical knowledge had significant ($p = 0.02$) influence their awareness level about the risk of heavy metals in dumpsites soil when accumulation in plants found on them

The soil physicochemical properties generally had improved levels in dumpsite soils than on background soils. They include bulk density, soil pH, soil organic matter, total nitrogen, and soil available phosphorus, exchangeable cations, exchangeable acidity, CEC, ECEC and base saturation. Cr, Fe, Ni, Cu, Zn, As, Cd, Hg and Pb at 0 - 15 cm and 15 - 30 cm depths of soil sampled were generally higher in dumpsites than in background soils. Cr, Ni, As, Cd and Pb were within allowable levels of concentration in soils but Hg, Cu and Zn in Kumasi Suame Magazine dumpsite soils were above standard levels by WHO/FAO (2001).

Ni, Cu, Zn, As, Cd and Pb in plantain leaves and fruits were in normal levels; Cr, Fe and Hg in plantain leaves and fruits were above normal allowable levels from SUA dumpsite. Cr, Fe, Ni Cu, Zn, As, Cd and Pb in Cocoyam leaves and corms were in acceptable levels. Hg in cocoyam leaves from KYE, and cocoyam corms from SUA, lettuce shoots from SUA were above allowable levels in plants reported by FAO/WHO (2011). A linear correlation showed that, Cr and Cd; Fe and Zn; Ni and Cu; Cu and As; Zn and As; As and Pb; Hg and Pb were strongly related, an indication that, metals may have come from similar pollution sources. Cr and Fe; Cu, Cr and Zn were not strongly related and this confirms an antagonistic and synergistic behavior.

A simple linear regression showed an influence of soil pH on Fe in soil, soil organic matter on Ni, Cu and Zn in soil; CEC influenced Ni, Cu, Zn and As in soil; soil clay content influenced Cr and Fe in soil; soil available P influenced Cd in soil. This result is an indication that, soil pH, SOM, CEC, soil clay content and soil available P, positively and significantly influenced total metal levels in the selected studied soils, an affirmation that, some metals are significantly related.

Evaluation of the geoaccumulation techniques (Igeo) at 0 - 15 cm found Cr, Fe, Ni, Cu, Zn, As, Cd and Hg as the most intense contaminants in SUA Kumasi dumpsite soil; While Pb was intensely the highest contaminant in KYE Mampong dumpsite soil.  At 15 - 30 cm depth of soil, Igeo similarly found Cr, Fe, Ni, Cu, Zn, As, Pb and Hg as the most intense contaminants in SUA Kumasi dumpsite soil while Cd was the top contaminant in KYE Mampong dumpsite soil. Soils in pots under field conditions found Cr, Cu, Zn, As, and Hg were intensely contaminated in SUA Kumasi dumpsite soil while Fe, Cd were intensely contaminated in KYE Mampong dumpsite soil. Ni and Pb were intensely contaminated in AYE Kumasi dumpsite soil.

Enrichment Factor (EF) contamination category at 0 - 15 cm found Cr, Fe, Ni, Cu, Zn, As, Cd and Hg very strongly influenced by human in SUA Kumasi dumpsite soil while Pb was very strongly influenced by human in AYE Kumasi dumpsite soil. At 15 - 30 cm of soil depth, Cr and Pb were very strongly influenced by human in AYE Kumasi dumpsite soil. Fe, Ni, Cu, Zn and Hg were very strongly influenced by human in SUA Kumasi dumpsite soil while As and Cd were very strongly influenced by human in KYE Mampong dumpsite soil. EF in pots under field conditions found Cr, Fe, Ni, Cu, Zn and Hg very strongly influenced by human in SUA Kumasi dumpsite soil. As and Cd were very strongly influenced by human in KYE Mampong dumpsite soil while Pb was very strongly influenced by human in AYE Mampong dumpsite soil.

Relative top soil enrichment factor (RTEF) for 0 - 15 cm and 15 - 30 cm depths under field conditions found Cr, Fe and Hg contamination of Kumasi AYE dumpsite top soil, Cu, As and Pb were found to have contaminated Kumasi MED background top soil, Zn contamination was found in Mampong KYE dumpsite soil while Cd contaminated Kumasi SUA dumpsite top soil. Transfer ratio (TR) values in pots under field studies showed that, Cr was the mostly transferred metal in lettuce in Mampong KYE dumpsite soil. Fe, Ni, Cd, Hg and Pb were the mostly transferred metals in Kumasi MED background soil. Zn and As were the mostly transferred metals in Mampong UEW forest background soil but Zn was the most highest transferred metal among the selected metals from Mampong UEW forest background soil into lettuce plant.

Translocation Factor (TF) found Cr, Ni and Hg as highly conducted metals in lettuce from Kumasi MED background soil. Fe, As, Cd and Pb were highly conducted in lettuce plant from Mampong UEW forest background soil. Cu and Zn were highly conducted in lettuce plant from Kumasi SUA Magazine dumpsite soil in pots under field conditions.

## 6.2 Recommendations

It is suggested that other ecological zones within the remaining regions in Ghana be covered to confirm the following results.

Bioassessibilty studies should be conducted to confirm if metal contaminated edible plant parts within the farming community could have a negative health impact.

Bioassessibilty studies needs to be conducted to confirm if metal contaminated edible plant parts within the farming community could have a negative health impact.

Vegetable farmers at Kumasi Suame magazine dumpsite (SUA) knowledge on hazardous toxic metals should be intensified to ensure better food safety adherence for the consuming public

Dumpsites at Kumasi Suame Magazine should be excavated and transported to fill a landfill site designated for hazardous wastes.

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# APPENDICES

## APPENDIX A

### UNIVERSITY OF EDUCATION

### DEPARTMENT OF CROPS AND SOIL SCIENCE EDUCATION.

### DUMPSITES FARMERS' SOIL PHYSICOCHEMICAL KNOWLEDGE IN KYEREMFASO IN MAMPONG MUNICIPAL, SUAME AND AYEDUASE IN KUMASI METROPOLIS IN THE ASHANTI REGION, GHANA.

QUESTIONAIRE

BACKGROUND DATA

1. Sex: (a) Male (b) Female

2. Age ……………………………

3. Religion: (a) Christian (b) Moslem (c) Traditionalist

4. Marital Status (a) Married (b) Single (c) Divorced (d) Widow (e) co-habiting / Separated

5. Educational Background (a) No School (b) Basic/Primary (c.) Middle School/JHS (d) Secondary School/SHS (e) Tertiary (f) Other (specify)………………………….

6. As a farmer what kind of crop do you grow? ……………………………..

7. Have you farm / farming on a dumpsite soil? (a) Yes (b) No. If No move to number 9

8. Any knowledge about the soil you farm on (a) Yes (b) No. If No move to number 18

9. What scientific knowledge do you have (a) physical (b) chemical (c) biological

10. How does soil physical knowledge affect your crops……………………………....

11. How does soil chemical knowledge affect your crops…………………………………

12. How does soil biological knowledge affect your crops…………………………………

13. Have you had any education on soil? (a) Yes (b) No. If No move to number 18

14. If yes, from who? (a) extension agent (b) N.G.O (c) media (d) other farmers

15. Have you taken your soil to an analytical laboratory before? (a) Yes (b) No. If No move to number 17

16. How was the results explained to you? (a) soil had high beneficial nutrient content (b) low nutrient content soil (c) traces of heavy metals were found

17. Who made the explanations clearer. (a) extension agent (b) research scientist (c) other farmer

18. How do you compare dumpsite soil to others.

…………………………………………….

19. Why do you prefer farming on dumpsite soils to others? (a) fertile soil (b) only available land

(c) relatively cheaper cost

20. Do you know plants take whatever is in the soil? (a) Yes (b) No. If No move to 21

21. Are you aware dumpsite soils contain toxic elements? (a) Yes (b) No. If No move to 23

22. If yes what kind of toxic elements are you familiar with?...............................................

23. Are you aware heavy metal contaminated plants can affect human and animals? (a) Yes (b) No. If No move to 24

24. Has any member of your family complained of any ailment after eating dumpsite soil products? (a) Yes (b) No. If Yes move to 25

25. What kind of ailment was that? (a) cholera (b) Diarrhea (c) Respiratory disease (d) others specify….