CHEMICAL AND BIOLOGICAL CHARACTERIZATION OF MUNICIPAL SOLID WASTE AT CHUNGA LANDFILL FOR POTENTIAL USE AS COMPOST

By

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A Dissertation submitted to the University of Zambia in Partial Fulfilment of the Requirements of the Degree of Master of Science in Sanitation

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ABSTRACT

The Chunga landfill located in the northern part of Lusaka city receives on a daily basis approximately 500 tonnes of comingled waste comprising mostly municipal solid waste (MSW). The MSW has being accumulating over the years within the limited space at the landfill without being recycled. Composting is one of the best methods of managing MSW because of the useful end product called compost. The application of compost to the soil has many benefits such as soil enrichment, fertility enhancement, and improvement of the soil's physical and chemical properties. The current study was conducted to characterize MSW compost at Chunga Landfill for chemical and biological parameters to assess its potential to be used as compost so as to free up some space for the incoming MSW. The samples were taken from cell 2 where no fresh MSW was added for one year. Parameters used to assess the quality of the MSW were pH, EC, C:N ratio, OM, nitrogen, phosphorous, potassium, cadmium, lead, chromium, copper, nickel, zinc, presence of *Salmonella spp. E. coli*, feacal coliforms and viable *Ascaris* ova. Results indicated pH 7.94 ± 0.01, EC 6.46 ± 0.03 mS/cm, OM 6.76 ± 0.02 percent, C:N ratio 5.10, total nitrogen 0.77 ± 0.01 percent, phosphorous 0.53 ± 0.04 percent, potassium 0.88 ± 0.03 percent, copper 156.8 ± 5.52 mg/kg, zinc 207.83 ± 18.60 mg/kg, cadmium 4.63 ± 0.94 mg/kg, chromium 60.7 ± 0.57 mg/kg, lead 109.58 ± 8.92 mg/kg, nickel 28.75 ± 0.49 mg/kg, feacal coliforms >1,100 MPN/g, *E. coli* >1,100 MPN/g, *Salmonella* not detected per 25g and *Ascaris* was non-viable. Chemical characteristics with regard to pH, EC and heavy metals were within the stipulated values for matured compost and FAO standards while OM, biological characteristics and NPK were below. Therefore, the Chunga Landfill MSW may be applied as compost on low value crops and as a soil conditioner. It is recommended that the Chunga Landfill MSW compost must be sanitized to get rid of *E. coli* and feacal coliforms, material to be segregated at source or at the disposal site to boost OM and lower the heavy metal concentration, the chemical and biological characteristics of Chunga Landfill MSW compost be monitored on a monthly basis for one calendar year to check for variations in analytical data, a portion of the Chunga landfill be dedicated where only the degradable organic material will be disposed and Government to come up with chemical and biological guidelines on the utilization of MSW as compost.

Keywords: MSW, compost, chemical, biological characteristics, Chunga Landfill

DEDICATION

I dedicate my dissertation work to my late father (Mr. Albert Zanda Mkandawire) for his inspirations. Even if you are gone father, I still dedicate this to you. (M.Y.S.R.I.P).

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ACRONYMS/ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AMBIC	Ammonium Bicarbonate
ATP	Adenosine Triphosphate
BGA	Brilliant Green Agar
CDM	Cleaner Development City
EC	Electrical conductivity
EFEPA	Ethopian Federal Environmental Protection Authority
E.coli	*Escherichia coli*
FAO	Food and Agricultural organization
EPA	Environmental Protection Agency
GHG	Greenhouse Gases
LCC	Lusaka City Council
MPN	Most Probable Number
MSW	Municipal Solid Waste
NADPH	Nicotinamide Adenine Dinucleotide Phosphate Hydrogen
OM	Organic Matter
ROS	Reactive Oxygen Species
SSMSW	Source Separated Municipal Solid Waste
STH	Soil Transmitted Helminthes
TSI	Triple Sugar Iron
UN	United Nations
UNZA	University of Zambia
UV	Ultra-violent
XLD	Xylose Lysine Deoxycholate

LIST OF SYMBOLS

$K_2Cr_2O_7$	Potassium Dichromate
H_3PO_4	Phosphoric Acid
$FeSO_4$	Iron (II) Sulphate
H_2SO_4	Sulphuric acid
NH_4	Ammonium
KCl	Potassium Chloride
NO_3	Nitrates
%	Percent
ppm	Parts Per Million
Mg/kg	Milligrammes per Kilogramme
HCl	Hydrochloric Acid
NaOH	Sodium Hydroxide
N	Nitrogen
C:N	Carbon Nitrogen ratio
pH	Potential of Hydrogen
NPK	Nitrogen Phosphorous Potassium

CHAPTER ONE: INTRODUCTION

1.0 Introduction

This chapter gives an overview of the study and highlights the content, scope and general understanding of the topic based on what has been done by other researchers.

1.1 Background

Chunga dumpsite also known as Chunga Landfill is the only legally designated dumpsite were solid waste from around the city of Lusaka is channeled to. It is a 10 acres piece of land located in the northern part of Lusaka which was built in 2004 and opened in 2006 with a life span of 25 years to service Lusaka (Muller *et al*., 2017). The Chunga Landfill receives all kinds of wastes from around the city. About 500 tonnes of comingled waste is received daily and disposed of in an open-air dump. The waste is largely made up of Municipal Solid Waste (MSW) (Muller *et al*., 2017).

Any unwanted solid, liquid, or gaseous substance is called waste (Ogwueleka, 2009). Of the generated waste about 50 percent is organic waste (Sharholy *et al*., 2008). The organic component of the waste that is degradable to form compost can help clean up the environment if recycled and thus reduce the amount of pollution that can come up if the waste is not properly managed (Sharholy *et al*., 2008). Waste generation can come from either residential, commercial, institutional or industrial activities. Depending on its origin and nature, solid waste can either be hazardous or nonhazardous. MSW also known as refuse is that part of nonhazardous waste that is taken to a dumpsite or landfill (EPA, 2014). Garbage is made up of decomposable food waste whose end product is compost (EPA, 2014). The poor management of MSW in developing countries has resulted in increased generation of solid waste exceeding the capacities of cities and municipalities to manage the solid waste. In low income countries, less than 70 percent of the generated waste is collected and from the collected more than 50 percent is usually disposed of in uncontrolled landfills (Kaza *et al*., 2018).

Report done by the World Bank in 2012 indicated an estimated quantity of 1.2 kg per person per day (1.3 billion tonnes per year) of MSW generated which is likely to

increase to 1.42 kg/capital/day (2.2 billion tonnes per year) by the year 2025 (Hoornweg & Bhada-Tata, 2012; Filho *et al*., 2015).

Initially when the population was small and sitting on vast land on which solid waste was easily managed, there was less concern for environmental degradation (Jodar *et al*., 2017). The increased quantities of MSW being generated is as a result of economic activities, explosion of the population, urbanization and industrialization (Rana *et al*., 2015). As a result of this significant increase in MSW, there is likely to be serious challenges on both the environment and public health (Sharma & Jain, 2020). Globally MSW management has reached critical levels and calls for sustainable strategies (Sharma & Jain, 2020).

Composting is a natural biological process where organic matter is recycled. For this process to occur, there should be oxygen, enough moisture and porous materials to facilitate an aerobic process that will stabilize the organic matter. In order for this process to run effectively there is always need for optimum temperature, sufficient levels of oxygen and moisture (Roman *et al*., 2015). Complex metabolic activities by microorganisms make the organic matter to decompose forming humic like material. This ultimately transforms the organic waste into a nutrient rich material known as compost. The compost so produced is a valuable stable mature product used to cultivate crops and fertilize the soil (Roman *et al*., 2015; Sanchez *et al*., 2017). Composting is now considered as the most effective method of managing MSW because of the useful end-product called compost that is produced (Hoornweg *et al*., 2006). The production of organic fertilizer through composting will lead to sustainable agriculture which will lead to a sustainable society (Sinha & Heart, 2002).

Compost, also known as black gold, is applied by farmers as a fertilizer because of its nutrients. The application of compost to the soil has many benefits such as soil enrichment, fertility enhancement, and improvement of the soil's physical and chemical properties (Aleandri *et al*., 2015). The nutrients that are contained in compost are non-volatile and unchanged during the composting phase and as such the proportion of the elements in the compost is the same as in the raw material that was used to process the compost (Sharma *et al*., 2017).

The composition of MSW is not homogeneous as it depends on the eating habits, season of the year and human activities (Sharma & Jain, 2020). However, there are compounds that are always present in the mixture of MSW despite the heterogeneity. These are water, organic compounds such as carbohydrates, proteins and fats (Sharma & Jain, 2020).

One of the major sources of organic fertilizer is composting. Composting is economical and ecologically sound because it provides the most acceptable way to dispose MSW at the same time adding value to it (Akram *et al*., 2009; Danso *et al*., 2006). It brings about a reduction in terms of the cost to dispose MSW and also savings on the use of expensive chemical fertilizers. Composting also leads to a sustainable ecology and environment through recycling nutrients (Scarpato *et al*., 2013). However, there could be some toxic heavy metals and pathogens in the compost that can lead to secondary contamination of the soil (Sharma *et al*., 2017). The quality of compost determines its usefulness (Jedrczak & Haziak, 2005). The high concentration of heavy metals in MSW compost can exclude them from being used in agriculture (Jasiewicz *et al*., 2010). Compost quality is important to safe guard the handler, know how much to apply and type of land use and ultimately protect the environment. (Hoornweg *et al*., 2006).

The fast-growing population of Lusaka which stood at 3.3 million in 2019 has led to an increase in generation of MSW (Nkana, 2021). About 1,200 tonnes of MSW is generated every day in Lusaka of which only about 480 tonnes per day reaches the disposal site while the rest is disposed of in undesignated areas (LCC, 2019). The MSW that is received at Chunga Landfill is made up of both organic and inorganic matter. The organic component becomes degraded biologically and forms a material that can be used as compost. Currently the MSW at Chunga Landfill is not being used as compost. This calls for the chemical and biological characterization of the MSW at Chunga Landfill to ascertain its potential to be applied as compost. Therefore, the purpose of carrying out this research is to characterize the MSW at Chunga Landfill chemically and biologically and thereafter determine its potential to be used as compost.

1.1 Statement of the problem

MSW at Chunga Landfill remains largely uncharacterized because there is no dedicated sorting out of the waste to determine its potential to be used as compost. Coupled with

diminishing space for waste disposal in Lusaka due to increase in demand for residential plots as the population continues to grow. Hence to alleviate this problem, there is need to characterize the MSW at Chunga Landfill chemically and biologically to assess its potential to be used as compost.

1.2 Aim

To determine the chemical and biological characteristics of the MSW at Chunga Landfill and its potential to be used as compost.

1.3 Objectives

i. To determine the chemical and biological characteristics of the sieved Chunga Landfill MSW compost;
ii. To compare the fertilizing capacity of the Chunga Landfill MSW compost with other MSW compost from literature; and
iii. To determine the appropriate land application with respect to organic fertilizer of the Chunga Landfill MSW compost.

1.4 Research questions

i. What is the chemical and biological characteristics of the sieved Chunga Landfill MSW compost?
ii. What is the fertilizing capacity of the Chunga Landfill MSW compost compared with other MSW compost?
iii. What is the most appropriate land application of the Chunga Landfill MSW compost with respect to agriculture?

1.5 Significance of the study

Knowing the chemical and biological characteristics of the MSW compost at Chunga Landfill will enhance the knowledge about its potential to be used as compost. This will also help to determine the correct land application of the MSW compost. The study will also provide scientific evidence to support the formulation of guidelines and legislation for Zambian standards on reuse of MSW as compost.

1.6 Ethical consideration

Ethical clearance was obtained from the University of Zambia Natural and Applied Sciences Research Ethics Committee Reference number NASREC-2021-DEC-003 as presented in appendix I. Permission was sought from the Lusaka City Council (LCC) office of the Town Clerk on the purpose of the research as shown in appendix X and that the findings will be shared with the local authority. Standard sampling procedures were strictly followed to protect the sampler and other people involved in the study.

1.7 Scope of the study

The study was conducted at Chunga landfill also known as Chunga Dumpsite located in the northern part of Lusaka city.

1.8 Chapter Summary

Chapter one highlighted the background to the study and introduced the topic. MSW has being found to good material for composting and that the compost produced can be used as organic fertilizer organic fertilizer. However, there could be toxic heavy metals and pathogens hence the need to know the chemical and biological characteristics of the MSW compost to determine the appropriate land use with respect to agriculture. The statement of the problem, aim, objectives, research questions, significance of the study and scope of the study are all presented in this chapter.

The next chapter looks at previous studies done by other researchers with regard to chemical and biological characteristics of MSW compost.

CHAPTER 2: LITERATURE REVIEW

This chapter looks at previous studies done by other researchers with regard to chemical and biological characteristics of MSW compost.

2.1 Municipal Solid Waste (MSW)

MSW is defined as domestic waste emanating from human activities (Karak *et al*., 2012). The increase in population, urbanization, improved living standards and developed social economic activities has led to an increase in the generation of MSW world over which is now posing challenges to the environment (Karak *et al*., 2012). Most processes produce unavoidable waste as byproducts whether unnecessary or undesirable. Globally, about 7 to 9 billion tonnes of waste is generated annually. For example, in the year 2016 MSW accounted for 2 billion tonnes of the total waste generated globally. This generated MSW now deserves special attention due to its impact on the environment at local, regional and global scale. The proximity of the MSW to people has potential health impacts (Kaza *et al*., 2018; Wilson & Velis, 2015).

MSW is largely composed of organic matter that is ideal for composting. Studies done by the Addis Ababa Bureau of Health, revealed that solid waste generated in Addis Ababa was composed of 90 percent by volume and 50 percent by weight organic matter that is decomposable. The significant variation in the composition of MSW amongst municipalities and countries is due to differences in life style, economic status, industrial activities, waste management best practices and regulations (Abdel-Shafy & Mansour, 2018). Knowing the composition and quality of the MSW is critical as it helps to determine the most appropriate ways of managing and handling of these waste (American Society of Mechanical Engineers, 2014). Urban cities such as Ibadan and Lagos have recorded an increase in population levels, booming economy, rapid urbanization and the rise in community living standards which has greatly accelerated the generation of MSW (Debnath *et al*., 2015; Minghua *et al*., 2009). This is also the case in U.S.A. where packaging of consumer goods accounts for more than one third of the waste stream generated (Pitchel, 2005).

2.2 Effects of chemicals in MSW compost on agriculture

Chemical properties of MSW compost are very important in evaluating the alternative processing and recovery options. The following are some important chemical composition to consider in MSW compost with respect to agriculture use:

2.2.1 pH

pH of MSW is defined as a measure of how acidic or alkaline the MSW compost is. pH is important because it affects the availability of nutrients to the plant roots and all microbial activities in the soil depend on pH which should be around the neutral range of 6.5 to 7.5 (Wong *et al*., 2009). MSW compost is normally alkaline with pH ranging from 7.0 to 8.0 (De Medina-Salas *et al*., 2013). The pH indicates maturity and stability of the compost which is supposed to be alkaline throughout the composting stages. When the pH of the compost is acidic, it might delay the process of composting as most microorganisms are destroyed (Ameen *et al*., 2016). When MSW compost with an alkaline pH and high buffering capacity is applied on acidic soils, the resulting pH of the soil increases (Shiralipour *et al*., 1992).

2.2.2 Electrical conductivity (EC)

EC is a measure of the soluble salt content in the MSW compost and is mostly influenced by the presence of ions that exist as soluble salts like sodium, potassium, calcium, magnesium, chloride, sulphate, carbonate, bicarbonate, nitrates and other micronutrients (Matthew *et al*., 2020). Compost with high EC is harmful if applied as a growing medium for germinating seeds and plants (Ghosh *et al*., 2010). But if the compost is used as a soil amendment then the level of EC does not apply as it is diluted when mixed with the soil. EC reflects the salinity in the compost product which is a direct indicator of the possible phytotoxic/phyto-inhibitory effects. Application of compost with high salinity greatly reduces the uptake of nutrients as the salts accumulate in the root zone of the plant which leads to limited vegetative growth, low germination rate, withering of the plant and yield (Grattan & Grieve, 1998).

2.2.3 Carbon Nitrogen ratio (C:N ratio)

The C:N ratio is used to determine the status of composting and the degree of maturity of the compost. The balance of nutrients in the composting process is indicated by the relative proportion of the carbon and nitrogen (Norbu *et al*., 2005). The nitrogen fraction influences the population growth of the bacteria as it is part of their structure and the carbon is used as a source of energy (Gajalakshmi & Abbasi, 2008). The C:N ratio is mostly applied to measure the stability index and should normally range from 15 to 20 in the final compost product (Gajalakshmi & Abbasi, 2008).

2.2.4 Organic matter (OM)

OM content is a measure of the amount of carbon based compounds that are contained in the compost (Cabrera *et al*., 2009). It is a vital component in compost as it plays a critical role in the maintenance of desirable soil structure, makes nutrients available, acts as a source of carbon that is utilized by microorganisms to generate energy and enhance the soil's ability to hold water (Pandey & Shukla, 2006). In order to archive this, the organic matter content in the compost should be between 30 and 60 percent. Excess organic matter in compost means that the organic waste is not yet fully matured and can affect the growth of plants (Rahmana *et al*., 2020). But when the organic matter is very low the intended improvement to the soil will not be archived when compared to compost with high organic matter (Rahmana *et al*., 2020).

2.2.5 Nitrogen

Nitrogen is an important macro element required to promote plant growth. The major component of chlorophyll which is the green colour in plants is as a result of nitrogen. There is urgent need to improve the efficiency of nitrogen uptake by crops both by increasing crop utilization of the element and by limiting its loss to the external environment. If there is an overdose of nitrogen to plants, this can bring about rapid plant growth with brilliant green colour, diminished root system and sometimes burning of leaves and plant death may occurs. Nitrogen is essential for plant growth as it is part of every living cell and therefore is required in large quantities. Adequate amounts of nitrogen produce a dark green colour in the leaves as a result of high concentration of chlorophyll while its deficiency

causes chlorosis (yellowing) caused by declining levels of chlorophyll. The yellowing starts first on oldest leaves, then progresses to younger ones as the deficiency becomes more severe. The symptoms of nitrogen deficiency in plants are stunted growth, slow growth, and production of fewer tillers than normal (Loks *et al*., 2014). Plants generally absorb most of their nitrogen requirement as ammonium or nitrate form. Compost has been reported to contain sufficient amounts of nitrogen that is required for plant growth (Khater, 2015).

2.2.6 Phosphorous

The second essential macronutrient is phosphorous and together with nitrogen is important for proper growth and development of all plants (Roch, *et al*., 2019). Phosphorous is part of the nucleic acid and other biomolecules of all cells like Adenosine Triphosphate (ATP), Nicotinamide Adenine Dinucleotide Phosphate Hydrogen (NADPH), sugar phosphates and phospholipids needed for both primary and secondary metabolic processes in plants. Cell division, generating new tissue and complex energy transformation in a plant all requires an input of phosphorous (Zhang, *et al*., 2009). Addition of phosphorous to soils leads to proper growth of plant roots, makes the plants to withstand low temperatures (winter hardness), makes tilling of the soil easier and promotes plant maturity. Lack of phosphorous normally leads to stunted growth, poor seed and fruit development, delayed maturity and change of matured leaves colour from dark blue to blue–green. Phosphorous in soils ranges from 400 to 1,200 mg/kg and exist in the form of apatite and other primary acids of which only a fraction is available for plant uptake due to its low solubility, slow diffusion and high reactivity with the soil (Walpola, 2012). In the soil 10 to 15 mg/kg phosphorous is the critical value that must be available for plant to absorb through the roots to complete the life cycle. The inorganic phosphorous (orthophosphate) is mostly found in association with iron and aluminium ions in acidic soils while in calcareous soils, it is bound to calcium making it unavailable to plant roots (Mishra, *et al*., 2017). Reports have indicated that compost contain optimum concentration of phosphorous (Khater, 2015).

2.2.7 Potassium

Potassium is ranked the third most important macronutrient and seventh most abundant element on the earth's crust (Etesami, *et al*., 2017). It is required for plant growth as it increases carotene, chlorophyll content, creation of sugars, vigor, plant's fight against diseases and makes the plant resist changes to harsh conditions of the weather like cold or drought. It is involved in photosynthesis reactions, production of ATPs, sugar transportation, movement of water and nutrients, synthesis of starch, nitrogen fixation in legumes, activation of enzymes and protein synthesis (Wolde, 2016). Despite being the seventh most abundant element on the earth's crust, less than 3 percent of the potassium is readily available in its soluble form to plants in the soil and about 95 percent exist in compounds with other minerals (Etesami, *et al*., 2017). If the plant has insufficient amounts of potassium, older leaves are burnt out as a result of too much sun (scorching) and this ends up affecting other leaves which also makes the stalk to become weak (Razaq *et al*., 2017). There are four forms in which potassium exist in the soil namely unavailable potassium (mineral potassium), available potassium (soluble potassium), non-exchangeable potassium (fixed or trapped potassium) and the exchangeable potassium (ionic potassium). The exchangeable potassium is the one that is readily available for plant uptake by the root system. In addition, there is some potassium that exist in OM among the microbial communities in the soil (Kour, *et al*., 2020). The uptake of potassium differs amongst plants but is mostly utilized in the early stages of plant growth and its uptake depends on soil moisture, temperature and the type of tillage used (Mouhamad, *et al*., 2016). Kammoun *et al*., (2017) reported that compost is a good source of potassium required for plant growth.

2.2.8 Cadmium

Cadmium is one of the most dangerous heavy metal which is not essential for plants. It is introduced in the environment through anthropogenic activities and risks the whole ecosystem (Jibril *et al*., 2017). Cadmium is mostly absorbed by plant roots but sometimes can be absorbed directly from the atmosphere (Ismael *et al*., 2019). When cadmium concentration in plants is high, it brings about changes in many physiological and

biochemical processes (Feng *et al*., 2010). The high cadmium level also inhibits some vital processes such as minerals transportation, photosynthetic apparatus, and nutrient uptake and sometimes it also inhibits the uptake of iron by plant shoots (Jibril *et al*., 2017; Schützendübel *et al*., 2002). High level of cadmium can also have an influence on the phenotype of the plant such as plant weight and length of roots and shoots become reduced, cytotoxicity (reduction in chlorophyll and inhibition of photosynthetic performance), metabolic processes are affected such as chlorosis and damage to the cell is also eminent (Hayat *et al*., 2018). Cadmium as a rare heavy metal is a hazardous to human health as it is carcinogenic and toxic to the kidneys (Johri, et al., 2010). The primary source of cadmium in MSW is kitchen, ash, plastic, and industrial wastes especially batteries and other electronic gadgets (Calace *et al*., 2001). Jagath *et al*, (2002) stated that the best way to come up with compost from MSW of good quality and free of heavy metals like cadmium is to separate the compostable waste at the point of generation (Jagath *et al*., 2002). The concentration of heavy metals in organic household separated waste (from parks and gardens, and household waste sites) are lower as compared to composted residual organic fraction coming from mechanically sorted MSW. This was proved by Amlinger *et al*., (2004) who concluded that heavy metals in compost that was source segregated was drastically reduced by a factor of 2 to 10 when compared to mechanically treated materials (Amlinger *et al*., 2004).

2.2.9 Zinc

Zinc is an essential trace element required by plants, a major constituent of many proteins as cofactor for many enzymes and is needed for optimal plant growth and development (Broadley *et al*., 2007). If zinc is in high concentration in the soil, it becomes phytotoxic making the plant that accumulated it through root absorption to pose health risks to consumers. This therefore calls for the regulation of zinc uptake by plants to reduce soil pollution and the eventual impact on plants, ecosystems, landscape, soil microbial biodiversity and human health (Bolan *et al*., 2014). The uptake of sodium under saline conditions is reduced in that the stem cell membrane's structural integrity and permeability is affected if there is excess zinc in the soil (Aktas, *et al*., 2006). Decreasing of sodium accumulation is effective if there is sufficient zinc which also improves the

ratio of potassium to sodium in plants grown under saline environments. However, deficiency of zinc leads to cell membranes becoming highly permeable and thus leaking some vital compounds from the root zone. Its deficiency can cause plants to wilt as toxic ions such as sodium and chloride accumulate (Yeşil, 2008).

2.2.10 Chromium

Chromium is considered as one of the most toxic heavy metals because of the adverse effects it has on the environment (Ali *et al*., 2018). The major sources of chromium are discharges from industries dealing in electroplating, leather tannery and effluent coming from alloy materials (Govil & and Krishna, 2018). Chromium exists in various oxidative states in the environment with the most dominant in the environment being chromium (III) and chromium (VI). Chromium (III) is among the essential micronutrients as it is required in animals for cell metabolism due to its stability and lower toxicity compared to chromium (VI) (Tepanosyan *et al*., 2020). Chromium (VI) is a highly soluble metal capable of crossing cell membranes and cause damages to organs such as the liver, lungs, and kidneys due to its high charge, irritability, toxicity and allergy (Bashir *et al*., 2020; Tepanosyan et al., 2020). MSW compost having high levels of chromium cannot be applied on high value crops but can be used on low value crops because of the negative effects on plants yield and the whole ecosystem (Mehmood *et al*., 2018b). Chromium in plants retards seed germination, reduces the rate at which plant shoots grow and leads to low production of biomass (Bashir *et al*., 2022). In addition, chromium disrupts the process of photosynthesis, utilization of nutrients, osmotic potential and affects catalytic reactions of enzymes producing a rare species of oxygen that is very reactive with lipids, nucleic acids and proteins eventually making plants die out (De Oliveira *et al*., 2014: Bashir *et al*., 2020).

2.2.11 Nickel

Nickel is number twenty two most abundant trace element found in the earth's crust and usually exists in natural soils in trace concentrations (Hussain, *et al*., 2013). Nickel is both an essential microelement as well as a toxic heavy metal for plants and bacteria (Correia *et al*., 2018). It is introduced in the soil through anthropogenic activities like mining,

smelting, application of some organic amendments such as sewage sludge or compost based on sewage sludge, fuel combustion, burning of diesel, and fuel oil, ceramic, glass, metal, and chemical industries (Correia *et al*., 2018; Ameen *et al*., 2019). Ameen *et al*., (2019) indicated that exposing plants to high levels of nickel results in a number of phytotoxic symptoms such as chlorosis, necrosis, limited shoot and root growth, and reduced leaf area (Ameen *et al*., 2019). The other negative effects of nickel on plants are that various enzyme activities are disturbed, oxidative stress initiation is affected and there is also interruption in the uptake of other minerals (Gupta *et al*., 2017). The phytotoxicity effects of nickel is as a result of the actions that takes place in the biochemical pathway reactions of the photosystems affecting the smooth running of the Calvin cycle, disturbing the electron transport chains due to accumulation of excess ATPs and NADPH (Yusuf, *et al*., 2011). Despite the negative effects of high concentration of nickel, at low concentrations it is an essential microelement as it promotes seed germination, growth of shoots and roots at the same time improves fruit yield and quality, promotes the synthesis of chlorophyll, protein, and carbohydrates in plant tissues (Ameen *et al*., 2019; Gupta *et al*., 1998). Most plant micronutrients including nickel are difficult to determine the normal requirement and the toxic level because they have a dynamic range and sometimes their concentrations and chemical speciation fluctuates in the soil (Krämer & Clemens, 2007).

2.2.12 Copper

Copper is one of the essential microelements required by plants and is naturally present in the soil between 2 and 100 mg/kg. However, in agriculture its continuous and prolonged use as a herbicide has led to pollution of the soil in specialized areas. It is involved in protein metabolism, respiratory electron transport, antioxidant activity, cell wall metabolism, nitrogen fixation, ion metabolism and hormone perception among others in plants (Arunakumara *et al*., 2013; Adriano, 2001). However, if the copper concentration in the soil exceeds the threshold of 60 to 125 mg/kg, it can induce toxicity symptoms both to plants as well as soil organisms that can lead to decreased numbers of collembolan and earthworm diversity, reduced microbial biomass and inhibition of metabolic activities (Karimi *et al*., 2021). High copper concentration in the soil lead to

compromise in the soil respiratory activity, germination of seed is greatly reduced, growth of roots and shoots become stunted, results in low yields and formation of reactive oxygen species (Romero-Freire *et al*., 2016). Excessive copper stress causes severe damage to metabolic pathways, photosynthetic process such as chlorophyll content are greatly disturbed making plants less productive (Hegedus, *et al*., 2001). Several anthropogenic activities such as use of both inorganic and organic ferilizers, sewage sludge and wastewater for irrigation have released large quantities of copper into the natural environment leading to soil contamination (Muhammad, *et al*., 2015). The concentration of copper in agricultural soils varies from as low as 5 mg/kg to as high as 30 mg/kg with concentration of 500 mg/kg detected in some vineyards. Copper is one of the heavy metals that contaminate agriculture soil thereby posing immediate and serious threats to human health, food safety and the environment in Europe and world over (Peralta-Videa, *et al*., 2009). Despite being an important element necessary for human development in small amounts, concentration above the limit can have negative impacts on the nervous system, liver, renal function, skin and eyes. Excess uptake of copper together with zinc may cause health complications in the reproductive system, lead to anemia and stomach upset (Oteiza, *et al*., 2004).

2.2.13 Lead

Lead is amongst the most common contaminants and contributes about 10 percent of the total pollution emanating from heavy metals (Zeng, *et al*., 2007). It is found in aquatic and terrestrial environments due to several anthropogenic activities such as lead batteries and construction. In the soil, plants do not absorb or accumulate lead but if the concentration is too high it can accumulate in the leaves of vegetables like lettuce and on surfaces of roots like those of carrots (Rosen, 2002). Since plants do not take up much lead from the soil, levels less than 300 ppm are considered safe for gardening. It has no nutritional value to plants and therefore, has no any biological purpose. Concentration above 300 ppm increases the risk of lead poisoning through the food chain (Rosen, 2002). It is taken up by plants which are the primary producers and affects their metabolic processes, growth rate and photosynthetic activities with concentrations above 42 percent causing a reduction in root growth (Zeng, *et al*., 2007). Lead contaminates food through

accumulation from the soil to the roots as observed in many plant species where only a small fraction is transported to aerial plants. Therefore, high levels of lead from the soil are likely to be found in root vegetables like carrots and sweet potatoes and low levels may be found in leafy greens like lettuce with the least levels in plants like tomatoes (Kumar, *et al*., 2017). Lead is a highly toxic heavy metal that can easily compromise the normal functioning of the human body system once inhaled. Lead in the body is poisonous to the central nervous system especially in children where it causes a disease known as encephalopathy (Meng, *et al*., 2016).

2.3 Chemical composition of MSW compost around the world

A physico-chemical characterization of solid waste study was done in Halishahar Munar Nagar area dumpsite, Chittagong Metropolitan City, Bangladesh. The study was conducted over a period of one year from January 2000 to December 2000. Chemical analysis results indicated a total organic nitrogen of 0.43 percent and phosphorous content of 0.08 percent (Sarkar & Bhuyan, 2018).

In Delhi, India a study was done on the MSW compost produced to assess its marketability based on the physical/chemical properties, polluting potential of heavy metals and fertilizing capacity. Twenty compost samples were collected from the Okhola Compost Plant and analysis performed was to check on the physico-chemical composition of compost produced in 2008. The compost had an EC range of 0.32-0.43 dS/m. The average pH was 8.4 ± 0.02. The C:N ratio varied from 8.89 to 10.51 with an average of 9.46. A follow up survey conducted on MSW compost chemical characterization from other 59 cities around India showed that most of them had high C:N ratio above 50. For the nitrogen, phosphorous and potassium (NPK) nutrient content, the MSW compost had a total nitrogen of 1.71 ± 0.09 mg/kg, total phosphorous of 1.67 ± 0.11 mg/kg and total potassium of 0.88 ± 0.27 mg/kg. The heavy metals concentration analyzed were cadmium 3.95 ± 1.15 mg/kg, zinc 389 ± 42 mg/kg, chromium 85.3 ± 58.7 mg/kg, nickel 18.5 ± 7.4 mg/kg, copper 326 ± 42.3 mg/kg, lead 112.6 ± 15 mg/kg (Papiya *et al*., 2014).

Another study was done on the characterization and composition of MSW that was generated in Sangammer City, of Ahmednagar District, Maharashtra, India. The waste

was first segregated into different components such as kitchen waste, paper, earth and fine material, slaughter house waste, leaves, metal and other waste, then it was sorted out into organic and inorganic waste. The organic component accounted for about 61 percent of the waste generated and the other 39 percent was inorganic. The chemical characteristics of the organic solid waste were evaluated and the results had an EC of 3.8 mS/cm, a pH value of 7.1, organic nitrogen content of 0.73 percent, phosphorous content of 0.93 percent and the potassium level was 0.35 percent. The analytical data indicated that the organic waste was a good source of nutrients for the agriculture sector (Thitame *et al*., 2010).

A case study was undertaken by Yusuff *et al*., (2014) in Castlereagh District, Northern Ireland to assess the physical, chemical composition and energy content of the solid waste. The organic nitrogen analyzed was 1.2 percent (Yusuff *et al*., 2014).

A similar study on MSW generated was characterized in Johannesburg City of South Africa and the results showed a concentration of 1.98 percent organic nitrogen (Ayeleru *et al*., 2018).

A study was done in Cajicá City of Colombia that makes compost from MSW as a strategy to manage MSW. The chemical characteristics of compost gave a pH of 8.29, cadmium level of 0.18 mg/kg, chromium was 7.5 mg/kg, nickel concentration was found to be 6.13 mg/kg and the lead concentration was 1.42 mg/kg (Ibicol Sas, 2018).

Chemical characteristics on MSW generated in New Delhi City of India which generates approximately 7,000–8,000 tonnes of MSW per day was done by Neeri, (2005). The waste considered was mostly made up of 54.42 percent compostable matter, 15.52 percent recyclable matter and 30.06 percent inert material weight per weight (w/w) basis. The chemical characteristics of the generated MSW were as follows: pH was from 6.02-8.23, total nitrogen was found at 0.79 percent, the phosphorous level was 0.76 percent and the potassium content was 0.86 percent (Neeri, 2005).

A study by Lord *et al*., (2021) in Agaard farm, Brandon MB, Canada on MSW compost found the following chemical characteristics: organic matter 6.76 percent , pH 8.1, zinc 3.77 mg/kg, potassium 176 mg/kg and copper 1.07 mg/kg (Lord *et al*., 2021).

Iran is another country that has ventured into the production of compost from MSW. A study in Barmshor Landfill of Shiraz in Iran on MSW compost found the chemical characteristics as: lead 27.35 mg/kg, cadmium 0.04 mg/kg, chromium 8.32 mg/kg, copper 56.89 mg/kg, nickel 15.34 mg/kg, zinc 95.26 mg/kg and cobalt was 0.4 mg/kg (Jalalipour *et al*., 2020).

Assessment of the quality and fertility of MSW compost that was produced from cleaner development mechanism (CDM) compost projects was done in Uganda. Twelve municipalities having CDM were selected from different regions of Uganda (Kasese, Lira, Fort Portal, Mbale, Mukono, Masindi, Hoima, Kabale, Jinja, Soroti and Arua). Site selection was based on the differences in ecological zones, climatic conditions and varying soil and usage rate as they accounted for 36.9 percent of organic fertilizer in the country. Triplicate compost samples were taken from each municipality from different parts and depths of the windrows from which a composite sample was constituted at each site. MSWCs from all locations had an average pH value of 9.16, EC 4,701 µS/cm, OM content 8.5 percent, C:N ratio 17.2, nitrogen 0.5 percent, Phosphorus content in all locations was found to be highest in Lira at 0.8 percent and lowest in Hoima, Kabale, Masindi, and Soroti at 0.2 percent with an average of 0.3 percent in all locations, potassium 1.3 percent. The heavy metals in the compost ranged from 272.8 to 1,088.7 mg/kg for zinc, 33.5 to 139.5 mg/kg for copper, 5.8 to 33.5 mg/kg for lead, <0.00 to 0.77 mg/kg for cadmium, and 3.7 to 15.9 mg/kg for chromium (Kabasiita *et al*., 2022).

Dessalegn *et al*., (2012) did a study to evaluate the quality of final compost produced using source separated MSW (SSMSW) at household level from the local residents living around the compost demonstration site managed by Addis Ababa- EPA. Aerobic composting method was used for the study over a period of 80 days in which compostable waste was collected, chopped to increase the surface area and the rate of decomposition in order to produce quality compost. Chemical characterization was done on the final compost. The pH of matured compost was 8.11 ± 0.02, EC was 3.82 ± 0.03 mS/cm, total nitrogen 1.07 percent, total phosphorous 0.47 percent, potassium 0.44 percent, OM 20.39 percent, C:N ratio 9.11 with heavy metals on dry weight in mg/kg giving cadmium at 0.3995 ± 0.0696, chromium of 10.095 ± 5.0085, cobalt 17.075 ±

0.3377, copper 32.536 ± 0.4295, lead at 234.886 ± 10.1094, nickel 31.656 ± 3.0068 and zinc content of 176.71 ± 29.0996 (Dessalegn *et al*., 2012).

Assessment on the quality of compost produced from MSW was done in Bangladesh's City of Mymensingh Pourashava. The waste was first collected and spread out to sort out degradable and non-degradable materials. Composting was done only on the degradable material and the product was later characterized for chemical and biological namely pH, C:N ratio, nitrogen, organic matter content, phosphorous, potassium, heavy metal content and pathogens. The MSW compost had a pH of 7.3, the EC was 2.4 dS/m, The C:N ratio was 14.5, OM content was 22.5 percent, The NPK content was 0.896 percent, 0.30 percent and 0.45 percent respectively. The heavy metal concentration in mg/kg were cadmium 0.39, cobalt 0.61, arsenic 2.27, chromium 17.15, copper 39.68 and lead 48 (Rouf & Rashid, 2020). Studies conducted in Bagdad City, Iraq on the quality of aerobically processed MSW compost based on the different layers of the composting bioreactors. Three sampling points were chosen at 20, 40 and 80 cm dimension by way of making screwed covers. The initial pH was 6.53 for the three layers and later ended up within a range of 7.40 to 7.44. The C:N ratio obtained in the three layers ranged from 13.8 to 16.1 while the final phosphorous content was between 0.89 and 1.23 percent and the potassium level ranged between 1.69 and 1.81 percent in the final compost (AL-Saedi & Ibrahim, 2019).

Studies were conducted to assess the chemical properties of the mature MSW that was utilized as fertilizer in Central-eastern Poland areas of Siedlce, Włodawa, Opoczno, Warszawa, Wołomin and Radom. Six compost samples were selected and studied to determine the organic fraction of the MSW in terms of quality and quantity. The chemical analysis done were: pH, nitrogen, phosphorous, potassium, zinc, copper, lead, chromium, nickel and cadmium. The pH range among the six sample was from 7.20-7.67 with mean heavy metal concentrations of 123.5 ± 46.3 mg/kg zinc, 21.4 ± 12.3 mg/kg copper, 9.60 ± 3.39 mg/kg lead, 6.60 ± 2.98 mg/kg chromium, 4.75 ± 1.98 mg/kg nickel and 0.18 ± 0.26 mg/kg cadmium (Becher *et al*., 2018).

2.4 Biological characteristics of MSW compost

The biological characteristics of importance in MSW compost are feacal coliforms, *E. coli, Salmonella* and *Ascaris*.

2.4.1 Pathogens in MSW Compost

MSW that is to be applied in agricultural activities must be free from pathogens because if the pathogens are present, they can lead to outbreaks of food borne diseases when raw agricultural products infested with pathogens are consumed. Microbial safety is required if organic amendments and other organic fertilizers are to be used in agriculture activities in order to prevent colonization by food-borne illness pathogens such as *E. coli* O157:H7 and *Salmonella* spp. (De Roever, 1998). MSW can have human excreta and animal waste that contain pathogens coming from the disposal of sludge, diapers, and yard trimmings containing domestic animal waste (Deportes, et al., 1998). Studies have shown the transfer of *Escherichia coli* 0157:H7 and *Salmonella enterica* from soils amended with compost to fresh agricultural products (Islam *et al*., 2004).

The human gut contains many pathogenic parasites that are mostly soil transmitted helminthes (STH) such as hookworms, *Trichuris trchiura* and *Ascaris lumbricoid*es. The infections from these parasites are highest in children living in developing countries in sub-Saharan Africa, Asia and Latin America especially in rural areas (Harhay *et al*., 2010). These parasites are mostly associated with diarrhea in humans (Utzinger *et al*., 1999) and the diseases are transmitted via the feacal oral route as a result of poor personal hygiene, environmental conditions mostly associated with contaminated soil and water source with human waste (Muttalib *et al*., 1983) and also if sewage is poorly disposed like using night soil as fertilizer (Mustafa *et al*., 2001). Soils that harbour these parasites can act as a conduit through which eggs can get onto vegetables and finally to the handlers (Koyabashi, 1999) or consumption of raw vegetables (Mustafa *et al*., 2001). The risk exposure to these internal parasites is rampant among communities found in developing countries residing in slums and high density areas characterized by overcrowding, ill health and poor waste management (Crompton & Saviolo, 1993). These parasites have been isolated from agricultural produce and tools used in agriculture. Some internal parasites have actually been found attached to vegetables, fruits, fingers, utensils, door

handles (Kagei, 1983). They can also be transmitted through vectors such as flies (Monzon *et al*., 1991).

In Delhi, India a study was done on the MSW compost produced in order to check and determine its marketability. The compost was examined for the presence of pathogens to ascertain the safety of the handlers. The analyzed samples were free of pathogenic bacteria and that was attributed to the high temperature obtained during composting which destroyed the pathogens (Papiya *et al*., 2014).

A similar study on biological characteristics of compost produced from MSW was done in Bangladesh, Mymensingh Pourashaya City. The MSW was first collected and then spread out to separate degradable from non-biodegradable material. Composting was done only on the biodegradable material and the final compost was then analyzed for *Salmonella* and *E.coli* which were not detected (Rouf & Rashid, 2020).

MSW is mostly domestic waste which might include animal waste from contaminated diapers, animal and other yard waste that contain viable *Ascaris* ova hence the need to examine and determine the safety of the MSW.

2.5 Composting

Composting is a method in which the organic waste is degraded and recycled as bio-fertilizer. The other inorganic components of the waste such as recalcitrant substances, polythene bags and plastics are non-biodegradable (Abdel-Shafy & Mansour, 2018). It is an effective way of managing MSW because of the valuable product called compost. In order to obtain compost of high quality that is also environmentally and technically better, there is need to source separate the MSW (Addis Ababa Bureau of Health, 2006).

There are two fundamental types of composting namely aerobic and anaerobic. The process that requires an uptake of oxygen (air) to degrade organic matter and results in the production of carbon dioxide, ammonia, water, and heat among other products is called aerobic composting. For aerobic composting to be effective there is need to have the right ingredients and conditions such as 60-70 percent moisture content and a carbon to nitrogen ration of 30:1. In order to maintain a constant supply of oxygen throughout the process, there is need to ventilate either by force or passive (Yvette *et al*., 2000). Anaerobic composting on the other hand is when organic waste is decomposed in the

absence of oxygen resulting in production of methane, carbon dioxide, ammonia, some traces of other gases and organic acids. This is now the most common way of composting MSW and green waste (Yvette *et al*., 2000).

During the process of composting factors such as temperature, moisture and oxygen are kept in check in order for the process to be effective (Roman *et al*., 2015). The breaking down and transformation of organic matter to a dark humic like material called compost is as a result of metabolic processes done by microbes.

Provided the conditions are favorable, the processing of compost follows various phases under which specific groups of microorganisms dominate. The three main phases in decomposition are active phase, cooling phase and maturation phase (curing phase) (Niwagaba *et al*., 2009). During the active phase, readily degradable organic materials are broken down by the increasing microbial population. As this is taking place heat is also generated which increases steadily from the mesophilic (25-45^{o}C) to the thermophilic of temperature above 45^{o}C. This high temperature is important because it is responsible for the death of most flying larvae, seeds of weed and pathogens that are found in the compost feedstock (Niwagaba *et al*., 2009). Under the cooling phase, compounds in the compost which were in an exited state loses the energy resulting in a decrease of temperature that favours the dominance of the mesophilic microorganisms in the pile. During the final phase of maturation, microbial activity becomes low although some natural reactions continue to happen. The main activity in this phase is the humification of the material to the final value product called compost (Hsu & Lo, 1999). The compost produced has useful applications such as soil enhancement, mulching and soil amendment used in crop cultivation and to fertilize the soil (Sanchez *et al*., 2017). When used as soil amendment, it increases the nutrients that are recycled back to the soil, increases the water retention capacity and improves soil structure (Wei *et al*., 2017). MSW management through composting greatly reduces the amount of solid waste (Haight & Taylor, 2000) and is the most common method used in U.S.A to manage solid waste (Goldstein & Steuteville, 1992).

The key parameters that are used to assess the suitability of compost used in agriculture are that it is must be stable and mature enough to safeguard both consumers and the

environment. The extent to which OM is decomposed and humus-like material formed determines the quality of the compost produced (Liu *et al*., 2018; Liu *et al*., 2019). Documented data have shown that soil OM is increased significantly if matured compost is used than using immature compost as the former has high levels of stable carbon (Daniel & Bruno, 2012; Bouajila & Sanaa, 2011).

Many countries have adopted MSW as the right choice of input in large scale production of compost, where the composting is done by government owned/ government-sponsored composting facilities and sometimes by private companies (Walls, 2005). In the United States, the government sub-contracts private businesses to collect solid waste, sort out materials into those that can be recycled and reused and that has helped clean up the environment of the generated waste (Walls, 2005). Many countries have succeeded in solid waste management through partnerships between government, industry and universities (Walls, 2005; da Cruz *et al*., 2014; Franchetti, 2017).

In Zambia there are two different types of solid wastes that are composted. These are MSW and agriculture or agro industrial waste. Most residents have come up with ways of making their compost from MSW in their backyards. Kitchen waste is dumped in pits and left to rot thereafter it is transferred and applied as compost mostly in horticulture. This procedure reduces the amount of MSW generated at house hold level (Muller, *et al*., 2017).

Agricultural waste comes from livestock droppings and crop residues. Composting using this type of waste is practiced both by small and commercial farmers. For example, Zambeef Products Plc at its Huntley Farm in Chisamba District has embarked on a project of making compost using the waste from animals and other organic waste produced within the farm. The straws from the harvested wheat are used as bedding for chickens and after accumulating the droppings, the material is decomposed to make compost. Decomposing the manure takes about three months to make the compost that is applied as fertilizer. It was reported that in 2016, about 400 tonnes of compost manure was produced at the farm in Chisamba District (Zambeef, 2017).

Although composting is the safest method to manage organic waste, it has some negative effects on the environment in that odour and greenhouse gases (GHGs) like carbon

dioxide, sulphur dioxide and nitrogen dioxide are released (Abdel-Shafy & Mansour, 2018). Air quality, water quality, public health and factors that affect climate change are all affected by the postconsumer waste, be it through its production or management (Bogner et al., 2007). If not properly managed, waste can affect the environment differently. For example, if the waste is disposed in open air dump, organic and inorganic pollutants can contaminate water bodies and also poses a threat to public health as vectors that cause diseases are attracted thereby endangering the lives of the people near the dump site (McDougall et al., 2001). Dioxins, furans, persistent organic pollutants and other pollutants are emitted when the waste is incinerated. These pollutants can mix globally and eventually harm humans and the ecology (Tchobanoblous & Kreith, 2002; White et al., 1999).

2.5.1 Methods of composting

Although the process of composting does not need any technology, it is a process that occurs naturally when microorganisms in the presence of oxygen break down organic matter. However, technology is necessary nowadays in order to come up with a certain quality of compost and also to speed up the process which can take up large volumes of the waste (Gonawala & Jardosh, 2018). There are different methods of composting. The selection of the method depends on the nature of the material and the objective of composting. The following are some of the methods applied for composting:

i. Vessel composting: In this method, the composting material is placed in a closed space. The composting is archived by various forces that are used to aerate and turn the material using mechanical techniques (Gonawala & Jardosh, 2018).
ii. Windrow Composting: The materials to be composted are placed in narrow piles which are long and turned regularly. Aeration is done by mixing the materials that quickly turns into compost (Gonawala & Jardosh, 2018).
iii. Sheet composting: The raw material such as leaves, weeds and vegetable food is spread directly on the soil similar to mulching. The material is then covered in soil and used as compost when it is fully decomposed (Misra *et al*., 2003).
iv. Vermicomposting: This one employ earthworms to breakdown all kinds of degradable organic matter through feeding (Arumugam *et al*., 2017). Earthworms

eat materials equivalent to their weight. Their excreta also known as casting is a rich compound comprising nitrates, phosphorous, potassium, calcium and magnesium that enhance the fertility of the soil. The growth of bacteria and actinomycetes is increased in the presence of earthworms (Bhat *et al*., 2018).

v. Static composting: Here the waste is composted with very little or no turning. Aeration is done passively through perforated poles or pipes (Gonawala & Jardosh, 2018).

2.6 Heavy metals in MSW compost

Increase in industrialization and economic activities in the past century has led to an increase in environmental pollution. Some diseases have been traced to be caused by metals like lead, chromium, cadmium, nickel and manganese amongst others (Tay *et al*., 1996). Waste dumpsites contain metals that exist in various forms which can either be pure metal or alloyed together with other metals. These toxic heavy metals that harm the quality of the environment can be categorized into urban-industrial aerosols, liquid and solid wastes from animal and man, mining and industry and agricultural chemicals (Gerald, 1996). There is a growing concern over the disposal of materials in waste dumpsites that are contaminated with heavy metals to people and plants that get in contact with them since they accumulate in soil overtime (Agirtas & Kilicel, 1999). In Nigeria the quality and quantity of solid waste generated varies widely every day, depending on the season of the year and the nature of the waste as a result of improper waste management (Adeniji & Ogu, 1998; Deriah *et al*., 2005). Factors that influence the concentration of heavy metals in soils that are found around waste dumpsites are: The types and nature of the waste, topography, amount of run off and levels of scavenging. Usually, the waste disposed at the dumpsite is left to decompose naturally for a long time and in the process the waste is eaten by animals, some of it is picked by scavengers while the other part is washed away and collects into large creeks and rivers where the quality of surface water is adversely affected (Ogbonna *et al*., 2007). Metalloids and heavy metals having an atomic density above 6g/cm^3 are known to accumulate and persist in the soil to levels that are environmentally hazardous (Alloway, 1993). Most towns in Nigeria have abandoned the cultivation of various crops on dumpsites because of the uptake of toxic

heavy metals either by capillary action through the roots or through foliar adsorption. Depending on the type of metal, some plant species and other parts of the plant assimilate metals which end up becoming part of the plant tissue through bioaccumulation (Juste & Mench, 1992). Consumption of these crops having high metal content may lead to accumulation of these metals to toxic levels to the body (Amusan *et al*., 2005).

The use and marketing of compost is dependent on the concentration of heavy metals because of the bioaccumulation property that these metals exhibit (Tibu *et al*., 2019). Contamination of soil with heavy metals has become a global concern as it affects the production of world food (Chibuike & Obiora, 2014). Heavy metals are considered to be part of the soil. However, when these heavy metals exceed the permissible limits, they become toxic both to plants and soil in that there is low availability of macro-nutrients and the soil becomes acidic thus affecting food quality and safety (Sutkowska *et al*., 2020). Plants require trace elements for proper growth and development but exposure of plants to heavy metals can severely damage the plant and sometimes lead to their death (Cabala & Teper, 2007). The rhizosphere is the starting point were heavy metals affect the plant as this is where metalliferous minerals and substances interact with the root exudates (Cabala & Teper, 2007).

Heavy metal content in the compost produced depend on the nature of the fresh organic waste and the method used for collection (Zhang *et al*., 2008). Some researchers have reported that composting is one way of immobilizing heavy metals (Singh & Kalamdhad, 2012). However, during decomposition process the reduction in mass and volume of the MSW leads to an increase in concentration of heavy metals in the compost causing negative effects on; soil properties, reducing crop production and eventually contaminating the various trophic levels in the food chain. This led to the establishment of heavy metals limits in compost used for agriculture purposes with standard limits differing amongst countries. Developing countries have lower limits to enable them use raw organics from mixed waste streams (Smith, 2009). Heavy metal content depending on the nature of the feedstock is shown in figure 2-1.

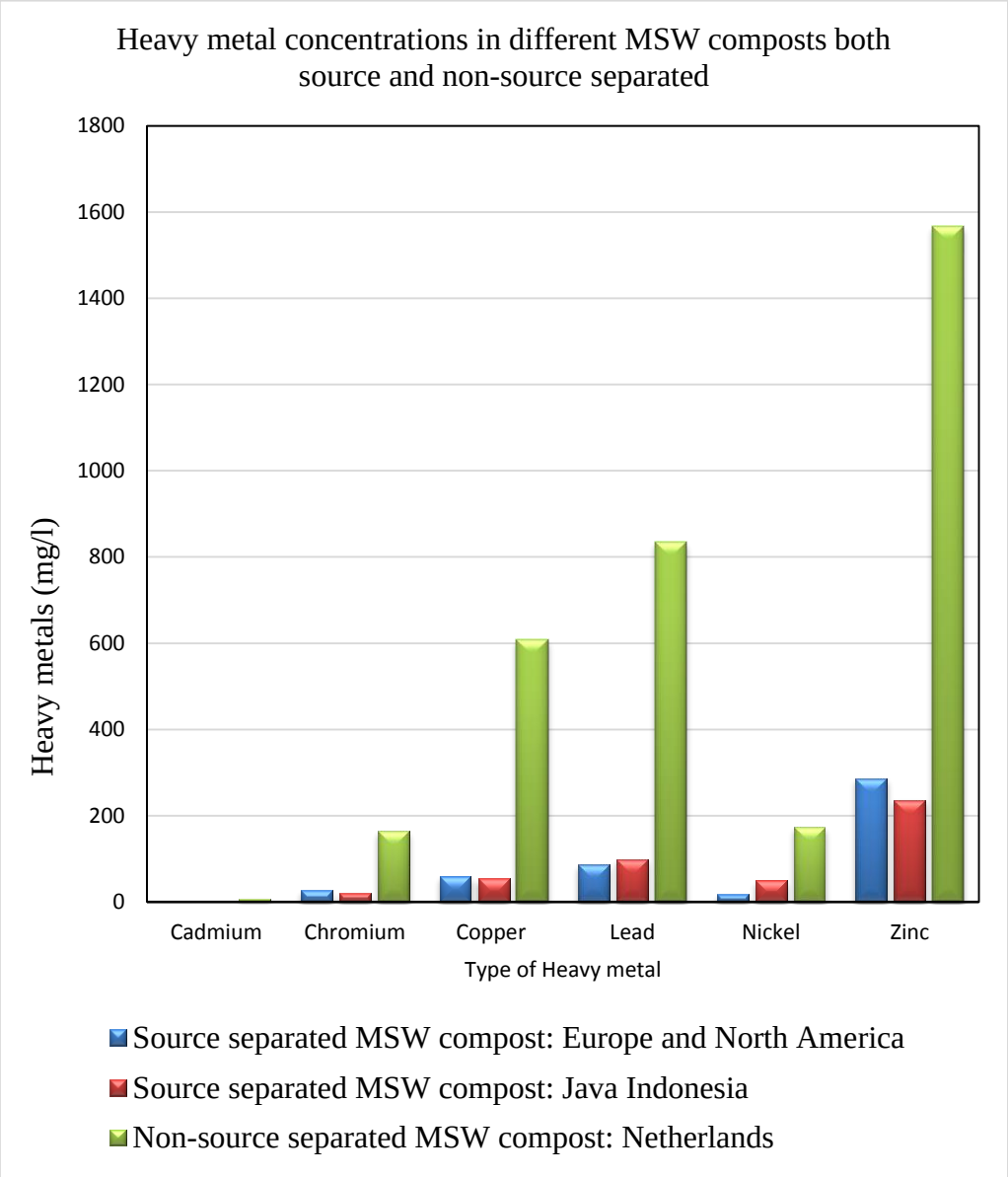


Figure 2- 1: Heavy metal concentrations in SSMSW and non-SSMSW composts (Source: World Bank, 1997a).

2.7 Compost Standards and Guidelines

In order to evaluate the agronomic effects of compost, certain plants are cultivated with the compost and the yield is used to ascertain the quality of the compost used. Generally, when compost is applied, there is always an increase in yield because of the nutrients

contained in the compost (Sharma *et al*., 2017). However, some composts when applied have produced low yields in plants due to low nutrient value. It is from this background that the nutrients in compost are supposed to be evaluated and where possible be supplemented with other materials containing the required nutrients (Lawal & Babalola, 2014). The quality of compost is assessed by carrying out chemical analysis to determine the concentration of the minerals (Brinton, 2000). Based on the 2001 Food and Agricultural Organization (FAO) of the United Nations (UN), there are standards that have been set as minimum. For example, nitrogen in organic fertilizer should not be less than 1 percent. Potassium and phosphorous, the minimum in organic fertilizer should be 1.5 percent. There is also a set standard for micronutrients such as zinc, copper, calcium in the range of 0.01-0.05 percent (Brinton, 2000).

Pathogenic microbes are present in compost and depend on the source and extent of maturity of the compost. Pathogens like *E. coli* and *Salmonella sp*. have been isolated in compost. It is therefore imperative that compost before being applied is thoroughly assessed for chemical and biological properties to assure safety of both humans and the environment (Chen *et al*., 2018).

The heightened levels of interactions and engagement between environmentalists, health regulators and traditional agricultural associations has compelled compost industries to scientifically report about the quality of compost (Brinton, 2000). Specific standards for regulating the quality of desirable compost on the market have been formulated and adopted by several countries in Europe, North America and India (Brinton, 2000). Various countries have come up with maximum permissible limits for heavy metals in compost and these limits make it possible for users to know the class of compost and where to apply it such as raising of high value crop, food crops, non-food fiber, soil conditioner, establishment of lawns, reclamation/rehabilitations of mining areas etc. (ENC, 2008). Figure 2-2 shows the standards for heavy metals in various countries. The values shown are the maximum permissible values for compost.

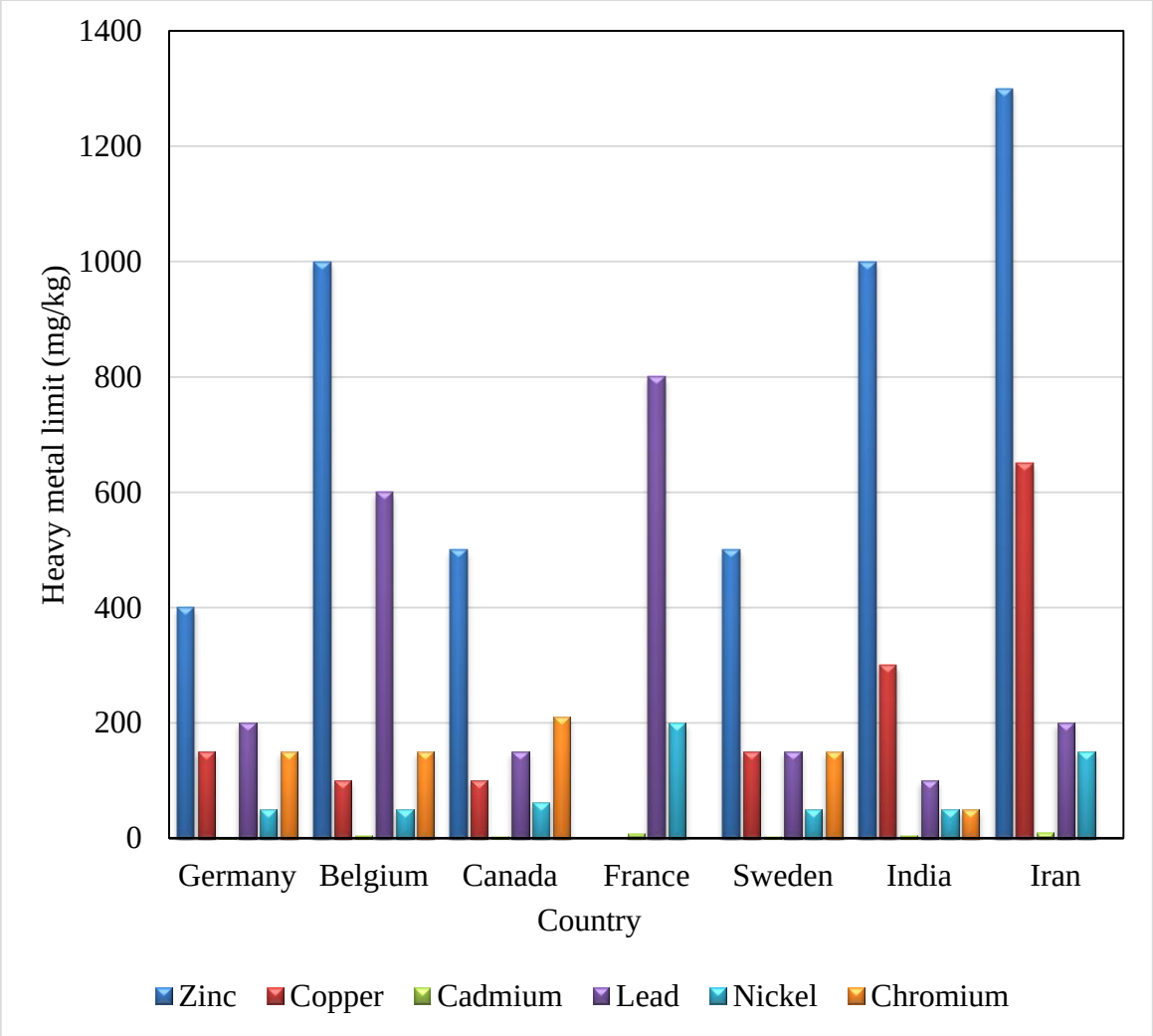


Figure 2- 2: Country-specific maximum permissible limits for heavy metals in compost (Source: ECN Report 2008).

In Spain, there are standards that were developed for fertilizer products that restrict the application of MSW with heavy metals. The regulation has categorized the compost into three groups based on the concentration of heavy metals (quality A, B and C). Quality A is the most restrictive with lowest concentration of heavy metals, class B has moderate concentration of heavy metals while class C has heavy metal concentration that are not supposed to be exceeded (Barrena *et al*., 2014). This is represented in figure 2-3.

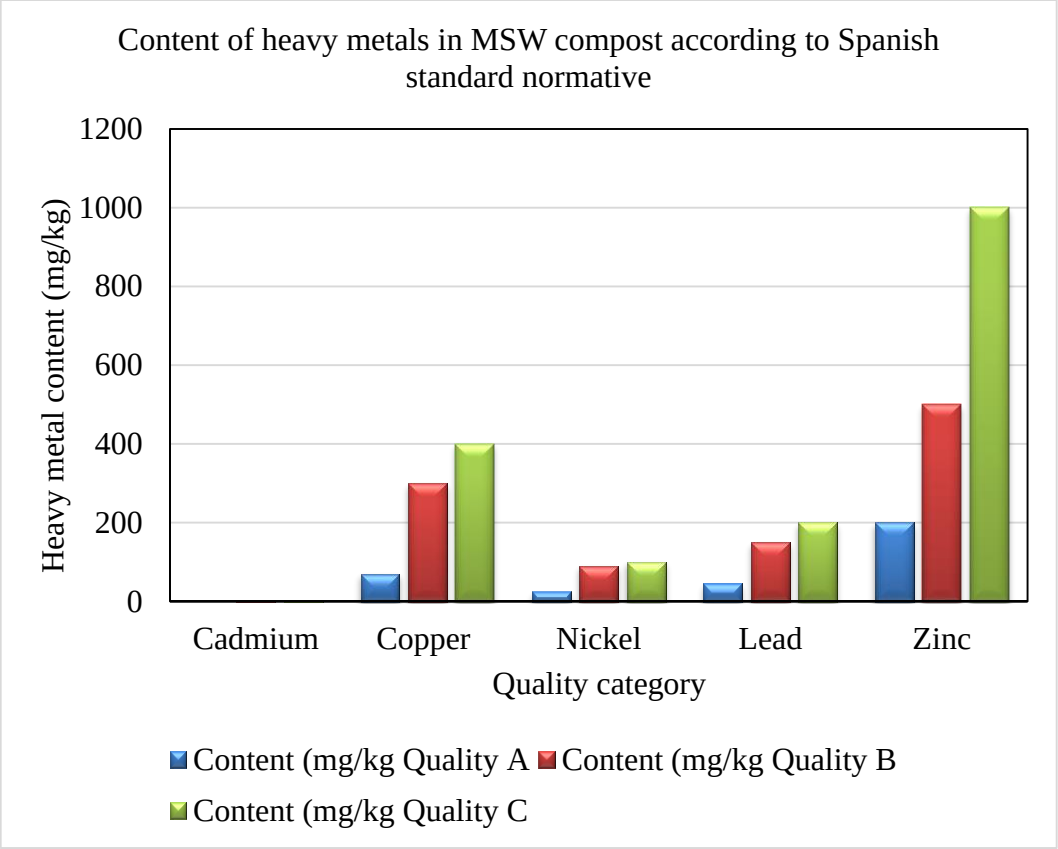


Figure 2- 3: Spanish standard normative content for heavy metals in MSW compost (Source Real, 2013).

2.8 Uses of MSW compost

MSW compost is used in various sector as explained in the ensuing sections.

2.8.1 Agricultural Sector

MSW is now widely recycled as organic fertilizer because it is cheaper to produce than chemical fertilizer (Creccchio *et al*., 2001). This option of recycling the MSW is important compared to landfilling which mostly leads to contamination of the environment that could result in ill health (Kathiravale & Yunus, 2008; Hargreaves et al., 2008a). Using MSW in agriculture eases the pressure for land that is supposed to be used for landfilling. Land application of MSW compost is important in that it augments yield

of plants and ameliorates the profile of nutrients in the soil, microbial activity buffering capacity as well as soil texture (Hargreaves *et al*., 2008a).

2.8.2 MSW compost impacts on plant growth and soil integrity

The use of MSW compost in agriculture is increasing because of the many benefits that come with using compost as fertilizer unlike the use of chemical fertilizer which deteriorates the quality of soil and pollutes the environment (Soobhany, 2019). Research globally has shown that MSW compost is beneficial both as a soil amendment and fertilizer which are released slowly (Sullivan *et al*., 2002; Sullivan *et al*., 2003). Sullivan *et al*., (2003) demonstrated that application of compost was able to release nitrogen over a period of seven years. In order to obtain good quality compost from MSW, the biodegradable components of the MSW must be recycled to the maximum possible (Malinger F & Weissteiner C, 1999). Compost also contains OM that is important in the soil as it enhances the soil's physico-chemical and biological (microbial biomass) properties (Araujo *et al*., 2010). In addition, OM increases the soil's capacity to hold water for a long time and lowers its bulky density (Soumare *et al*., 2003). Soil OM consists of remains of both animals and plants that are at different stages of decomposition. Adequate levels of OM benefit the soils in many ways such as improving physical condition, increasing water infiltration, improving soil tilth and supplying plant nutrients (Soumare *et al*., 2003). Other essential plant elements are also contained in soil OM like phosphorus, magnesium, calcium, sulphur and micro-nutrients. As OM decomposes, these elements become available to support the growth of plants (Garcia-Gil *et al*., 2002). OM in compost provides a conducive environment for microorganisms such as bacteria and fungi to flourish. When this happens biomass increases resulting in an increase in the transformation of insoluble organic matter to nutrient rich substrates and breaking down of toxic elements into less harmful substances. This culminates into proper growth of the plant at all stages which leads to better yields (Durake *et al*., 2011). The carbon in OM helps to balance both macro and micro fauna biodiversity like earthworms (Roman *et al*., 2015). The buffering capacity and cation exchange capacity are intensified by the humic acid that is contained in the MSW compost (Garcia-Gil *et al*., 2004). Using MSW

compost is now considered as the best option to chemical fertilizer due to many benefits derived from it such as increasing the OM as well as the C:N ratio in the soil which helps to maintain soil fertility and productivity (Crecchio *et al*., 2004; Garcia-Gil *et al*., 2004): Hargreaves *et al*., 2008a).

Adding compost to soils is essential to improve soil structure and texture as it plays a key role in carbon storage and strongly influences nutrient retention and availability. According to a survey on MSW compost, organic carbon content from the total carbon in the composted MSW is about 20 percent on average (Hamarashid *et.al*, 2010).

During compositing there is a rise in temperature which kills most of the pathogens that are found in the soil. Applying compost as fertilizer makes available the microorganism that promotes plant growth (Pane *et al*., 2014). Microbial diversity is enhanced which leads to nutrient recycling that happens as the microbes metabolize the organic matter in the waste material, minerals are released through a process known as mineralization (Giorgi, 2013).

2.8.3 Disease control and restoration of soil

The microorganisms that are found in the compost play a major role in remediation of most of the diseases that affect plants. This is achieved when microorganism in compost compete for nutrients with those harmful microbes found in the soil, in which case the former dominates the later which later die out, compost microbes benefit resources from soil microbes and in the process harm them (parasitism), compost microbes referred to as predators kill and eat other microbes found in the soil referred to as prey (predation). Microbes in compost produce chemicals (antibiotics) that inhibit the growth of other microorganism and sometimes can secret enzymes that degrades harmful microbes, (Olanrewaju *et al*., 2017). Lin *et al*., (2014) reported that the wilting of the plants and damping-off diseases were countered by *Bacillus* sp. that was in the compost (Lin *et al*., 2014). Compost is useful in the remediation of soils that are heavily polluted with heavy metals. It also helps to clean up soils contaminated with hydrocarbon compounds, wood preservatives, and other dangerous chemicals contained in explosives and pesticides. This

is achieved by either absorbing or degrading such elements, adsorption, complexation and redox reactions (Katoh *et al*., 2014; Soares *et al*., 2016; Tsang *et al*., 2014).

2.8.4 Biorefinery

There are a lot of valuable products that are derived from MSW compost that has made it to be treated as a renewable resource. The organics present in the MSW compost can be utilized through an integrated bio refinery concept to produce levulinic acid that can boost the economy by 110-150 percent (Sadhukhan *et al*., 2016). When levulinic acid is produced there are byproducts that are formed which could be further utilized in the production of biogas and fertilizer. From the same organic fraction of the waste, useful bio-products from acetic, propanoic, lactic and n-butyric acids are produced like acetate and lactate among others (Agler *et al*., 2011). Other value added byproducts derived from MSW compost are industrial chemicals and organic acids. However, the biggest challenge to produce these valuable byproducts is the high operational costs especially for developing countries (Bastidas-Oyanedel *et al*., 2016).

2.9 Solid Waste Management

All local authorities in developing countries are faced with the challenge of proper disposal of huge volumes of solid waste generated within cities and towns. This challenge comes about because of large quantities of solid waste generated at household level and insufficient funds allocated in the municipal budget to get rid of the garbage (Guerrero *et al*., 2013). The improper management of waste has raised serious and highly publicized pollution incidents which have led to the public being concerned about lack of controls, inadequate legislation, environmental and human health impacts (Guisti, 2009). Composting, waste-reuse and recycling are some of the environmentally sound criteria that favors the proper management of solid waste (Fudala-Ksiazek *et al*., 2016). With the current technological advancements coupled with improved legislation and systems put in place in the field of waste management, there is still a lot of public outcry about the adverse health and environmental effects on the location of waste disposal and treatment facilities especially if located near human settlements (Guisti, 2009). The whole health issues are tracked throughout the waste management chain and these include handling,

treatment, and disposal of waste. This can come about directly during the recovery and recycling activities of the solid waste or through exposure to hazardous substances contained in the waste or emissions coming from incinerators and landfill sites, vermin, odors and noise. The other health issues can be indirect through ingestion of contaminated water, soil, and food (Guisti, 2009; Darley *et al*., 2015).

2.10 Methods of MSW Disposal

Waste can be disposed of either conventionally or by composting. The following are the classified waste disposal methods under composting and conventional means:

2.10.1 Open Dump

In this method the waste is just dumped indiscriminately on any space that is available. This can be on the street or indeed on the highway. This is a bad practice of disposing waste as it becomes a breeding ground for house flies and rodents which are vectors for most diseases such as cholera and Lassa fever. Open dumping also causes offensive odours that pollute the atmosphere (Alam & Ahmade, 2013).

2.10.2 Animal Feeding

Domestic waste such as crop peels, leftover vegetable leaves and kitchen waste are fed to domestic animals. If the waste is infected, the infection can be transferred in the food chain to the highest trophic level. Animals fed with contaminated food pick up the diseases that are eventually passed to humans. One human disease that has been traced from animals that were fed with contaminated raw cabbage is trichinosis (Abdel-Shafy & Mansour, 2018; Lasaridi *et al*., 2018).

2.10.3 River and Ocean Dumping

Most waste is composed of various harmful material that is disposed as effluent into water bodies like lakes, rivers, oceans and dams resulting in water pollution. If aquatic animals that are contaminated are consumed, there is a likelihood of bio magnification of the toxins in humans (Ogwueleka, 2009). Some of the waste that is disposed into water bodies

can carry pathogens such as *Shigella* sp., *Salmonella* sp. and *Vibrio* sp. which can cause serious infection in humans (Xie *et al*., 2017).

2.10.4 Incineration

This is the process in which waste is burnt to ashes resulting in 90 percent volume reduction of the waste with the remains of metals and glasses taken to a landfill for disposal (Alam & Ahmade, 2013). There is production of energy during incineration which is better than the energy from coal and can save about 2-2.6 metric tonnes of carbon dioxide per year (Jeswani & Azapagic, 2016).

2.10.5 Deep-Well Injection

This is when waste is deposited into the subsurface, impermeable rock layers and it is mostly applied to disposal of toxic waste fluids from industries such as acid, alkaline and brine chemicals. However, before the waste is disposed, there is need to consider the local subsurface geology in order to protect ground water from possible pollution (Alam & Ahmade, 2013).

2.10.6 Sanitary Landfills

The waste is spread and compressed to a thin layer using a bulldozer. For every three meters height of waste pile, a thin layer of clean soil is introduced and compressed. This procedure is repeated until the pit is full (Alam & Ahmade, 2013). The waste disposed in this manner can harm the soil, soil organisms and humans if it contains pathogenic microbes or toxic chemicals. This is possible if polluted air is inhaled or contaminated water is consumed and these negative effects have made landfills to be discouraged by EU member states (Wang *et al*., 2018).

2.11 Solid Waste reuse in Zambia

According to Solid Waste Regulation and Management 362 No. 20 of 2018, Solid Waste Regulation and Management 5. The following key concepts and principles apply to the management and regulation of solid waste:

a) solid waste is a resource;

b) promotion of a solid waste hierarchy for recovery of solid waste, where prevention, reduction, re-use, recycling and composting is of primary consideration followed by other means of recovery such as energy recovery and lastly disposal.

2.12 Chapter Summary

The chapter considered previous studies done by other researchers with regard to chemical and biological characteristics of MSW compost justifying the need to carry out the research on the Chunga Landfill MSW compost to determine its viability. The next chapter looks at the methodology that was applied to conduct the study.

CHAPTER 3: METHODOLOGY

3.1 Study site

Chunga landfill is located in the northern part of Lusaka city 15º20'57.97"S 28º16'09.81". It was opened in 2006 initially meant to be a sanitary landfill with a life span of 25 years. The landfill receives comingled wastes from around the city which is degraded in an open-air dump. The waste is largely made up of MSW which has kept on piling over the years. It is segmented into two cells from which cell 2 was selected for the study as shown in appendix II. The study site map is shown in figure 3-1.

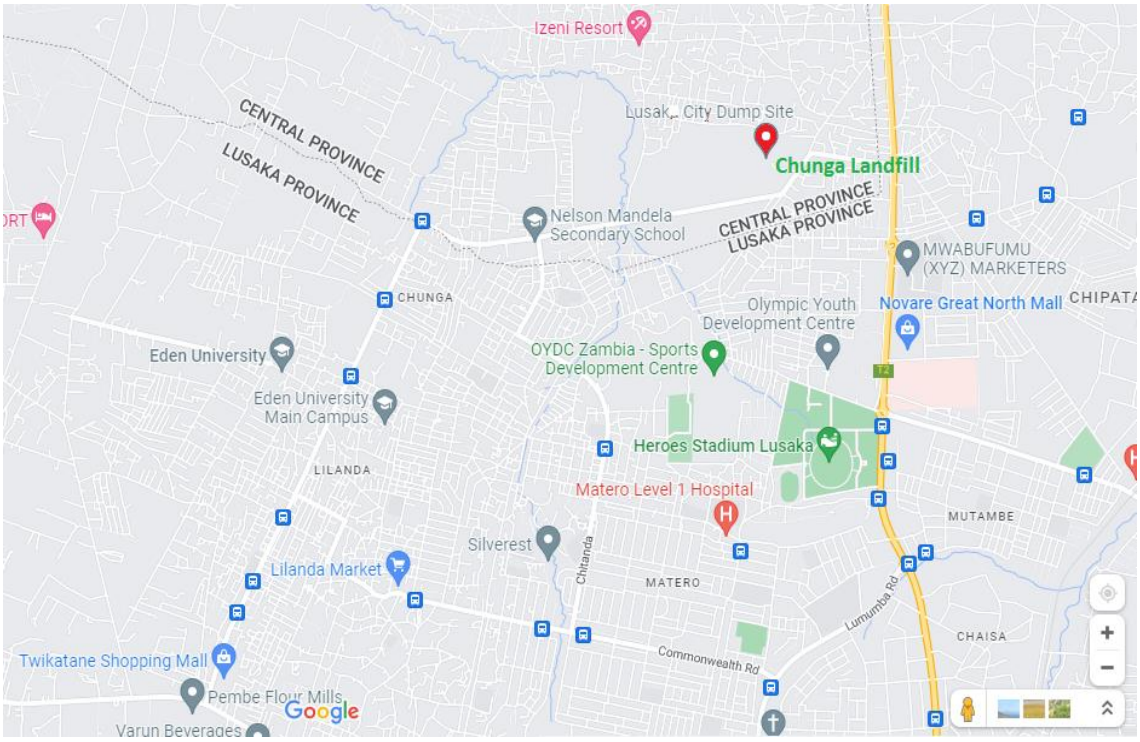


Figure 3-1: Site location of Chunga Landfill.

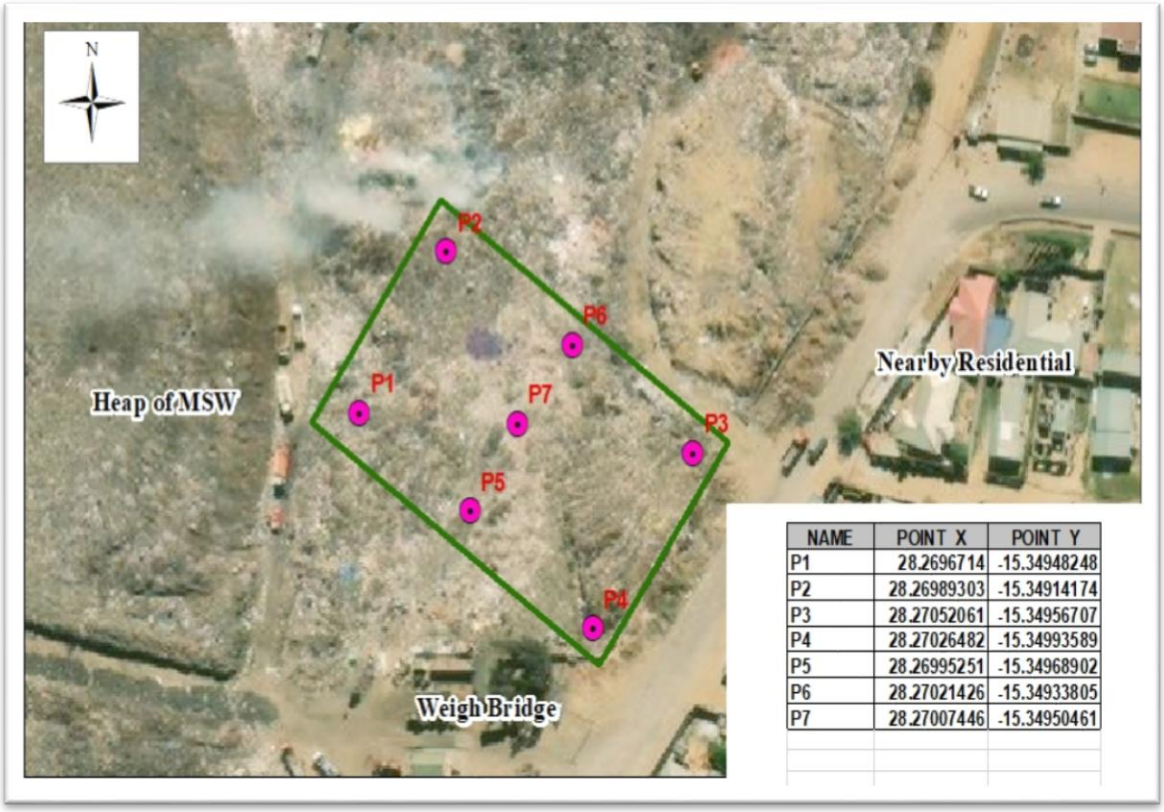
(Source: Google maps; https://www.google.com/maps/@-**:** accessed 17.10.2022).

3.2 Research design

3.2.1 Experimental design

The research employed a quantitative research approach which used an experimental design to characterize the MSW compost at Chunga Landfill.

3.2.2 Sampling



NAME	POINT X	POINT Y
P1	28.2696714	-15.34948248
P2	28.26989303	-15.34914174
P3	28.27052061	-15.34956707
P4	28.27026482	-15.34993589
P5	28.26995251	-15.34968902
P6	28.27021426	-15.34933805
P7	28.27007446	-15.34950461

Figure 3-1: Site map Showing Cell 2 were seven comingled sub samples of MSW compost were collected.

The MSW compost at Chunga Landfill was collected on the 6th November, 2021. The site has two cells (one and two). Cell one is where the MSW is currently being disposed of. The samples were collected from cell 2 because the MSW had been lying in the cell for a year without any fresh waste been introduced as can be seen in appendix III. The site was approximately 90,000 m^2. Seven sampling points evenly spaced around the cell were identified and marked for sampling as shown in figure 3-2. The samples were collected at 30 cm depth in sterile black polythene plastic bags according to the soil sampling procedure as shown in appendix IV. A minimum of 2 kg sample was collected from each point. The samples were quickly transported in a cooler box to the Environmental Engineering laboratory at the University of Zambia (UNZA). The collected samples were heterogeneous in nature with not only the degraded organic material but also other non-

degraded materials. All the samples collected were already dry and were immediately sieved using a 2 mm sieve to separate the degraded waste called compost from the non-degraded waste called trash as shown in appendix V. A composite sample from the study site was constituted by mixing 1 kg of the sieved seven subsamples.

3.2.3 Laboratory tests

Sample analysis was done at UNZA (School of Agricultural Sciences-Soil Science Department for chemical analysis and Food Science Department for biological analysis) and Mt. Makulu Central Research Station Soil Chemistry Research Unit in Chilanga for chemical parameters not done at UNZA.

3.2.4 Parameters

Tests carried out on the Chunga landfill MSW compost were pH, electrical conductivity (EC), carbon nitrogen ration (C:N ratio), total organic matter, nitrogen, phosphorous, potassium, cadmium, lead, chromium, copper, nickel, zinc, presence of *Salmonella spp. E. coli*, feacal coliforms and viable *Ascaris* ova.

3.3 Analytical methods

Various analytical methods were employed as each parameter had its own procedure of analysis.

3.3.1 Determination of metals using Aqua Regia

1g sample of the sample was weighed into a 250 ml conical flask and moistened with enough water to make the sample wet. 20 ml of aqua regia was added and the mixture was put on a hot plate at 200^{o}C in the fume hood. It was left to boil until about 5 ml of solution remained in the flask. The sample was removed from the hot plate and allowed to cool. After cooling, another 20 ml of aqua regia was added and the procedure was repeated. After the second cooling, about 30 ml distilled water was added and the mixture was filtered using whatman number two filter paper. After filtration, the filtrate was transferred to a 100 ml volumetric flask and made to volume with distilled water. The

elements cadmium, copper, zinc, chromium, lead, nickel and potassium were then analyzed using the Atomic Absorption Spectrophotometer (AAS) (Perkin Elmer Analyst 400). To determine the elements in the digest. The AAS was calibrated with each element's standards made in dilute nitric acid (1:10) over a suitable range. The concentration of each element in the digest was read and the percentage of element in the sample was calculated.

3.3.2 Determination of phosphorous/Phosphate using UV Spectrophotometer

1ml of the digest was pipetted into a 25 ml volumetric flask. Same volume of blank and standard 10 mg/l were also made. 10 ml distilled water and 4 ml ascorbic acid reagent were added. This was mixed thoroughly and made up to volume with distilled water. The concentration was read at 882 nm after 10 minutes of colour development using a Jenway 6305 UV Spectrophotometer.

3.3.3 Determination of soil organic matter

This was determined by the WALKELY-BLACK procedure which utilizes the oxidation of organic carbon by dichromate in an acid medium. The sample was treated with an excess dichromate. After oxidation, the excess dichromate was back-titrated with standard iron (II) reducing solution. 1 g of air dry sample was weighed in a 250 ml conical flask (triplicates). 10 ml of 1N potassium dichromate ($K_2Cr_2O_7$) was added. 20 ml of concentrated sulphuric acid (H_2SO_4) was added. This was swirled gently until the sample and solution were mixed. The suspension was stored in the fume hood for 30 minutes. Then 150 ml of distilled water and 10 ml concentrated phosphoric acid (H_3PO_4) were added. 10 drops (1ml) of the diphenyl amine indicator was added and titrated with iron (II) sulphate ($FeSO_4$) solution. The colour changed from yellow brown to blue and finally the end point of green colour. A blank titration was also performed without the sample for use to compute the organic matter.

Calculations: Suppose ‘a’ ml of $FeSO_4$ is added to the blank, and ‘b’ ml $FeSO_4$ is added to the sample, then the titration difference (a-b) ml will be equivalent to the carbon contained in the organic material. The total organic carbon content (C_t) is thus found as:

Percent C_t = (a -b) ×0.4

Assuming that soil organic matter (O.M.) consists of 50 percent carbon, we finally derive: percent O.M. = 2.0 percent C_t (Cottenie & Verloo, 1982; Kalra & Maynard, 1991; Black & Evans, 1965).

3.3.4 Determination of total and available nitrogen

To determine the total nitrogen, the sample was digested with H_2SO_4 to convert organic N to ammonia as nitrogen (NH_4^+-N) and nitrates as nitrogen (NO_3-N). The available forms of nitrogen (NH_4^+ - N and NO_3^- - N) were extracted from the sample using 2M potassium chloride (KCl). 1g of sample was weighed and transferred into the digestion tubes. 4 g of mixed catalyst (Kjeltab) was added after which 10 ml of concentrated H_2SO_4 was dispensed into each tube using a micro pipette. Sample tubes were then placed on the Digestion Block set at 410^{o}C. This was digested for 45 minutes until samples were clear. After digestion the tubes from the block were removed and allowed to cool for 15 minutes. They were then distilled into 25ml boric acid indicator solution with 40 percent sodium hydroxide (NaOH) and finally the distillate was titrated with 0.01M hydrochloric acid (HCl) (Cottenie & Verloo, 1982; Kalra & Maynard, 1991).

3.3.5 Determination of pH and EC

These two parameters were determined by mixing the MSW compost sample with distilled water in a 1:1 ratio. 50 g of the MSW was placed in a 100 ml beaker. 50 ml of distilled water was added and the contents shaken. This was given a contact time of 30 minutes with occasional shaking every 10 minutes. pH was measured using a Hanna pH-ISE meter and the EC was measured using a SPER Scientific Benchtop meter.

3.3.6 Detection of *E. coli* and feacal coliforms

This was done using **t**he most probable number method (MPN) which is a statistical multi-step assay consisting of presumptive, confirmed and completed phases. In the assay, serial dilutions of the MSW compost samples were inoculated into broth media. The number of gas positive (fermentation of lactose) tubes were recorded from which the

other two phases of the assay were performed and then used the combinations of positive results to consult a statistical table to estimate the number of organisms present.

3.3.7 Detection of *Salmonella*

The presence or absence test method was used. This involved the pre-enrichment, enrichment and isolation of *salmonella* species. The enrichment steps were meant to suppress the growth of other competing organisms in the compost matrix. The media used were Vassiliadis (RV) medium, Xylose Lysine Deoxycholate (XLD) medium, Brilliant Green Agar (BGA) and Triple Sugar Iron Agar (TSI). 25 g of sample was weighed and 225 ml of Buffered Peptone water was added in a stomacher bag. The suspension was blended for 2 minutes to obtain a homogenous distribution of microorganisms. This was incubated on pre-enrichment culture at 35°C for 24 hours. 0.1 ml of the pre-enrichment culture was transferred into a tube containing 9 ml of RV by using a sterile pipette. It was then incubated using enrichment media at 42°C in a water bath for 24 hours. *Salmonella* species were isolated by transfer of a loopful of the incubated enrichment culture to two plates of sterile XLD and two sterile BGA plates. The inoculated plates of XLD and BGA were incubated at 35°C for 24-48 hours. If no typical *Salmonella* colonies appeared on both XLD media and BGA media, it indicates the absence of *Salmonella.*

3.3.8 Recovery of *Ascaris* ova

The ammonium bicarbonate (AMBIC) procedure was used to recover Ascaris ova from Chunga Landfill MSW compost. The procedure consisted of three major steps:

(i) Preparation of the sample for analysis.
(ii) Mixing with ammonium bicarbonate (AMBIC) Solution
(iii) Recovery with an adjusted zinc sulphate floatation solution.

1 g of MSW sample was weighed and put in a 15 ml conical test tube. 14 ml of saturated AMBIC solution was added and the content was vortexed for 3 minutes after which it was left to stand for one hour during which period vortexing was repeated after 30 minutes followed by manual shaking for 2 minutes. When the one hour period elapsed, a 3 minutes centrifuge was done to the mixture and the whole supernatant was removed.

14 ml distilled water was added and the contents were thoroughly mixed for 2 minutes. A zinc sulphate solution with specific gravity of 1.4 was added and vortexed for 2 minutes and centrifuged for 3 minutes. Equal volumes of the supernatant was put into clean conical test tubes. 12 ml distilled water was added to all the tubes and centrifuged for another 3 minutes. After discarding the whole supernatant, a light microscope was used to view and count the ova in the sample. The remainder sample was subjected to floatation and analyzed following the same procedure above and the ova was counted.

3.4 Determining the fertilizing capacity and appropriate land application of the Chunga landfill MSW with respect to agriculture

The chemical and biological characteristics of the Chunga landfill MSW compost were compared with other MSW compost from literature. It was compared with the FAO standard for organic fertilizer. The comparison was based on the NPK nutrient content. The other characteristics of OM, heavy metals and biological parameters were used to determine the most appropriate land application of the Chunga Landfill MSW compost with respect to agriculture.

3.5 Data Analysis

Descriptive statistical analysis was used to analyze the data. The analysis was done in duplicate at Mt. Makulu Central Research Station and triplicate at UNZA, School of Agricultural Sciences because of cost implications. Microsoft excel was used to analyze all the data collected and expressed as mean ± standard deviation.

3.6 Chapter Summary

This chapter presented the methodology applied to conduct the research. These included study site, experimental research design, parameters considered, analytical methods used and determination of the fertilizing capacity and land use and how the data was analyzed. The next chapter presents the results of the study.

CHAPTER 4: RESULTS

This chapter analyzes results obtained from the analysis of the Chunga Landfill MSW compost and are presented in tables and graphs.

4.1 Chemical characteristics of Chunga Landfill MSW compost

The chemical parameters analyzed on the Chunga Landfill MSW compost were: pH, EC, total nitrogen, phosphorous, potassium, copper, nickel, zinc, cadmium, chromium, lead, OM and C:N ratio. Table 4-1 and appendix VI and IX shows results of chemical composition of Chunga Landfill MSW compost.

Table 4- 1: Mean results of the chemical composition of Chunga Landfill MSW compost.

Parameter	**Value**
pH	7.94 ± 0.01
EC (mS/cm)	6.46 ± 0.03
Total nitrogen (%)	0.77 ± 0.01
Phosphorous (%)	0.53 ± 0.04
Potassium (%)	0.88 ± 0.03
OM (%)	6.76 ± 0.02
C:N ratio	5.10
Copper (mg/kg)	156.8 ± 5.52
Nickel (mg/kg)	28.75 ± 0.49
Zinc (mg/kg)	207.83 ± 18.60
Cadmium (mg/kg)	4.63 ± 0.94
Chromium (mg/kg)	60.7 ± 0.57
Lead (mg/kg)	109.58 ± 8.92

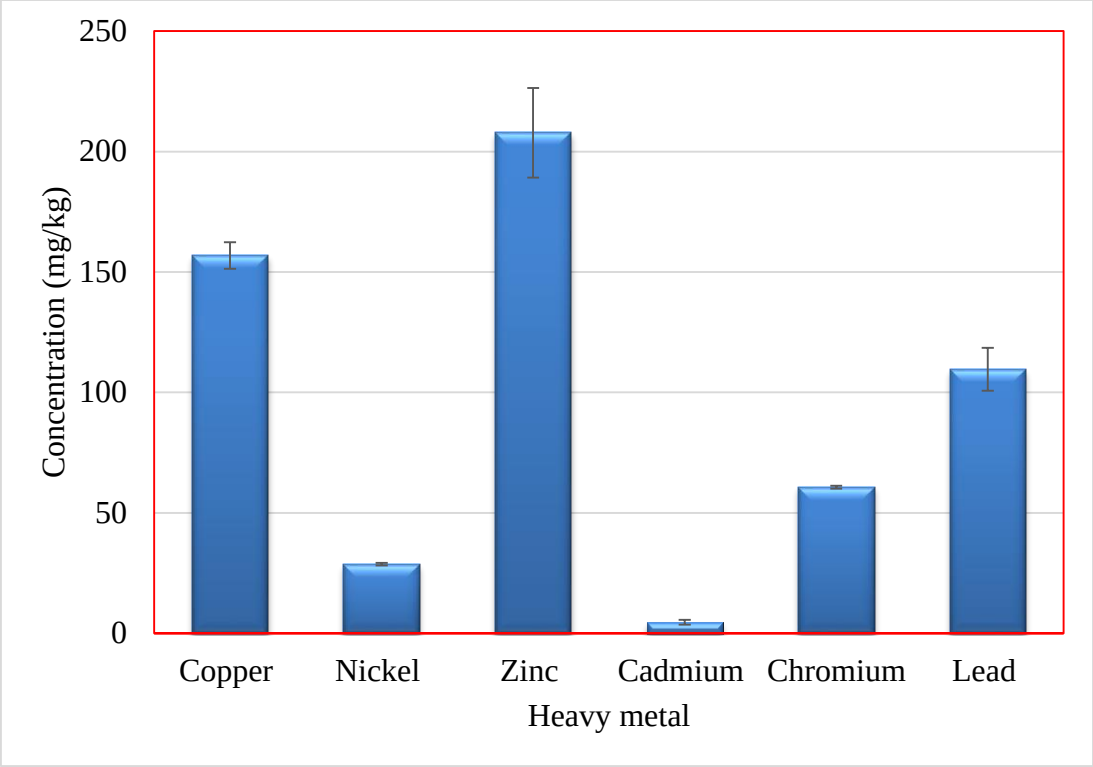


Figure 4- 1: Mean results of the heavy metals in MSW compost from Chunga Landfill

4.2 Biological characteristics of the Chunga Landfill MSW compost

The biological parameters analyzed on the Chunga Landfill MSW compost were *E. coli*, feacal coliforms, *Salmonella* spp. and *Ascaris*. Table 4-2 and appendix VII shows *E. coli*, feacal coliforms, *Salmonella* spp. results obtained for the biological parameters analyzed.

4.2.1 *E. coli*, feacal coliforms and *salmonella*

Three tubes each at 0.1, 0.01 and 0.001 g inocula gave three positive tubes for each corresponding to greater than 1,100 MPN/g from the MPN table.

Table 4- 2: Biological results of MSW compost at Chunga Landfill

Parameter	**Value**
E. coli (MPN/g)	>1,100
Feacal coliforms (MPN/g)	>1,100
Salmonella spp.(#/25g)	Not detected

Ascaris recovery was performed on the MSW compost at Chunga Landfill and the results are in table 4-3 and appendix VIII.

Table 4- 3: *Ascaris* recovery results on MSW compost from Chunga Landfill

Test No.	***Ascaris* Ova/g**	**Viability/non-viable**
1	200	Non-viable
2	Nil	N/A
3	Nil	N/A
4	100	Non-viable
5	Nil	N/A
6	Nil	N/A
7	Nil	N/A
8	100	Non-viable
9	Nil	N/A
10	Nil	N/A

Literature review Chapter two sub sections 2.3 (Chemical characteristics of MSW compost), 2.4 (Biological characteristics of MSW compost), 2.7 (Compost standards and guidelines) and the analytical data results on the Chunga Landfill MSW compost where used to determine the fertilizing capacity and the appropriate land application of the Chunga Landfill MSW compost with respect to agriculture.

4.3 Chapter Summary

This chapter presented the results of the study and analyzes results obtained from the chemical and biological characteristics of the Chunga Landfill MSW compost. The next chapter will discuss the results obtained in the current study and compare and contrast with results obtained by other researchers and thereafter determine the possibility of utilizing the Chunga Landfill MSW compost.

CHAPTER 5: DISCUSSION

5.1 Introduction

This chapter discusses results obtained in this study and compares and contrasts with results obtained by other researchers who did similar studies. The possibility of utilizing MSW compost at Chunga landfill is also discussed in this Chapter.

5.2 Chemical characteristics

Chemical characteristics important in MSW compost are discussed in the preceding section.

5.2.1 pH

The pH of the MSW compost at Chunga Landfill was 7.94 ± 0.01. In a study by Lord *et al*., (2021) in Canada, the pH of MSW was 8.1 which agrees that of Chunga Landfill MSW compost. Papiya *et al*., (2014) conducted a study in Delhi, India on MSW compost quality and found an average pH of 8.4 ± 0.02 which is close to that of the Chunga Landfill MSW compost and in line with that reported by Lord *et al*., (2021) in Canada. Studies done by Thitame *et al*., (2010) on the Characteristics and composition of MSW generated in Sangamner City, District Ahmednagar, Maharashtra, India reported pH of 7.1 which is close to the that of the Chunga Landfill MSW compost. Studies in Uganda by Kabasiita *et al*., (2022) on the quality of MSW reported a high alkaline mean pH of 9.16. Dessalegn *et al*., (2012) did a study in Addis Ababa city of Ethiopia to check the quality of compost produced from SSMSW. The pH of the matured compost was 8.11 ± 0.02 which is close to that of Chunga Landfill MSW compost. Similar studies by Rouf & Rashid, (2020) in Mymensingh Pourashava City of Bangladesh found the pH at 7.3 which was also close to that of the Chunga Landfill MSW compost. Studies conducted in Bagdad, Iraq by AL-Saedi & Ibrahim, (2019) on aerobic MSW compost taken from different layers of the composting bioreactor had an initial pH of 6.53 for the three layers and a final pH range of 7.40 ± 0.01 was recorded which is also close to that of Chunga Landfill MSW compost. Therefore the Chunga Landfill MSW compost pH agrees with the pH of most MSW compost in other countries. Therefore, determining the initial pH of MSW compost is critical as it alters the pH of the soil either increasing or decreasing

it which in turn affects the availability of nutrients to plants. Matured MSW compost has a pH range of between 6.0 and 8.0 (Tester, 2009). The pH of the soil regulates the bioavailability, mobility and solubility of trace elements which is responsible for their translocation in plants mostly by precipitation/dissolution reactions (Förstner, 1995). Soil pH regulates OM solubility by influencing the humic compounds charge density and microbial activity either by stimulating or repressing their rate. pH of the soil has an effect on the cell's physiological function influenced by environmental conditions and thus determine the microbial biomass. Efficient microbial activities occur mostly in the near neutral pH range with bacteria preferring a pH of between 6.0 and 7.5 while fungi pH range is 5.5 and 8.0 (Andersson, 2000).

5.2.2 EC

The EC of the MSW compost at Chunga Landfill was 6.46 ± 0.03 mS/cm. Another study done by Thitame *et al*., (2010) on the Characterization and composition of MSW compost generated in Sangamner City, district Ahmednagar, Maharashtra, India reported an EC of 3.8 mS/cm which was about 50 percent less than the EC of the Chunga Landfill MSW compost. Studies in Uganda by Kabasiita, *et al*., (2022) aimed at determining the quality of MSW compost indicated an average EC of 4.70 mS/cm which was less than the one in Chunga Landfill MSW compost. Other studies by Dessalegn *et al*., (2012) in Ethiopia's Addis Ababa city reported EC of 3.82 ± 0.03 mS/cm in the matured MSW compost. Similar studies conducted by Rouf & Rashid, (2020) in Mymensingh Pourashava City of Bangladesh on the quality of MSW compost produced from solid waste recorded an EC of 2.4 mS/cm which is half the one reported by Kabasiita, *et al*., (2022) in Uganda.

The EC of Chunga Landfill MSW compost was about twice higher compared to other MSW compost reviewed and this could be attributed to high concentration of salts such as potassium, calcium, magnesium, iron, chlorides, sulphates, manganese, copper, zinc, cobalt and other trace elements. This EC however, was in line with the EC of matured compost which is supposed to be between 2.2 and 9.3mS/cm (Gebru, 2011).

5.2.3 Total nitrogen

The total nitrogen content in the MSW compost at Chunga Landfill was 0.77 ± 0.01 percent. A Similar study done in New Delhi, India by Neeri, (2005) reported the total nitrogen of 0.79 percent in MSW compost which is in line with the one in the Chunga Landfill MSW compost. Another study conducted by Sarkar & Bhuyan, (2018) to determine the physical and chemical properties of solid waste taken from the dumpsite area in Halishahar Munir Nagar area, Chittagong Metropolitan City, Bangladesh reported a total nitrogen content of 0.43 percent which is less by about 50 percent to the one found in the Chunga Landfill MSW compost and the one reported by Neeri, (2005) in New Delhi, India. A study done by Thitame *et al*., (2010) on the Characteristics and composition of MSW compost generated in Sangamner City, District Ahmednagar, Maharashtra, India reported an organic nitrogen of 0.73 percent which again is in line with the one reported in the Chunga Landfill MSW compost. In a case study conducted by Yusuff *et al*., (2014) in Castlereagh District, Northern Ireland aimed at assessing the Physico-chemical characteristics and energy content of solid waste reported total nitrogen content of 1.2 percent which is about twice more than the one in the Chunga Landfill MSW compost. A similar study by Ayeleru *et al*., (2018) assessed the chemical characteristics of MSW compost generated in Johannesburg City, South Africa showed a concentration of 1.98 percent organic nitrogen which is more than double the concentration in the MSW compost at Chunga Landfill. Studies in Uganda by Kabasiita *et al*., (2022) to assess the quality of MSW compost reported an average of 0.5 percent nitrogen which was lower than that in the Chunga Landfill MSW compost. Dessalegn *et al*., (2012) conducted a research aimed at determining the quality of final compost made from SSMSW in Addis Ababa city, Ethiopia. Results indicated 1.07 percent total nitrogen because of using source segregated feedstock. Similar studies by Rouf & Rashid., (2020) in Mymensingh Pourashava City of Bangladesh on the assessment of the chemical composition of MSW compost derived from solid waste found 0.896 percent nitrogen content which is close to the one in Chunga Landfill MSW compost. Becher *et al*., (2018) conducted a study in Central-eastern Poland to assess the quality of MSW compost and

reported a nitrogen content of 1.28 percent which was in agreement with the nitrogen concentration of 1.2 percent reported by Yusuff *et al*., (2014) in Northern Ireland.

The low level of nitrogen in the Chunga Landfill MSW compost may be attributed to the fact that MSW compost have relatively low nutrients due to the low levels in the feed stock and the stage of maturity (Rahmana *et al*., 2020). Seperation of the MSW into organic and inorganic components before composting can greatly increase the level of nitrogen in the MSW as reported by Dessalegn *et al*., (2012) in Ethiopia, Addis Ababa were total nitrogen of 1.07 percent was recorded on SSMSW. The nitrogen content in the Chunga Landfill MSW compost agrees with some MSW compost and in other instances is less by half compared to other reviewed MSW compost. This content of nitrogen is below the FAO standard of ≥1.0 percent. Therefore, the MSW compost at Chunga landfill with total nitrogen of 0.77 percent has the fertilizing capability and may be used in agriculture on low value crops or when supplemented with nitrogen on high value crops. Rahmana, et al., (2020) reported that feed stock and stage of maturity determine the concentration of nutrients in the MSW. They went further to say that compost have relatively low nutrient content when compared to most commercial fertilizers and that the nutrients in compost are released slowly and are more environmentally friendly.

5.2.4 Phosphorous

The MSW compost at Chunga Landfill had a phosphorous content of 0.53 ± 0.04 percent. A similar study by Ibicol Sas (2018) on SSMSW compost in Columbia's City of Cajicá had phosphorous of 1.09 percent double the one in the MSW compost at Chunga Landfill. Another study in New Delhi, India by Neeri, (2005) on MSW compost also had high phosphorous content of 0.76 percent. A similar study by Lord *et al*., (2021) in Agaard farm, Brandon MB, Canada conducted to assess the quality of MSW compost had very low phosphorous concentration of 0.01 percent. Another study by Sarkar & Bhuyan, (2018) in Halishahar Munir Nagar area, Chittagong Metropolitan City, Bangladesh aimed at determining the physico-chemical properties of solid waste collected from the dumpsite area reported low phosphorous concentration of 0.08 percent. Another study done by Thitame *et al*., (2010) on the Characterization and composition of MSW compost generated in Sangamner City, District Ahmednagar, Maharashtra, India reported

phosphorous content of 0.93 percent about twice more than the one in the Chunga Landfill MSW compost. Studies in Uganda by Kabasiita *et al*., (2022) on the assessement of the quality of MSW compost recorded an average of 0.8 percent phosphorous which was close to the one reported in New Delhi, India by Neeri, (2005). In a study conducted by Dessalegn *et al*., (2012) to check the quality of compost produced aerobically by local residents at household level using SSMSW in Addis Ababa city, Ethiopia. The phosphorous concentration was 0.47 percent which is close to one in the Chunga landfill MSW compost. Similar studies by Rouf & Rashid, (2020) in Mymensingh Pourashava City of Bangladesh on the assessment of the chemical composition of MSW compost derived from solid waste reported 0.30 percent phosphorous. According to studies by Becher *et al*., (2018) on matured MSW compost applied as organic fertilizer in Central-eastern Poland, the mean phosphorous content was reported at 0.23 percent which is less by about half to that in the Chunga Landfill MSW compost.

The level of phosphorous in the Chunga Landfill MSW compost is low compared to most MSW compost reviewed and below the FAO standard of ≥ 1.5 percent. Therefore, with this level of 0.53 percent phosphorous, it may be used in agriculture on low value crops or when supplemented with phosphorous on high value crops.

5.2.5 Potassium

Potassium in the Chunga Landfill MSW compost was reported at 0.88 ± 0.03 percent. A similar study by Ibicol Sas (2018) in Columbia's City of Cajicá found the potassium level in MSW compost at a higher concentration of 1.69 percent which was double the one in the Chunga Landfill MSW. Another study in New Delhi, India by Neeri, (2005) found the potassium level in the MSW compost at 0.86 percent which is in line with the one at Chunga Landfill MSW compost. Another study by Lord *et al*., (2021) in Agaard farm, Brandon MB, Canada on MSW compost reported low potassium concentration of 0.02 percent. Another study done on the characterization and composition of MSW generated in Sangamner City, District Ahmednagar, Maharashtra, India by Thitame *et al*., (2010) reported potassium content of 0.35 percent which is less than the one in the Chunga Landfill MSW compost by about half. Studies conducted in Uganda by Kabasiita *et al*., (2022) on the chemical properties of MSW compost gave an average of 1.3 percent

potassium from all locations which was higher than that in the Chunga Landfill MSW compost. Similar study by Rouf & Rashid, (2020) in Mymensingh Pourashava City of Bangladesh on assessment of the chemical composition of MSW compost derived from solid waste reported 0.45 percent potassium less by half to that in the Chunga Landfill MSW compost. Studies conducted in Bagdad, Iraq by AL-Saedi & Ibrahim, (2019) on the quality of aerobic MSW compost taken from different layers of the composting bioreactor had a final potassium content of 1.69 and 1.81 percent which was the highest from the reviewed MSW compost potassium levels. Becher *et al.,* (2018) conducted a research to determine the chemical composition of matured MSW compost that was used as organic fertilizer in Central-eastern Poland recorded a mean potassium concentration of 0.52 percent lower than the one in the Chunga Landfill MSW compost. The potassium in the MSW compost at Chunga landfill is below the FOA of ≥ 1.5 percent. Therefore, with this level of 0.88 percent potassium, it may be used in agriculture on low value crops or when supplemented with potassium on high value crops.

5.2.6 OM

The OM in the Chunga Landfill MSW compost was 6.76 ± 0.02 percent. Studies in Uganda carried out by kabasiita *et al*., (2002) on the assessment of the quality of MSW compost reported an average OM of 8.5 percent in all locations. Research done by Dessalegn *et al*., (2012) in Ethiopia, Addis Abba City aimed at characterizing the chemical properties of aerobically made compost using SSMSW sorted out local residents reported total OM in the final compost at 20.39 percent. The high OM content was as a result of using SSMSW feedstock rich in OM. A similar study by Rouf & Rashid, (2020) done in Mymensingh Pourashava City of Bangladesh on the assessment of the chemical composition of MSW compost derived from solid waste reported an OM content of 22.5 percent which was in agreement with that reported by Dessalegn *et al*., (2012) in Ethiopia, Addis Ababa City. Another study conducted by Becher *et al*., (2018) in Central-eastern Poland aimed at assessing the chemical composition of matured MSW compost applied as organic fertilizer recorded mean OM of 28.21 percent. The high OM content was in the same range with that reported by Dessalegn *et al*., (2012) and Rouf & Rashid, (2020) in Ethiopia and Bangladesh respectively. The low OM under the current study is less than

the 25 percent reported in the UK (Ge *et al*., 2006), and Ethiopia (EFEPA, 2004) and the stipulated 28 to 42 percent for matured compost (Khater, 2015).

5.2.7 C:N ratio

The C:N ratio in the MSW compost disposed at Chunga landfill was 5.10. According to studies in Columbia at the Cajicá municipality by Ibicol Sas, (2018), the C:N ratio in the MSW was 11 about twice the one in the Chunga Landfill MSW compost. In Delhi, India a research done by Papiya *et al*., (2014) on MSW compost found a mean C:N ratio of 9.46 ± 0.91 which was about twice more than that in the Chunga Landfill MSW compost but in line with 9-11 C:N ratio of matured compost. Studies by Kabasiita *et al*., (2022) on the quality of MSW compost in Uganda reported an average C:N ratio of 17.2 in all locations which was more than three times the one in the Chunga Landfill MSW compost. Studies conducted by Dessalegn *et al*., (2012) in Addis Ababa, Ethiopia on aerobically produced compost using SSMSW sorted out at household level by local residents, the C:N ratio in the matured compost was 9.11 which was in line with that of matured compost. A Similar study by Rouf & Rashid, (2020) in Mymensingh Pourashava City of Bangladesh done to assess the quality of MSW compost produced from solid waste found the C:N ratio of 14.5. This again was more than two times the one in Chunga Landfill MSW compost. Studies conducted in Bagdad, Iraq by Al-Saedi & Ibrahim, (2019) to determine the quality of compost produced from MSW using aerobic method and then determine changes that occur at different layers of the composting material in the bioreactor reported the C:N ratio of between 13.8 and 16.1 in the three layers of the composting material which also was three times more than what was found in the Chunga Landfill MSW compost. C:N ratio is useful in determining the status of composting and the degree of maturity of the compost. The balance of nutrients in the composting process is indicated by the relative proportion of the carbon and nitrogen (Norbu *et al*., 2005) with nitrogen fraction influencing the population growth of bacteria as it is part of their structure and the carbon is used as a source of energy (Gajalakshmi & Abbasi, 2008). The C:N ratio is mostly applied to measure the stability index and should normally range from 15 to 20 in the final compost product (Gajalakshmi & Abbasi, 2008). It is below that of matured compost of between 9 and 11 (Dadi, *et al*., 2012).

5.3 Heavy metals

Heavy metals analyzed in the Chunga MSW compost were cadmium, zinc, copper, lead, nickel and chromium and the mean concentration results are presented in figure 4-1.

5.3.1 Cadmium

The cadmium analyzed in the Chunga Landfill MSW compost was 4.63 ± 0.94 mg/kg. A similar study in Columbia at the Cajicá municipality by Ibicol Sas, (2018) found the cadmium level in the MSW compost at low concentration of 0.18 mg/kg. Jalalipour *et al*., (2020) conducted a study in Barmshor landfill of Shiraz in Iran on MSW compost and found low cadmium concentration of 0.04 mg/kg. Lord *et al*., (2021) conducted a research on MSW compost in Agaard farm, Brandon MB, Canada and reported a 0.04 mg/kg cadmium content which was in line with the one reported by Jalalipour *et al*., (2020) in Iran. In a related study conducted by Papiya *et al*., (2014) on MSW compost in Delhi, India, the cadmium level was 3.95 ± 1.15 mg/kg. Studies in Uganda by Kabasiita *et al*., (2022) on the quality of MSW compost gave a range of 3.7-15.9 mg/kg cadmium which was similar to 3.95 ± 1.15 mg/kg reported by Lord *et al*., (2021) in Canada. Dessalegn *et al*., (2012) carried out a research in Addis Ababa, Ethiopia to check the quality of compost produced aerobically using SSMSW sorted out by local residents at household level. The cadmium level in the matured compost was 0.3995 ± 0.0696 mg/kg. The low cadmium was as a result of using SSMSW feedstock. Studies by Rouf & Rashid, (2020) in Mymensingh Pourashava City of Bangladesh on MSW compost derived from solid waste found low concentration of 0.39 mg/kg cadmium which is in agreement with 0.3995 ± 0.0696 mg/kg reported by Dessalegn *et al*., 2012 in Ethiopia, Addis Ababa. Becher *et al*., (2018) conducted a study in Central-eastern Poland reported low mean cadmium concentration of 0.18 ± 0.26 mg/kg.

Cadmium is one of the most dangerous heavy metals which is not essential for plants. It is introduced in the environment through anthropogenic activities and risks the whole ecosystem (Jibril *et al*., 2017). It is mostly absorbed by plant roots but sometimes can be absorbed directly from the atmosphere (Ismael *et al*., 2019). High concentration in plants bring about changes in many physiological and biochemical processes (Feng *et al*., 2010)

like inhibiting some vital processes such as minerals transportation, photosynthetic apparatus, and nutrient uptake and sometimes uptake of iron by plant shoots (Jibril *et al*., 2017; Schützendübel *et al*., 2002). High level of cadmium can also have an influence on the phenotype of the plant such as plant weight and length of roots and shoots become reduced, cytotoxicity (reduction in chlorophyll and inhibition of photosynthetic performance), metabolic processes are affected such as chlorosis and damage to the cell is also eminent (Hayat *et al*., 2018). The high cadmium content in the Chunga Landfill MSW can be traced to high quantities of the toxic metal contained in the MSW and that the primary source of cadmium in MSW is kitchen, ash and plastic (Calace, *et al*., 2001. Jagath *et al*, (2002) reported that the best way to come up with compost from MSW of good quality and free of heavy metals like cadmium is to separate the compostable waste at the point of generation. When the Chunga Landfill MSW is separated at source or at the disposal site, the levels of cadmium may drastically reduce as observed from other SSMSW compost reviewed. Reducing the cadmium content in the Chunga Landfill MSW compost will make it to be in line with other MSW compost in other regions with low cadmium.

5.3.2 Zinc

The zinc concentration in the Chunga landfill MSW compost was 207.83 ± 18.60 mg/kg. A similar study by Lord *et al*., (2021) in Agaard farm, Brandon MB, Canada on MSW compost had a zinc content of 3.77 mg/kg. In Barmshor landfill of Shiraz in Iran a study by Jalalipour *et al*., (2020) on SSMSW compost had zinc content of 95.26 mg/kg proving that when MSW is separated at source the levels of heavy metals reduce as compared to non-separated MSW like is the case with the Chunga landfill MSW compost. According to a research by Papiya *et al*., (2014) in Delhi, India on non SSMSW compost, the zinc concentration of 389 ± 42 mg/kg was reported which was higher than the one at in Chunga Landfill MSW compost. In other studies by Dessalegn *et al*., (2012) in Ethiopia, City of Addis on SSMSW, the zinc level in the matured compost was 176.71 ± 29.0996 mg/kg which was on the lower side when compared to the one found in the MSW compost at Chunga Landfill because of using SSMSW feed stock. Studies by Becher *et al*., (2018) to characterize the chemical composition of organic fertilizer made from matured MSW

was conducted in Central-eastern Poland and the mean concentration of zinc was 123.5 ± 46.3 mg/kg.

The zinc concentration in the Chunga Landfill MSW compost is generally within the same range with other MSW compost. If the MSW is separated at source or at the disposal site so that only the biodegradable organic waste is degraded, the level of zinc may be drastically reduced like is the case with other SSMSW compost. This concentration is within the FAO standard of between 100 and 500 mg/kg. Zinc is an essential trace element required by plants and a major constituent of many proteins as cofactor for many enzymes needed for optimal plant growth and development (Broadley *et al*., 2007). If it is in high concentration in the soil, it becomes phytotoxic making the plant that accumulated it through root absorption deposition to pose health risks to consumers. This therefore calls for the regulation of zinc uptake by plants to reduce soil pollution and the eventual impact on plants, ecosystems, landscape, soil microbial biodiversity and human health (Bolan *et al*., 2014).

5.3.3 Copper

The copper content in the Chunga Landfill MSW compost was 156.8 ± 5.52 mg/kg. Studies by Jalalipour *et al*., (2020) in Iran on SSMSW compost from Barmshor landfill of Shiraz reported the copper content of 56.89 mg/kg. Another study in Delhi, India by Papiya *et al*., (2014) on MSW compost found copper concentration of 326 ± 42.3 mg/kg which was twice higher than the one in the Chunga Landfill MSW compost. A study by Lord *et al*., (2021) in Agaard farm, Brandon MB, Canada on MSW compost found a low copper concentration of 1.07 mg/kg. According to a research by Rouf & Rashid, (2020) in Mymensingh Pourashava city of Bangladesh, MSW compost derived from solid waste was reported to have 39.68 mg/kg copper. In other studies by Dessalegn *et al*., (2012) done in the city of Addis Ababa Ethiopia on SSMSW, the copper content in the matured compost was 32.536 ± 0.4295 mg/kg. The low copper analyzed was as a result of using source separated feed stock. In a related study by Becher *et al*., (2018) in Central-eastern Poland, analysis gave a mean concentration of 21.4 ± 12.3 mg/kg copper. The copper in the Chunga Landfill MSW compost was generally higher than other MSW compost. If

the MSW is segregated, the copper content may be reduced. This copper content conforms to the FAO standards of between 100 and 500 mg/kg.

Copper is one of the essential microelement required by plants as it is involved in protein metabolism, respiratory electron transport, antioxidant activity, cell wall metabolism, nitrogen fixation ion metabolism and hormone perception among others in plants (Arunakumara *et al*., 2013). It is naturally present in the soil between 2 and 100 mg/kg. However, in agriculture its continuous and prolonged use as herbicide leads to pollution of the soil. If the copper concentration exceeds the threshold, it can induce toxicity symptoms both to plants as well as soil organisms that can lead to decreased numbers of collembolan and earthworm diversity, reduced microbial biomass and inhibition of metabolic activities (Karimi *et al*., 2021). It can also lead to compromise in the soil respiratory activity (Romero-Freire *et al*., 2016), germination of seed is greatly reduced, growth of roots and shoots become stunted, results in low yields and formation of reactive oxygen species (Romero-Freire *et al*., 2016). Several anthropogenic activities such as use of both inorganic and organic ferilizers, sewage sludge and wastewater for irrigation releases large quantities of copper into the natural environment leading to soil contamination (Muhammad, *et al*., 2015). Copper is one of the heavy metals that contaminate agriculture soil thereby posing immediate and serious threats to human health, food safety and the environment in Europe and world over (Peralta-Videa, *et al*., 2009). Despite being an important element necessary for human development in small amounts, concentration above the limit can have negative impacts on the nervous system, liver, renal function, skin and eyes. Excess uptake of copper together with zinc may cause health complications in the reproductive system, lead to anemia and stomach upset (Oteiza, *et al*., 2004).

5.3.4 Lead

Lead content in the Chunga Landfill MSW compost was 109.58 ± 8.92 mg/kg. Studies by Jalalipour *et al*., (2020) in Barmshor landfill of Shiraz in Iran on SSMSW compost reported low lead content of 27.35 mg/kg. A similar study by Ibicol Sas, (2018) in Columbia's city of Cajicá found very low concentration of lead level at 1.42 mg/kg. Studies in Uganda by Kabasiita *et al*., (2022) on the quality of MSW compost reported a

lead range of 5.8 to 33.5 mg/kg which was in line with the 27.35 mg/kg reported by Jalalipour *et al*., (2020) in Iran. Other studies by Dessalegn *et al*., (2012) in Addis Ababa city, Ethiopia on SSMSW, the lead level in the matured compost was 234.9 ± 10.1 mg/kg which was twice higher than the one in the Chunga Landfill MSW compost. Similar studies by Rouf & Rashid, (2020) in Mymensingh Pourashava City of Bangladesh on MSW compost derived from solid waste found a lead concentration of 48.88 mg/kg. Other Studies done by Carreira & Pacheco (2017) on the chemical quality of MSW compost found low concentration of 0.10722 mg/kg lead. Becher *et al*., (2018) conducted a study on the chemical characteristics of matured MSW utilized as fertilizer in Central-eastern part of Poland. The mean lead concentration was 9.60 ± 3.39 mg/kg.

Lead is amongst the most common contaminants and contributes about 10 percent of the total pollution emanating from heavy metals (Zeng, *et al*., 2007). It is found in aquatic and terrestrial environments due to several anthropogenic activities such as lead batteries and construction. In soil, plants do not absorb or accumulate lead but if the concentration is too high, it can accumulate in the leaves of vegetables like lettuce and on surfaces of roots like carrots (Rosen, 2002). Since plants do not take up much lead from the soil, levels of less than 300 ppm are considered safe for gardening. Any concentration of lead above 300 ppm increases the risk of lead poisoning through the food chain (Rosen, 2002). It is taken up by plants which are the primary producers and affects their metabolic processes, growth rate and photosynthetic activities with concentrations above 42 percent causing a reduction in root growth (Zeng, *et al*., 2007). Lead contaminates food through accumulation from the soil to the roots as observed in many plant species where only a small fraction is transported to aerial plants. Therefore, high levels of lead from the soil are likely to be found in root vegetables like carrots and sweet potatoes and low levels may be found in leafy greens like lettuce with the least levels in plants like tomatoes (Kumar, *et al*., 2017). Lead is a highly toxic heavy metal that can easily compromise the normal functioning of the human body system once inhaled. Lead in the body is poisonous to the central nervous system especially in children where it causes a disease known as encephalopathy (Meng, *et al*., 2016).

5.3.5 Nickel

The content of nickel in the MSW compost at Chunga Landfill compost was 28.75 ± 0.49 mg/kg. A similar study by Ibicol Sas, (2018) in Columbia's City of Cajicá found the nickel level on SSMSW at 6.13 mg/kg. A similar study by Jalalipour *et al*., (2020) in Barmshor landfill of Shiraz by in Iran on SSMSW compost had nickel content of 15.34 mg/kg which was less by about half the one in the Chunga Landfill MSW compost. Another study in Delhi, India by Papiya *et al*., (2014) on MSW compost found nickel at 18.5 ± 7.4 mg/kg. Other studies by Dessalegn *et al*., (2012) in Addis Ababa city, Ethiopia, the nickel level in the matured compost was 31.656 ± 3.0068 mg/kg which was close to the one in the Chunga Landfill MSW compost. A study by Carreira & Pacheco, (2017) done to determine the chemical characteristics and changes that occurred in the mineral nutrients' concentration in the MSW compost reported a mean nickel content of 0.07 ± 0.01 mg/kg. In a related study by Becher *et al*., (2018) in Central-eastern Poland, 4.75 ± 1.98 mg/kg nickel was reported in the matured MSW utilized as organic fertilizer. If the MSW at Chunga Landfill is sorted out at the point of generation or at the disposal site, the levels of nickel may drastically reduce.

Nickel is the twenty second most abundant trace element found in the earth's crust and usually exists in natural soils in trace concentrations (Hussain, *et al*., 2013). It is both an essential microelement as well as a toxic heavy metal for plants and bacteria (Correia *et al*., 2018). It is introduced in the soil through anthropogenic activities like mining, smelting, application of some organic amendments such as sewage sludge or compost based on sewage sludge, fuel combustion, burning of diesel, and fuel oil, ceramic, glass, metal, and chemical industries (Correia *et al*., 2018; Ameen *et al*., 2019). Ameen *et al*., (2019) indicated that exposing plants to high levels of nickel results in a number of phytotoxic symptoms such as chlorosis, necrosis, limited shoot and root growth, and reduced leaf area. The other negative effects of nickel on plants are that various enzyme activities are disturbed, oxidative stress initiation is affected and there is also interruption in the uptake of other minerals (Gupta *et al*., 2017). The phytotoxicity effects of nickel is as a result of the actions that takes place in the biochemical pathway reactions of the photosystems affecting the smooth running of the Calvin cycle, disturbing the electron

transport chains due to accumulation of excess ATPs and NADPH (Yusuf, *et al*., 2011). Despite the negative effects of high concentration of nickel, at low concentrations it is an essential microelement as it promotes seed germination, growth of shoots and roots at the same time improves fruit yield and quality, promotes the synthesis of chlorophyll, protein, and carbohydrates in plant tissues (Ameen *et al*., 2019; Gupta *et al*., 1998). Most plant micronutrients including nickel are difficult to determine the normal requirement and the toxic level because they have a dynamic range and sometimes their concentrations and chemical speciation fluctuates in the soil (Krämer & Clemens, 2007).

5.3.6 Chromium

The chromium analyzed in the MSW compost at Chunga Landfill was 60.7 ± 0.57 mg/kg. Another study in Barmshor Landfill of Shiraz in Iran by Jalalipour *et al*., (2020) conducted on SSMSW compost had chromium content of 8.32 mg/kg far much lower because of using segregated materials to reduce on the levels of chromium found in some non-biodegradable waste that can contaminate the compostable material. A similar study by Ibicol Sas, (2018) in Columbia'sCcity of Cajicá found the chromium level on SSMSW had chromium at 7.5 mg/kg which was similar to the 8.32 mg/kg reported by Jalalipour *et al*., (2020) in Iran. Another study in Delhi, India by Papiya *et al*., (2014) on non SSMSW compost found chromium level of 85.3 ± 58.7 mg/kg which was higher than one in the Chunga Landfill MSW compost. Other studies by Dessalegn *et al*., (2012) in Ethopia, Addis Ababa City the chromium level in the matured compost was 10.095 ± 5.0085 mg/kg again lower than the Chunga Landfill MSW compost because of using SSMSW feed stock. In a similar study by Rouf & Rashid, (2020) in Myymensingh Pourashava City of Bangladesh, the chromium in the MSW compost derived from solid waste was 17.15 mg/kg. A related study by Carreira & Pacheco, (2017) reported mean chromium content of 0.21 ± 0.03 mg/kg. Other studies by Becher *et al*., (2018) in Central-eastern Poland reported a mean chromium concentration of 6.60 ± 2.98 mg/kg.

Chromium is considered as one of the most toxic heavy metals because of the adverse effects it has on the environment (Ali *et al*., 2018). Major sources of chromium are discharges from industries dealing in electroplating, leather tannery and effluent coming

from alloy materials (Govil & and Krishna, 2018). Chromium exists in various oxidative states in the environment with the most dominant in the environment being chromium (III) and chromium (VI). Chromium (III) is among the essential micronutrients as it is required in animals for cell metabolism due to its stability and lower toxicity compared to chromium (VI) (Tepanosyan *et al*., 2020). Chromium (VI) is a highly soluble metal capable of crossing cell membranes and cause damages to organs such as the liver, lungs, and kidneys due to its high charge, irritability, toxicity and allergy (Bashir *et al*., 2020; Tepanosyan *et al*., 2020). Applying MSW compost having high levels of chromium on high value crops will not only have negative effects on plants yield but the whole ecosystem (Mehmood *et al*., 2018b). Chromium in plants retards seed germination, reduces the rate at which plant shoots grow and leads to low production of biomass (Bashir *et al*., 2022). In addition, chromium disrupts the process of photosynthesis, utilization of nutrients, osmotic potential and affects catalytic reactions of enzymes producing a rare species of oxygen that is very reactive with lipids, nucleic acids and proteins eventually making plants die out (De Oliveira *et al*., 2014: Bashir *et al*., 2020).

5.3.7 Conclusion on heavy metal concentration in MSW compost

All the heavy metals analyzed in the Chunga Landfill MSW compost were generally higher compared to other MSW compost reviewed. Amlinger *et al*., (2004) indicated that the concentration of heavy metals in organic household separated MSW waste was lower compared to composted residual organic fraction coming from mechanically sorted MSW. Therefore, concluded that heavy metals in compost that was segregated at source was drastically reduced by a factor of between 2 and 10.

5.4 Biological characteristics

Feacal coliforms and *Escherichia coli (E. coli)*, and *Salmonella* spp. were analyzed on the Chunga Landfill MSW compost. The results are presented in Table 4-2.

5.4.1 Feacal coliforms, *E. coli* and *Salmonella* spp.

The MSW compost at Chunga Landfill had *E. coli* and feacal coliforms above 1,100 MPN/g and *Salmonella* was not detected. The presence of *E. coli* and feacal coliforms

could be as a result of recontamination considering the state in which the MSW compost is managed. Another study in Delhi, India by Papiya *et al*., (2014) on MSW compost found an absence of pathogenic bacteria (*E. coli* and *Salmonella* spp.) in compost produced using MSW which was attributed to the high temperature during composting that destroyed the pathogens. A Similar study by Rouf & Rashid, (2020) in Mymensingh Pourashava City of Bangladesh to assess the quality of compost produced from MSW where the the final component that was degraded was used to check for the presence of *Salmonella* spp. and *E.coli* and both tests where negative. This study was in line with studies in Delhi, India by Papiya *et al*., (2014) on MSW compost who also found an absence of pathogenic bacteria (*E. coli* and *Salmonella* spp.) in the MSW compost.

The positive results for feacal coliforms in the Chunga Landfill MSW compost does not automatically indicate the presence of pathogens but rather a useful indicator of hygiene as reported by Brinton, (2000). This is in line with studies by Strauch (1996) who indicated that pathogens such as *E. coli* and *Salmonella* may be present in organic fertilizer and may contaminate the soil and plant roots (Strauch, 1996).

Salmonella spp. was not detected in the MSW compost at Chunga Landfill. In order to reduce bias and increase the surface area, the sample size for analysis was deliberately increased from one gram to 25 g. Holley (2006) stated that *Salmonella* is able to survive in soil from six to several hundred days which poses a real threat to soil and plant growth. In the case of MSW compost at Chunga Landfill the *salmonella* could have died out as a result of the heat coming from the fire. Several authors have proved that most pathogens die as a result of elevated temperatures of between 55 and 60 ^{o}C for 24 hours and moisture content of about 50 percent (Polprasert, 2007; Hassen *et al*., 2001).

5.4.2 *Ascaris*

The MSW compost at Chunga Landfill is mostly domestic which might include contaminated diapers and animal waste that may contain *Ascaris*. Harhay *et al*., (2010) indicated that human gastrointestinal track contains many pathogenic parasites mostly STH such as Hookworms, *Ascaris lumbricoides* and *Trichuris trichiura*. If the soil gets

contaminated with these pathogens, their eggs can easily be transferred onto vegetables then to the hands of the handler (Koyabashi, 1999) or by consumption of raw vegetables (Mustafa *et al*., 2001). The risk exposure to internal parasites is very high in less developed countries among communities residing in high density areas characterized by poor waste management and ill health as is the case with Lusaka City (Crompton & Saviolo, 1993). This is the reason why *Ascaris* helminthes eggs and their viability was examined so as to determine the safety of the Chunga Landfill MSW compost. Some vegetables and other crops grow on the MSW compost at Chunga Landfill and these are consumed by the surrounding communities. Researchers have isolated some these parasites from agriculture produce and farm facilities (Kagei, 1983). The parasites can also be transmitted through vectors such as flies (Monzon *et al*., 1991). Ten sub samples were examined for the presence of A*scaris* and viable ova. One sample was found to have *Ascaris* ova of 200 and the other two had 100 each per gramme of sample. Further analysis on the viability of the eggs indicated none of the eggs were viable. This confirmed that feacal matter is also part of the MSW at Chunga Landfill.

5.4.3 Conclusion on biological characteristics

Feacal coliforms and *E. coli* where detected in the Chunga Landfill MSW compost most likely because of recontamination as there is no proper care and management of the processed MSW compost. *Salmonella* was negative, most likely because of the burning fires that take place at the facility. *Ascaris* ova was found in the MSW compost confirming the presence of animal waste although none of the eggs were viable.

5.5 Fertilizing capacity of the Chunga Landfill MSW compost

The Chunga Landfill MSW compost with pH 7.94, EC of 6.46 mS/cm is within the specifications for matured compost of 6.0 to 8.0 and 2.2 to 9.3 mS/cm respectively (Gebru, 2011). The high EC of 6.46 mS/cm in the Chunga Landfill MSW compost is not suitable material to be applied as growth media for seedlings and plants because the high salts can accumulate in the root zone and result in wilting (Li *et al*., 2008). It may be applied as soil amendment since the salt concentration will be diluted by the soil (Chan *et al*., 2016). The content of nitrogen, potassium and phosphorous (NPK) at 0.77, 0.53

and 0.88 percent respectively is below the FAO standards of ≥1.0, 1.5 and 1.5 percent respectively. Therefore, the Chunga Landfill MSW may be applied as a soil conditioner and compost on low value crops.

5.6 Appropriate land application of the Chunga Landfill MSW compost with respect to agriculture

The low OM and C:N ratio in the Chunga landfill MSW at 6.76 percent and 5.10 respectively is below the stipulated OM content for matured compost of between 28 and 42 percent and C:N ratio of between 9 and 11. Using the Chunga Landfill MSW as compost with low OM content will not increase; the soil's capacity to hold enough water for a longer period of time, nutrients supplied to the plants, maintenance of the desirable soil structure and provision of carbon to soil microorganism compared to compost with sufficient OM (Pandey & Shukla, 2006). In order to compensate the low OM content and C:N ratio, there should be high rate of application of the Chunga Landfill MSW compost to boost the amount of OM and C:N ratio to required levels. Hence may be used as soil amendment or compost on low value crops. Heavy metals in the Chunga Landfill MSW compost were within the FAO standard of 100 to 500 mg/kg. The presence of fecal coliforms and *E. coli* restricts the application of the Chunga Landfill MSW compost on high value agricultural crops especially those that are consumed raw but may be used on low value crops.

5.7 Chapter Summary

This chapter discussed results obtained in this study and compare and contrasted with results obtained by other researchers who did similar studies. The possibility of utilizing MSW compost at Chunga landfill was also discussed in this Chapter. The objectives and research questions were answered in the discussion. The next chapter will the conclusions and make recommendations on what can be done on the Chunga Landfill MSW compost.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes all the findings based on the specific objectives of the study and make recommendations.

6.1 Conclusion

In the current study chemical and biological characterization was done on the Chunga Landfill MSW compost, compared with other MSW compost and the FAO standards to assess its potential to be used as compost. Chemical characteristics with regard to pH, EC and heavy metals were within the stipulated values for matured compost and FAO standards while OM, biological characteristics and NPK were below. Therefore, the Chunga Landfill MSW may be applied as compost on low value crops and as a soil conditioner.

6.2 Recommendations

(i) The Chunga landfill MSW compost needs to be sanitized first to get rid of *E. coli* and feacal coliforms if it to be applied as compost.

(ii) Monthly monitoring of the chemical and biological characteristics of the Chunga Landfill MSW compost for one calendar year to check for variations in the analytical data.

(iii) The MSW is supposed to be separated at source or at the Chunga Landfill site before disposal to reduce the heavy metal concentrations and increase the OM content.

(iv) Dedicate a portion of the Chunga landfill where only the degradable organic material can be recycled as compost.

(v) The Government should come up with chemical and biological guidelines on the utilization of MSW as compost.

6.3 Chapter Summary

This chapter summarized all the findings based on the specific objectives of the study and made recommendations on what can be done on the Chunga Landfill MSW compost.

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APPENDICES

Appendix I: Ethics approval letter

THE UNIVERSITY OF ZAMBIA
DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road Campus | P.O. Box 32379 | Lusaka10101 | Tel: +260-211-290 258/291 777
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APPROVAL OF STUDY

24th January, 2022

REF NO. NASREC-2021-DEC-003

Dan Mkandawire
The University of Zambia
School of Engineering
Department of Civil and Environmental Engineering
P.O. Box 32379
LUSAKA

Dear Mr. Mkandawire,

RE: "CHEMICAL AND BIOLOGICAL CHARACTERIZATION OF MUNICIPAL SOLID WASTE AT CHUNGA LANDFILL FOR POTENTIAL USE AS COMPOST"

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

Review Type	**Ordinary Review**	**Approval No. NASREC-2021-DEC-003**
Approval and Expiry Date	Approval Date: 20th December, 2021	Expiry Date: 19th December, 2022
Protocol Version and Date	Version - Nil.	19th December, 2022
Information Sheet, Consent Forms and Dates	• English.	To be provided
Consent form ID and Date	Version - Nil	To be provided
Recruitment Materials	Nil	Nil
Other Study Documents	Questionnaire.	

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be

informed.

Conditions of Approval

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.
- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.
- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.
- All protocol deviations must be reported to NASREC within 5 working days.
- All recruitment materials must be approved by NASREC prior to being used.
- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.
- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.
- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled "late submissions" and will incur a penaltyfee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.
- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.
- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO),both NASREC
- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.
- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have any direct or indirect contact with the research participants or animals for the study.
- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.
- A reprint of this letter shall be done at a fee.
- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be

reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,

Dr. E. M. Mwanaumo

CHAIRPERSON
THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH ETHICS COMMITTEE - IRB

cc: Director, Directorate of Research and Graduate Studies
Assistant Director (Research), Directorate of Research and Graduate Studies
Assistant Registrar (Research), Directorate of Research and Graduate Studies

Appendix II: Cell 2 site at Chunga Landfill containing MSW compost

MSW compost Site identification at Chunga Landfill were Cell 2 was chosen for sampling. The site was compost of heterogeneous material (both biodegraded and non-biodegraded components)

Appendix III: MSW compost in Cell 2 at Chunga Landfill

Marked Sampling point of the MSW compost at Chunga Landfill and subsequent sampling of the material. The black humic like material was identified as the core material to be used as compost.

Appendix IV: Sub samples of MSW compost from Cell 2 at Chunga Landfill

A total of seven samples were collected from the site which was a mixture of organic and inorganic materials both biodegraded and non-biodegraded.

Appendix IV: Sieving of MSW compost samples from Cell 2 at Chunga Landfill

Sieving the Chunga Landfill MSW compost through a 2 mm sieve to come up with the fine working sample for laboratory analysis.

Appendix V: Sieved MSW compost from Cell 2 at Chunga Landfill

The final black humic material of the composite MSW sample from Chunga Landfill after passing through a 2 mm sieve ready for laboratory analysis

Appendix VI: UNZA-Dept. of Soil Science lab.: Chemical results of MSW compost

The University of Zambia
Department of Soil Science
Service Laboratory

P.O Box 32379
Lusaka
Tel 295421
E-mail: soil@unza.zm

ATTN: Mr Dan Mkandawile
UNZA, School of Engineering

Soil Analysis Results - November, 2021

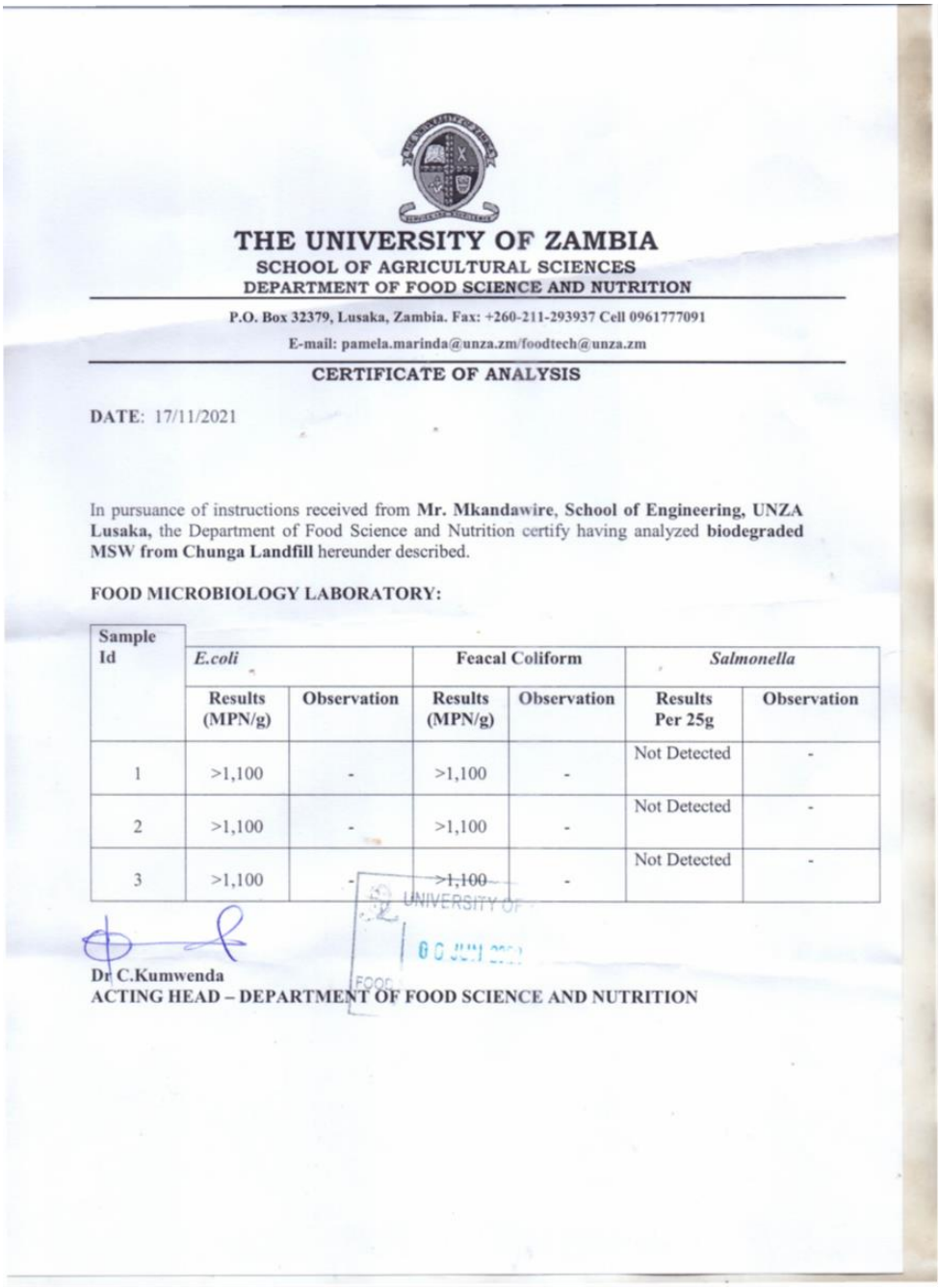
Lab	Sample	Sampling	OM	OC	N	C/N	pH	EC	P	K	Zn	Pb	Cd
			Walkley & Black		Kjeldahl		1:2.5	1:5	Dry ashing				
no.	Id	Date	%			Ratio	H_2O	mS/cm	%		mg/kg	mg/kg	mg/kg
20211408	Run 1	06/11/2021	6.76	3.93	0.77	5.10	7.94	6.46	0.53	0.86	212.0	119.0	5.7
20211409	Run 2	06/11/2021	-	-	-	-	7.95	6.47	0.57	0.87	187.5	101.3	4.5
20211410	Run 3	06/11/2021	-	-	-	-	7.94	6.44	0.50	0.92	224.0	108.5	3.8

UNIVERSITY OF ZAMBIA
08 JUN 2022
DEPARTMENT OF SOIL SCIENCE
P.O. BOX 32379, LUSAKA

G. Musukwa
Chief Technician
22/11/2021

Head,
Dept of Soil Science

Appendix VII: UNZA- Dept. of Food Science: Biological results of MSW compost



THE UNIVERSITY OF ZAMBIA
SCHOOL OF AGRICULTURAL SCIENCES
DEPARTMENT OF FOOD SCIENCE AND NUTRITION

P.O. Box 32379, Lusaka, Zambia. Fax: +260-211-293937 Cell 0961777091
E-mail: pamela.marinda@unza.zm/foodtech@unza.zm

CERTIFICATE OF ANALYSIS

DATE: 17/11/2021

In pursuance of instructions received from **Mr. Mkandawire, School of Engineering, UNZA Lusaka,** the Department of Food Science and Nutrition certify having analyzed **biodegraded MSW from Chunga Landfill** hereunder described.

FOOD MICROBIOLOGY LABORATORY:

Sample Id	*E.coli*		Feacal Coliform		*Salmonella*	
	Results (MPN/g)	Observation	Results (MPN/g)	Observation	Results Per 25g	Observation
1	>1,100	-	>1,100	-	Not Detected	-
2	>1,100	-	>1,100	-	Not Detected	-
3	>1,100	-	>1,100	-	Not Detected	-

Dr C.Kumwenda
ACTING HEAD – DEPARTMENT OF FOOD SCIENCE AND NUTRITION

Appendix VIII: UNZA-Dept. of Civil & Environmental Engineering laboratory: Biological (*Ascaris*) results of MSW compost

SCHOOL OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT
ENVIRONMENTAL ENGINEERING LABORATORY
P.O Box 32379, Lusaka

EXAMINATION OF BIODEGRADED CHUNGA LANDFILL MSW

Attn : Dan Mkandawire
UNZA-School of Engineering
Lusaka
Sampling date : 06.11.2021
Report date : 24.11.2021

Ascaris recovery results in biodegraded MSW from Chunga Landfill

Test No.	Ascaris Ova/g	Viability/non-viable
1	200	Non-viable
2	Nil	N/A
3	Nil	N/A
4	100	Non-viable
5	Nil	N/A
6	Nil	N/A
7	Nil	N/A
8	100	Non-viable
9	Nil	N/A
10	Nil	N/A

Hindiyeh, (1995)

UNIVERSITY OF ZAMBIA
SCHOOL OF ENGINEERING
24 NOV 2021
DEPT. OF CIVIL ENGINEERING
P.O. BOX 32379 LUSAKA

Tested by: C. Makai ..... Checked & Approved by: Joshua Liyungu .....
Lab. Technician Lab. Manager /Co-ordinator

Appendix IX: Mt Makulu lab.: Heavy metals chemical results of MSW compost

All communications should be addressed to the
DIRECTOR
Telephone: CHILANGA (+260 211) 278380/278141/278130
Fax: +260 211 278130
E-mail: zamdirector@gov.zm
www.zam.gov.zm

In reply please quote:

No.:.....

REPUBLIC OF ZAMBIA

MINISTRY OF AGRICULTURE

ZAMBIA AGRICULTURE RESEARCH INSTITUTE
MOUNT MAKULU CENTRAL RESEARCH STATION
PRIVATE BAG 7
CHILANGA

Client Name: Dan MKANDAWIRE

UNIVERSITY OF ZAMBIA

SCHOOL OF ENGINEERING

P.O BOX 32379

LUSAKA

No of sample	Cu Ppm total	Cr Ppm total	Ni Ppm total
1	152.9	61.1	29.1
1	160.7	60.3	28.4

Sampling Date: 06.11.2021

Report Date: 22.11.2021

Report Done by: BESTER BILIMA (AGRICULTURE RESEARCH OFFICER)

Signed by: BILIMA BESTER.....

REPUBLIC OF ZAMBIA
MINISTRY OF AGRICULTURE
NATIONAL SOILS LABORATORY
22 NOV 2021
ZAMBIA AGRICULTURE RESEARCH INSTITUTE
MOUNT MAKULU RESEARCH STATION
PRIVATE BAG 7, CHILANGA

Appendix X: Permit from Lusaka City Council to access the Chunga Landfill

LUSAKA CITY COUNCIL
OFFICE OF THE TOWN CLERK

P.O BOX 30077
CIVIC CENTRE
LUSAKA, ZAMBIA 10101

TELEPHONE: +260 211 252926
TELEFAX : +260 211 252141
E-MAIL : admin@lcc.gov.zm

Ref: 6/9/1/MC/ek

23rd September, 2021

Dr. J. Nyirenda (PHD)
Senior Lecturer and Supervisor
School of Natural Sciences
Department of Chemistry
P.O Box 32379
The University of Zambia

LUSAKA

Dear Sir/Madam,

REF: RESEARCH PROJECT ATTACHMENT- MR. DAN MKANDAWIRE

The above subject matter refers.

I acknowledge receipt of your letter dated 23rd August, 2021 in which you sought to access information on Physical-Chemical and biological data at Chunga Landfill for the study design.

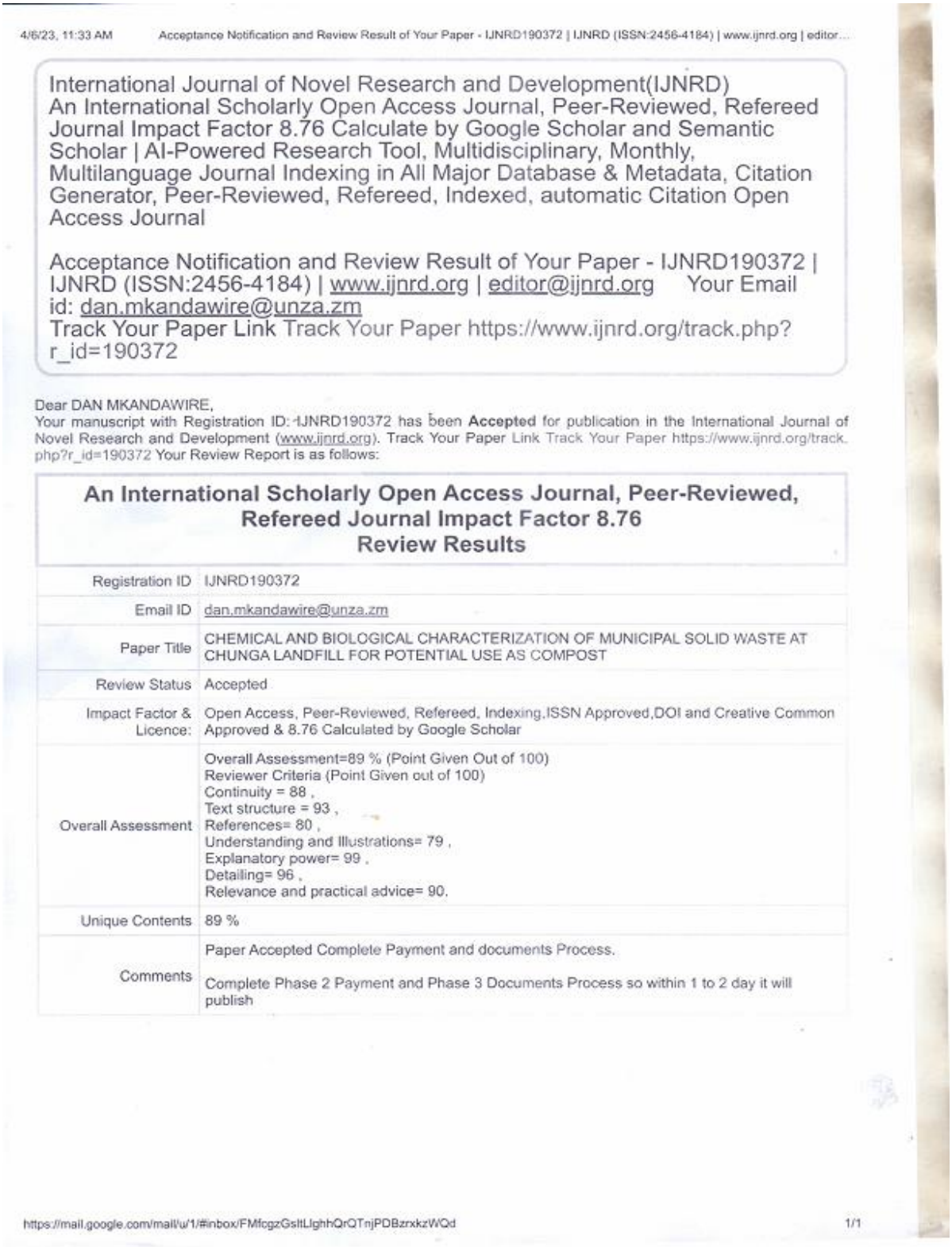
I hereby inform you that I have no objection to allow you to access the Chunga Landfill for the information required.

Yours Faithfully,

Alex Mwansa
TOWN CLERK

TC
FYS
DPH

Appendix XI: Review and acceptance of manuscript for publication



4/6/23, 11:33 AM Acceptance Notification and Review Result of Your Paper - IJNRD190372 | IJNRD (ISSN:2456-4184) | www.ijnrd.org | editor...

International Journal of Novel Research and Development(IJNRD)
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Acceptance Notification and Review Result of Your Paper - IJNRD190372 | IJNRD (ISSN:2456-4184) | www.ijnrd.org | editor@ijnrd.org Your Email id: dan.mkandawire@unza.zm
Track Your Paper Link Track Your Paper https://www.ijnrd.org/track.php?r_id=190372

Dear DAN MKANDAWIRE,
Your manuscript with Registration ID: IJNRD190372 has been **Accepted** for publication in the International Journal of Novel Research and Development (www.ijnrd.org). Track Your Paper Link Track Your Paper https://www.ijnrd.org/track.php?r_id=190372 Your Review Report is as follows:

An International Scholarly Open Access Journal, Peer-Reviewed, Refereed Journal Impact Factor 8.76
Review Results

Registration ID	IJNRD190372
Email ID	dan.mkandawire@unza.zm
Paper Title	CHEMICAL AND BIOLOGICAL CHARACTERIZATION OF MUNICIPAL SOLID WASTE AT CHUNGA LANDFILL FOR POTENTIAL USE AS COMPOST
Review Status	Accepted
Impact Factor & Licence:	Open Access, Peer-Reviewed, Refereed, Indexing,ISSN Approved,DOI and Creative Common Approved & 8.76 Calculated by Google Scholar
Overall Assessment	Overall Assessment=89 % (Point Given Out of 100) Reviewer Criteria (Point Given out of 100) Continuity = 88 , Text structure = 93 , References= 80 , Understanding and Illustrations= 79 , Explanatory power= 99 , Detailing= 96 , Relevance and practical advice= 90.
Unique Contents	89 %
Comments	Paper Accepted Complete Payment and documents Process. Complete Phase 2 Payment and Phase 3 Documents Process so within 1 to 2 day it will publish

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