# HEAVY METALS AND PATHOGEN CONTENT ON SOIL, WATER, AND PRODUCE IN URBAN AGRICULTURE OF NAIROBI CITY

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# Heavy Metals and Pathogen Content on Soil, Water and Produce in Urban Agriculture of Nairobi City

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# DECLARATION

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

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# DEDICATION

This thesis is dedicated to Nairobi urban peasant farmers who daily eke out a living against all odds. Your consistent fight against food insecurity, poverty, and unemployment is commendable. The dedication also goes to my four children: Job Gicheru, Liz Wanjeri, Gloria Nyai, and Rock Mwamba. Your academic struggle shall never be in vain if you persist.

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## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF APPENDICES

## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **ANOVA** | Analysis of variance |
| **ASK** | Agricultural Society of Kenya |
| **CBD** | Central Business District |
| **FAO** | Food and Agriculture Organization |
| **GDP** | Gross Domestic Product |
| **GPS** | Geographical Positioning System |
| **JKIA** | Jomo Kenyatta International Airport |
| **JKUAT** | Jomo Kenyatta University of Agriculture and Technology |
| **KNBS** | Kenya National Bureau of Statistics |
| **MoALF** | Ministry of Agriculture, Livestock and Fisheries |
| **NCC** | Nairobi City County |
| **NEMA** | National Environmental Management Authority |
| **NGO** | Non-Governmental Organisation |
| **RUFORUM** | Regional Universities Forum for Capacity Building in Agriculture |
| **SPSS** | Statistical package for social studies |
| **SSA** | Sub-Saharan Africa |
| **SPSS** | Statistical Package for the Social Sciences |
| **TF** | Transfer Factor |
| **UA** | Urban Agriculture |
| **UNDP** | United Nations Development Programme |
| **UN-HABITAT** | United Nations Human Settlements Programme |
| **UPUA** | Urban and Peri-Urban Agriculture |
| **WHO** | World Health Organisation |

## ABSTRACT

Urban and peri-urban agriculture in Nairobi City County (NCC) is growing as a means of income generation, employment, nutrition and food security. However, environmental health risks outweigh urban agriculture practices in the city, as evident from widespread pollutant sources such as garbage dump site heaps, burst raw sewage pipes, contaminated wetlands, industrial effluent, and motor vehicle exhaust. Consumers are increasingly aware of the importance of buying safe food, and therefore urban agriculture practitioners must be informed on the safety status of their produce in order to adjust to good agricultural practices and take full advantage of the easily accessible consumer food market. The objectives of this research were to assess heavy metal incidence in inputs and food crops for urban farms in eastern zone of Nairobi, determine microbial incidences in food crop produce from farms, determine differences in element uptake by the crops, and to examine influence of environmental quality of the surrounding spaces on crop produce safety. A purposive sampling of farmers who grew any of the three target crops namely arrowroot (*Colocasia esculenta* L.), kale *(Brassica olerasii var.Acephala* L.) and tomatoes *(Lycopersicon esculentum* Mill.) was conducted of which ninety five farmers were identified. To focus on the critical regions of the city and with the guidance of Sub-County Agricultural Officers, three sub-counties of Starehe, Kamukunji and Kasarani, in the Eastern part of Nairobi City County were selected. Farm plots that met the criteria for the three target crops were identified (Starehe 4, Kamukunji 7 and Kasarani 4). From each of the 15 farm plots, samples of tomatoes, arrowroots, kales, water and soil were obtained with three replications per farm, following standard procedures for sample collection. Farmer's immediate environment (neighbourhoods) were classified according to three pollution levels low, moderate, and high that were classified based on source and type of inputs and the condition of the environment surrounding the farm plot. Contents of cadmium, manganese, zinc and lead were analysed using Atomic Absorption/Flame Emission Spectrophotometer. Microbial analysis on irrigation water and the three produce was done to test for presence of salmonella, shigella and *Escherichia coli* bacteria. One way ANOVA was applied (i) to examine differences in means of heavy metals between locations and to compare transfer factor (TF) index of the crops and (ii) to examine differences on occurrence of the pathogenic microbes. Elements that were above allowable limits in the crops were Cd, Mn, Pb and Zn in arrowroots; Cd and Mn in kales and Cd, Mn and Pb in tomatoes. Cadmium content was highest in farm plots within Kasarani ($2.44\pm0.86$ mk/kg) and was significantly different from other two locations ($p<0.05$, Tukey HSD test). Between the neighbourhood qualities, heavy metal contents were different but not significant ($p>0.05$) between classes. The mean TF index for the heavy metals decreased in the order Cd>Pb>Zn>Mn. A transfer factor index of > 1 for cadmium was recorded in arrowroots, kales, and tomatoes. Overall, the highest mean of *E.coli* bacteria count was recorded in arrowroots at the Kamukunji sub-county ($P=0.002$). Between neighbourhoods, *E.coli* was significantly higher in irrigation water and arrowroots in the low-quality neighbourhoods ($p<0.05$). Kamukunji had the highest occurrence of Salmonella in irrigation water and arrowroots at 40%. There was no significant difference between neighbourhood classes in the prevalence pattern of Salmonella. The sub-county also had the highest prevalence of Shigella in irrigation water, at 20%. The overall mean rate of occurrence of Shigella was highest in irrigation water and in kales, at a rate of 17% in both cases. Compared to the other sub-counties, Kasarani had a much higher prevalence of Shigella in tomatoes with a significant difference in distribution pattern (p=0.001). Based on FAO/WHO standards, the measured heavy metal contents were high enough to cause health risk concerns. Produce from areas designated as of low environmental quality was not necessarily contaminated, as perceived. Urban agriculture producers in Nairobi need technical risk reduction technologies and legislative support to guarantee quality produce and valuable participation in the urban food system framework. It is recommended that future studies diversify crop types and localities and enhance collaboration between stakeholders.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background Information

### 1.1.1 Features of Urban Agriculture

The United Nations, Food and Agriculture Organization (FAO *et al.,* 2022) defines urban agriculture as a farming endeavour producing, processing and marketing food and fuel, largely in response to the daily demand of consumers within a town, city or metropolis, on land and water dispersed throughout the urban and peri-urban areas applying intensive production methods, (re)using natural resources and urban waste to yield a diversity of crops and livestock. Urban Agriculture (UA) is practised for income earning, food security, recreation (hobby), and relaxation. Akaeze & Nandwani (2020) and Brock & Foeken (2006) define urban agriculture as any activity within the administrative boundary of an urban centre. Mougeot (2000) and Mensah (2023) defined urban agriculture as an industry located within (intra- urban) or on the fringe (peri–urban) of a town, a city or a metropolis, which grows and raises, processes and distributes a diversity of food and non-food products re-using largely human and material resources, products and services found in and around that urban area, and in turn supplying human and material resources, products and services largely to that urban area.

### 1.1.2 Importance of Urban Agriculture Today

The role of enhancing access to and distribution of food in order to fill the hunger gap is best fulfilled by UA. Urban agriculture allows democratic institutions, like departments of agriculture in a city, to fulfil their mission of allowing access to food for all. Production of animals and crops within the boundaries of an urban area has a bearing on poverty alleviation, food security, and waste management. Poor urban waste management is one of the causes of unsafe food production through heavy metal and pathogen contamination (Lee-Smith, 2010; Moschitz & Kueffer, 2016). Nutrient recycling is enabled by small crop-livestock urban farms, which are ‘the backbone of urban agriculture systems. Most urban farmers produce vegetables that have a shorter production cycle. Some like kales can be harvested within sixty days of planting and hence are well-suited for urban farming (Dobele & Zvirbule, 2020). Urban vegetable growers spend less on transport, packaging, and storage. Urban-produced foods can be sold directly through street food stands and market stalls, hence, more income to farmers instead of middlemen. Growers often operate without permits, since it is officially “invisible” (Mdee & Harrison, 2019). In many cities, the sector receives no public assistance or oversight.

Urban and peri-urban agriculture (UPA) moves outwards (towards the periphery) with the growth of a city. This suggests that urban agriculture is a form of “shifting cultivation” (Prain *et al.,* 2010). In Nairobi city county, there is an urban agriculture gradient in that there are more farmers in the informal settlement sectors (which are found in the city’s periphery) than in the City Centre (Tomno *et al.,* 2020). Urban farmers who irrigate with greywater can produce and sell vegetables during the dry season (Prain *et al.,* 2010). Few employment alternatives are as lucrative, and incomes up to 50% above the minimum wage have been reported (Mathew *et al.,* 2023). Urban agriculture enables urban environmental (ecological) sustainability through the recycling of wastewater and the processing of organic waste. This reduces waste and pollution, which is important because most cities are planned without environmental sustainability in mind (Smit & Nasr, 1992; Yalew *et al.,* 2020). Modern time urban agriculture arable land, is decreasing due to soil and environmental degradation, surges in industrial development and need to accommodate increasing urban population (Mustafa *et al.,* 1999; Thomas *et al.,* 2021b) To deal with space issue, farming is done in community garden, backyards or on flat roof tops (Lardinois *et al.,* 1994) and in cities like Cairo, the Egyptian capital, farmers produce on roof tops a practice that was officially adapted by F.A.O. in 2001. In Egypt, compost was found to be severely contaminated with heavy metals because of poor sorting of inorganic waste from urban garbage (Abdel-Shafy & Mansour, 2018). A report from Kampala city notes that Ugandan urban farmers are professionals who grow food after working in other economic sectors, such as computer geeks, lawyers, teachers, and shoemakers

(Kirungi *et al.*, 2023). Urban farming helps to fulfil the requirement of the Right to Food, which is a minimum obligation of both the county and central governments, significantly helping to achieve food security among urban dwellers (Lee-Smith *et al.*, 2019).

### 1.1.3 Key issues in Urban Agriculture

Kenyan urban and peri-urban agriculture is growing as a means of generating income, improving nutrition, and enhancing food security. These three are hampered by urban environmental health risks. These are evident in garbage dump sites, burst raw sewage pipes, contaminated wetlands, industrial effluent, and motor vehicle exhaust. One way of managing risks is through waste disposal through composting. Urban agriculture is mostly a livelihood strategy among the poor. They usually have low-quality irrigation water, farm inputs of unknown sources, narrow crop choice, fear of vandalism, less farming space, and urban waste as a resource. Some world cities like London, New York, and Beijing have an urban agriculture policy. Nairobi, the Kenyan capital city, enacted an urban agriculture policy only recently. County council bylaws are a challenge that hampers urban food production. Urban consumers are increasingly aware of the importance of buying and growing safe food. Foods that are produced from contaminated soil and water could contain heavy metals and pathogens. This affects human health. Other urban agriculture issues affecting human health include air, soil, and water pollution. The most striking feature of urban agriculture that distinguishes it from rural agriculture is its integration into urban economic and ecological systems. Urban agriculture is embedded in and interacts with the urban ecosystem, influenced by urban policies and plans; it also has both positive and negative effects on urban ecologies (Chiara & Hoekstra, 2017). Urban food production is not only a direct food source but also a means of saving on expenditure and freeing up income for other purposes. Furthermore, commercializing urban farms also offers an opportunity for the modernization of agriculture due to their proximity to more consumers and information (Chari & Ngcamu, 2022). The two largest (and poorest) categories of urban farmers, those farming for food security or survival, and the commercial ones, need policies to provide them with a" safety net". This could be organized access to farms designated for urban agriculture and provision of agricultural extension to help them produce safe and nutritious food (David *et al.,* 2010).

## 1.2 Statement of the Problem

Most urban agriculture is practiced as a livelihood strategy mostly by the urban poor. This socio-economic assumption needs to be carefully examined because urban farmers cut across broad socio-economic, ethnic, educational and occupational statuses. Urban farmers may include professionals, administrators, government officials, urban planners, married women, single mothers as heads of households, students, casual labourers, the unemployed, part-time and full-time workers. Among the Kenyan urban poor, water and land are scarce resources. Water scarcity and poverty in urban areas contribute to the use of polluted water, like raw sewage and grey water, for irrigation purposes. High fertiliser cost, unavailability and lack of efficient composting technologies lead farmers to use poor quality growing media, which causes water and soil pollution, the key inputs for crop production. Further, land scarcity makes urban farmers use contaminated spaces like dump sites and grey water wetlands for farming. Previous research in UA has assessed different aspects of UA, such as crop food safety, but did not consider the surrounding farming environment, and the focus has usually been on one crop type. There is a need to relate what was in a farmer's produce to inputs, especially soil and irrigation water, as well as to the nature of the surrounding environment. Food security does not only entail enough food but also safe and nutritious food (Odey *et al.,* 2022). The study could help improve food quality (safety) and quantity (amount).

## 1.3 Justification

Urban agriculture in Kenya is prevalent in major cities (Nairobi, Mombasa, and Kisumu) and major towns like Nakuru, Nyeri, Eldoret, Thika, and Garissa. Kenya's capital city has both commercial and subsistence farmers. Among the Kenyan urban poor, water and land are scarce resources. An example is seen in Nairobi, where farmers use waste water (like sewage) for the irrigation of kales (Karanja *et al.,* 2011). Fertiliser cost, unavailability, and lack of efficient composting technologies lead the farmer to use poor-quality growing media, which causes water and soil pollution. Land scarcity makes farmers use contaminated spaces like dump sites and wetlands.

Information from this research would guide the city policy makers on how they should manage urban agriculture. Information (data) on heavy metals and pathogen content in urban and peri-urban agriculture would help stakeholders make decisions on safe food production practices. Farmers will be able to know the crop that is able to accumulate more contaminants and avoid or develop better cultivation practices. Consumers' (buyers') perception will raise demand for produce, thus resulting in food, nutritional and income security to urban agricultural practitioners. The public health department will be able to mitigate the diseases and disorders that might arise from contaminated produce and the environment. Nairobi City County Authority will accept urban agriculture as a safe livelihood strategy for its residents and therefore include it in planning. The county government, private sector players and other food regulation authorities will work together to ensure that policies and legal frameworks that support food safety practices, such as testing, surveillance and enforcement of food safety standards in urban agriculture, are put in place. Consumers will have the duty to query how and under what conditions the food they buy was produced. The concerned crop producers will be able to perform agricultural practices that mitigate the contamination of produce.

## 1.4 Objectives

### 1.4.1 Overall Objective

To determine farming characteristics and safety levels of crop produce and input media for the purpose of improving food safety in urban agricultural production systems.

### 1.4.2 Specific Objectives

1. To determine the levels of heavy metals in kales, tomatoes, arrowroots, irrigation water and soils in farming systems of Nairobi city county.
2. To establish the levels and presence of pathogens in kales, tomatoes, arrowroots and irrigation water in Nairobi City County farms.

### 1.4.3 Research Questions

i. Which are the key factors that influence the urban agriculture characteristics of Nairobi city?
ii. (ii) Do heavy metal content in produce, water and soil of Nairobi City County differ according to neighbourhoods' environmental quality (pollution levels)?
iii. Are the levels and presence of pathogens in produce and irrigation water related to neighbourhood environmental quality?

## 1.5 Scope

The study geographical area was the Nairobi City County and focused more on the eastern part of the county, classed as low-income settlement areas within the Nairobi City County. The research targeted active urban farmers who grew the three crops: kale, tomatoes, and arrowroot. Data collection was limited to farms where landowners gave consent to be involved in the investigation and were recommended by the agricultural extension officers. The depth of *Salmonella* and *shigella* species analysis only involved their presence or absence while *Escherichia coli* involved their levels in terms of colony forming units per kilogram (for crops) or per millilitres (for irrigation water).

## 1.6 Limitations

Unexpected weather changes were the main limitation and initially the research was carried out under an extended rainy period. However, confirmatory sampling and analysis were done during the dry season. There were instances of uncooperative respondents, especially when they suspected the researcher to have coming from the Nairobi city county inspectorate. The level of suspicion was higher among residents who conducted illegal activities like sewage diversion to their farms, illegal brew (like chang'aa) sales. The researcher had to endure heavy pollution from garbage and human faecal matter in informal settlements (like City carton, Kiamaiko and SoS village slums) where pit latrines are not allowed by the county authority, making residents defecate in the open, on cropped farms. Moreover, research cost considerations only allowed for the analysis of a few farmers' samples for both heavy metals and pathogen contents.

## CHAPTER TWO

## REVIEW OF LITERATURE

### 2.1 Quality of Urban Agricultural Produce

Urban dwellers are unable, in most cases, to access clean food (Akaeze & Nandwani, 2020). Within urban agricultural systems, pollution risk factors are high and a major cause of concern. The presence of heavy metals has been reported in many urban agricultural systems, both locally and internationally (Karanja *et al.*, 2011; Ndunda & Mungatana, 2013; Martellozzo *et al.*, 2014). The key sources of heavy metals in the soil environment and agriculture are both of natural and anthropogenic origin, such as through atmospheric deposition, livestock manure, irrigation with wastewater, agricultural chemicals, fertilisers, and sewage sludge (Chary *et al.*, 2008; Cai *et al.*, 2009; Luo *et al.*, 2009; Mansour *et al.*, 2009; Lv *et al.*, 2015; Elgallal *et al.*, 2016; Woldetsadik *et al.*, 2017; El-Kady & Abdel-Wahhab, 2018). Urban agriculture would require roughly a third of the total global urban area to meet the global vegetable consumption of urban dwellers. This estimate does not consider how much urban area may actually be available and suitable (Yin & Hu, 2024). Farmers' continued use of polluted water for irrigation means that food quality requirements are not fully met (Ndunda & Mungatana, 2013; Murimi *et al.*, 2019). Heavy metals are absorbed together with mineral nutrients during the active transport of a plant (Grennan, 2009; Zainal & Hamzah, 2018). Taken up by plants, heavy metals may enter the food chain in significant amounts (Jin *et al.*, 2010; El-Kady & Abdel-Wahhab, 2018). In soils and vegetables irrigated with sewage water in Greater Hyderabad, India, the following ranges of heavy metal concentration were zinc (0.386±0.003-17.740±0.060), manganese (0.096±0.006-9.450±0.070), cadmium (0.012±0.002-1.750±0.050) and lead (0.067±0.006-3.530±0.040) mg/kg (Feng *et al.*, 2010; Gopi et al., 2015). Heavy metal concentration in plants is strongly influenced by the source (soil or air), plant species and organs (roots, leaves, seeds and fruits ) and the type of heavy metal (Lee-Smith *et al.*, 2019; Smith, 2009). People’s exposure to heavy metals will depend upon the choice of the crop, the part of the crop that is edible (consumed), the nature of the pollution, their age (children are more affected), their Target Hazard Quotient (THQ) and the preparation method. Unlike pathogens, heavy metals are not removed by cooking and pose a special problem through environmental persistence (Nabulo *et al.*, 2006; Szwalec *et al.,* 2020). Comparative assessment of heavy metal concentrations in treated wastewater cultivated for different crops found that the highest levels of cadmium were found in soils under maize and declined linearly from maize to spinach (a leafy vegetable like kale) to tomatoes and control site. The pattern for the other heavy metals, zinc and lead, was generally in the reverse order (Dikinya & Areola, 2010; Mohamed *et al.,* 2018). The use of secondary treated wastewater, rather than raw effluent water, appeared to have few physical, chemical and biological adverse effects on vegetables and fruits (Emongor & Ramolemana, 2004; Liu *et al.,* 2021, 2005) observed that cadmium was a heavy metal that was of immense concern to the environment due to its toxicity to animals and plants.

## 2.2 Dominance of Heavy Metal Pollution

Industrialised societies have various heavy metal environmental contaminants (Lasat, 1999; Lubal, 2024). Soil pollution by heavy metals is different from pollution of air and water in that heavy metals persist much longer than in other biosphere compartments (since they do not degrade fast). Over recent decades, the annual worldwide release of heavy metals reached 22,000 metric tons of cadmium, 939,000 tons of copper, 783,000 tons of lead and 1,350,000 tons of zinc (Singh *et al.,* 2003). Sources of heavy metal contaminants in soils include manufacturing activities such as metaliferous mining and smelting, metallurgical industries and electronic industries (Singh *et al.,* 2003; Timothy & Tagui Williams, 2019), energy and fuel production such as through emissions from power stations, mining, smelting and refining such as tailings and transportation, automobiles like combustion of petroleum leaded fuels, incineration of wastes and waste disposal, recycling operations like smelting of scrap (Chen *et al.,* 2023). Processing activities include sewage sludge treatment, waste disposal sites, agricultural fertilisers (phosphorus), pesticides and irrigation water, warfare and military training (bullets contain lead), natural sources such as soil parent materials, volcanic eruptions, marine aerosols, and forest fires. Heavy metal contamination issues are becoming increasingly common. The occurrence of heavy metals in agricultural soils, both polluted and natural, has been the subject of many studies (Dudka *et al.,* 1996; Caussy *et al.,* 2003; Cui et al., 2004; Leventeli *et al.*, 2019). Commonly encountered heavy metals include Arsenic, Selenium, Lead, Mercury, Cadmium, Iron, Manganese and Aluminium. Others are Cobalt, Copper, Molybdenum, Silver and Tin.

### 2.3 Human Heavy Metal Toxicity Side Effects

Humans may be at risk when they consume crops grown in or near contaminated areas. The health risk will depend on the chemical composition of waste material, its physical characteristics, cultivated crops, and consumption rate (Cobb *et al.,* 2000; Sarhat & Al-Obaidi, 2023a). Heavy metals are absorbed together with mineral nutrients during the active transport of a plant (Grennan, 2009). Taken up by plants, heavy metals may enter the food chain in significant amounts (Jin *et al.,* 2010; Sarhat & Al-Obaidi, 2023a). Food safety issues and potential health risks make heavy metal accumulation in edible plant parts the most serious environmental concern. Toxic effects of heavy metals like zinc, manganese, cadmium, and lead, among others, on humans, other animals, and organisms are well documented (Rapheal & Adebayo, 2011; Shi *et al.*, 2020). Although zinc and manganese are classified as essential trace elements for humans, they can act as biological poisons even at low parts-per-billion (ppb) levels. An example of a hazard to humans is Cadmium, which damages the kidneys and bones (Ma *et al.*, 2021). Heavy metal concentration in plants is strongly influenced by the source (soil, water or air), plant species and organs (roots, leaves, seeds and fruits) and the type of heavy metal (Smith, 2009; Lee-Smith *et al.*, 2019). People's exposure to heavy metals will depend upon the choice of the crop, the part of the crop that is edible (consumed), the nature of the pollution and the preparation method. Unlike pathogens, heavy metals are not removed by cooking and therefore pose a special problem through persistence in the environment (Nabulo *et al., 2006).* Nairobi urban kale contained 5000 milligrams lead per kilogram, well above the United Nations Environment Programme-recommended 300 milligrams lead per kilogram (Chen *et al.,* 2021). Heavy Metal intoxications, particularly neurotoxicity, genotoxicity, or carcinogenicity, are widely known (Martinez-Zamudio & Ha, 2011; Sarhat & Al-Obaidi, 2023b). The unifying factor in determining toxicity and carcinogenicity for all metals is the generation of reactive oxygen and nitrogen species.

Toxic manifestations are caused primarily due to an imbalance between pro-oxidant (e.g. free radicals) and antioxidant homeostasis, which is termed oxidative stress. Metals have a high affinity for thiol groups containing enzymes and proteins, which are responsible for the normal cellular defence mechanism.

Cadmium adversely affects several important enzymes. The heavy metal can cause painful osteomalacia (bone disease), destruction of red blood cells and renal damage (Rapheal & Adebayo, 2011). Lead is a non-essential element with no known biological requirement in the human body. The uptake is via binding to biomolecular substances (such as proteins and enzymes), which are crucial to various physiological functions. Lead toxins affect the reproductive, central nervous, hematopoietic, and immune systems (Sharp *et al.,* 1987; Ding, 2024). Ingesting pollutants may result in human diseases, disorders, and organ malfunction and malformation due to heavy metal toxicity (Raheem *et al.,* 2014). Organic pollutants can be changed into harmless forms, but heavy metals cannot. (Vasilachi *et al.,* 2023) reported that heavy metals such as lead, cadmium, zinc, and manganese enter the animal and human food chain. The toxic effects of heavy metals are amplified along the food chain at each stage of the food web (Vasilachi *et al.,* 2023). Signs and symptoms of heavy metal contamination in humans do not appear early (Ma *et al.,* 2021; Yongo *et al.,* 2023). Vegetables are highly recommended human foods, and large amounts are consumed as part of a daily diet. Accumulation of heavy metals in the edible parts of vegetables represents a direct pathway for their incorporation into the human food chain.

### 2.4 Crop Heavy Metal Uptake Determinant Factors

Plants grown in soils with elevated metal concentrations exhibit increased heavy metal ion content, and heavy metal uptake is influenced by metal species and plant parts. (Rapheal & Adebayo, 2011; Huang *et al.,* 2024), in a study conducted in Nigeria, observed that while restricting the data to the edible parts of the vegetables and fruits generally, crops harvested in soils presented higher levels of metals when compared to those levels from irrigation water which was interpreted to mean to mean that if the levels of these metals in soils is significantly increased, the test vegetables have the potential of showing increased uptake of metals. Metal uptake by plants can be affected by general factors, including soil pH, organic carbon content, metal bioavailability (lead is lowly bioavailable), cation exchange capacity, organic matter content (especially cadmium), types of plant, age and varieties of plants, soil texture and loss on ignition. However, it is generally accepted that the metal concentration in soil is the dominant factor. Plants accumulate heavy metals depending on their species, growth stage, soil types and conditions, metals, weather and environment (Khairiah *et al.*, 2004; Vasilachi *et al.*, 2023).

### 2.5 Pathogenic Contamination in Urban Agricultural Produce

Cattle are the primary reservoir of the foodborne pathogen *Escherichia coli* O157:H7 (Munns *et al.,* 2016; Abdullahi *et al.*, 2021). Environmental factors, including contaminated water used to irrigate or wash produce, are the source of diarrhoea-causing microorganisms. Plant debris can serve as a source of inoculum, transferring contamination from one plant to another, even when previously contaminated crops were grown. Salmonella can survive up to 6 weeks in fallow soils with the ability to contaminate subsequent crops via crop debris. Brassicaceae family members, such as kales, were noted to have a higher incidence of pathogen outbreaks than carrots, lettuce, and tomatoes (Barak & Liang, 2008a). Sanitising washes cannot kill the pathogen, as it can be intracellularly localised within crop tissues (Jay *et al.*, 2007). Internalisation and localisation of enteric pathogens at subsurface sites on leafy green plant tissue impede removal during washing (e.g., Erwinia) and, mechanistically, through the root system (during active transport). Harvesting can result in cut edges, and Escherichia coli preferentially attaches to them due to its latex (Barak & Liang, 2008b; Mootian *et al.,* 2009; Karanja *et al.,* 2011). Kales from Nairobi are produced using 56% stream water and 36% sewage water, often leading to market rejection due to consumer perception of wastewater use. Poorly composted garbage may contaminate vegetables (Abukutsa-Onyango, 2007; Casanovas-Massana *et al.*, 2021). This occurs because the pathogens in the compost are not fully destroyed due to insufficient heat for decomposition. Scientists believe that antimicrobial resistance will occur from consuming bacteria-contaminated crops and water. This could result in drug-resistant bacteria, which might result in a pandemic. Science is never wrong since the health and welfare of all humans depend on their environment.

## 2.6 Status and Importance of Urban Agriculture

The world faces an ever-increasing challenge of urbanisation and absolute and relative growth in urban poverty, which intensifies food insecurity. Many urbanites have turned to farming as a livelihood strategy and source of income, which, in most countries, supplements rural agriculture and increases the efficiency of national food systems (FAO *et al.*, 2022). Park & Shin (2023) noted that urban farmers produce substantial amounts of food for urban consumers. The costs of supplying and distributing food from rural areas or importing for the cities were continuously rising; hence, food security would increase (Dobele & Zvirbule, 2020). In the late eighties and mid-nineties, it was estimated that 800 million urban poor dwellers were actively engaged in urban agriculture in one way or another (von Grebmer *et al.*, 2008; Prain *et al.*, 2010). In 1998, it was estimated that by 2020, 35 to 40 million people in six East African countries (including Kenya) and Southern Africa would depend on urban agriculture for their food. The World Food Summit Declaration of 2009 observed that more than one billion people were suffering from hunger and poverty. In contrast, the year before, 800 million people were estimated to be food insecure, mostly in poor countries such as sub-Saharan Africa. The last ten years have shown a rapid growth in interest and activity in city farming (Lee-Smith, 2010; Prain *et al.*, 2010). Rapidly urbanising countries are least prepared to meet their food needs and mostly depend precariously on food aid and imports (Dobele & Zvirbule, 2020; Mougeot, 2000). There is now general recognition of the importance of urban agriculture in most countries, particularly in Africa. Food security at the individual, national, regional, and global levels is achieved when all people at all times have economic access to sufficient, safe, and nutritious food (FAO, 2006; Santeramo, 2024). The use of grey (waste) water for irrigation has been recorded in Germany and the United Kingdom in the sixteenth and eighteenth centuries, respectively. In contrast, irrigation with the same type of water has a long history in China and India (Akaeze & Nandwani, 2020). The United Nations-Habitat asserted that global urban agriculture plays a critical role in sustaining environmental integrity and contributes to food self-reliance, thereby improving the livelihoods of the urban poor. However, urban agriculture receives the lowest priority in many countries, particularly in development planning

(Mougeot, 2000; UN-Habitat, 2020). 77% of Nairobi city county urban farmers produce mostly for household consumption (Ayaga *et al.*, 2004). Studies have shown that 64% of Kenyan city dwellers, such as in Nairobi, Nakuru, and Kisumu, practice a form of urban agriculture (Brock & Foeken, 2006; Jonkman *et al.*, 2023)

## 2.7 Challenges in Urban Agriculture

No categorisation of urban agriculture exists in the land-use zoning of Nairobi City County, and policy does not recognize it as a land use. Health risks associated with urban agriculture are cited in the restriction and prohibition of the land use system (Ayaga *et al.*, 2004; Sarker *et al.*, 2019). The existence of practical regulations to guide and support urban food production and their implementation is unknown and unclear (Ayaga *et al.*, 2005; Moschitz & Kueffer, 2016). Urban produce from roadsides and riverbank sites is highly prone to pollution from contaminants commonly found on these sites and may pose health risks to consumers (Smith, 2009; Lee-Smith *et al.*, 2019). Farmers face the challenge of contamination from pathogens (such as enteric bacteria) and toxic chemicals (such as heavy metals) in the waste materials used in urban agricultural systems. Despite the problems facing urban agriculture, NGOs and financial institutions are supporting urban farmers and pouring money into new technologies associated with controlled environment agriculture (CEA), such as vertical farming, and promoting the practice. Despite programmes by NGOs such as Cities Farming for the Future (CFF) and the International Development Research Council (IDRC)'s AGROPOLIS, there is still no comprehensive, in-depth information available on who is conducting urban agriculture and how. The urban poor mostly lack sustainable livelihood approach tools, which comprise tangible (like land) and intangible (like skills and social networks). Subsistence is an economic imperative of urban farmers. Satisfaction with basic needs rather than profiteering is the primary motivation factor for urban agriculture (Mireri, 2002). Integration of urban agriculture into the urban land use systems and the creation of a favourable policy have not been done by county authorities. The two are critical steps in the development of urban agriculture.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Site Description

The study was carried out in Nairobi City County, Kenya. Geographically, Nairobi is within the central highlands of Kenya, bounded by co-ordinates S1026’48.11’’ and E3706’24.56’’ lower right and S109’ 29.59 and E36039’49.88” upper left, with an area of about 696 square kilometres. The annual temperature ranges from 10 °C to 24 °C, and the mean elevation is 1730 meters, that is, 1660-1800 meters above sea level. Nairobi is the capital of Kenya and has a population of over 3.5 million (KNBS, 2019). It is estimated that the urban farming population is 700,000, of which about 300,000 are active farmers (Memon & Lee-Smith, 1993; Lee-Smith, 2010). The study area was selected to represent the socio-economic zones of Nairobi that benefit from urban agriculture, mainly the Eastern zones. These zones are characterised by highly populated informal settlements with relatively poor infrastructure and low-income-earning communities, and a landscape dotted with many waste-dumping sites. In this social setting, urban agriculture contributes significantly to overall household income and food security compared to other zones of Nairobi, and hence, the issue of food safety is critical. They include the administrative sub-counties of Starehe, Makadara, Kamkunji, Embakasi, Kasarani, Njiru, Westlands, Dagoretti, and Langata. The easter zone selected for the study were Starehe, Kamukunji (urban) and Kasarani (peri-urban)

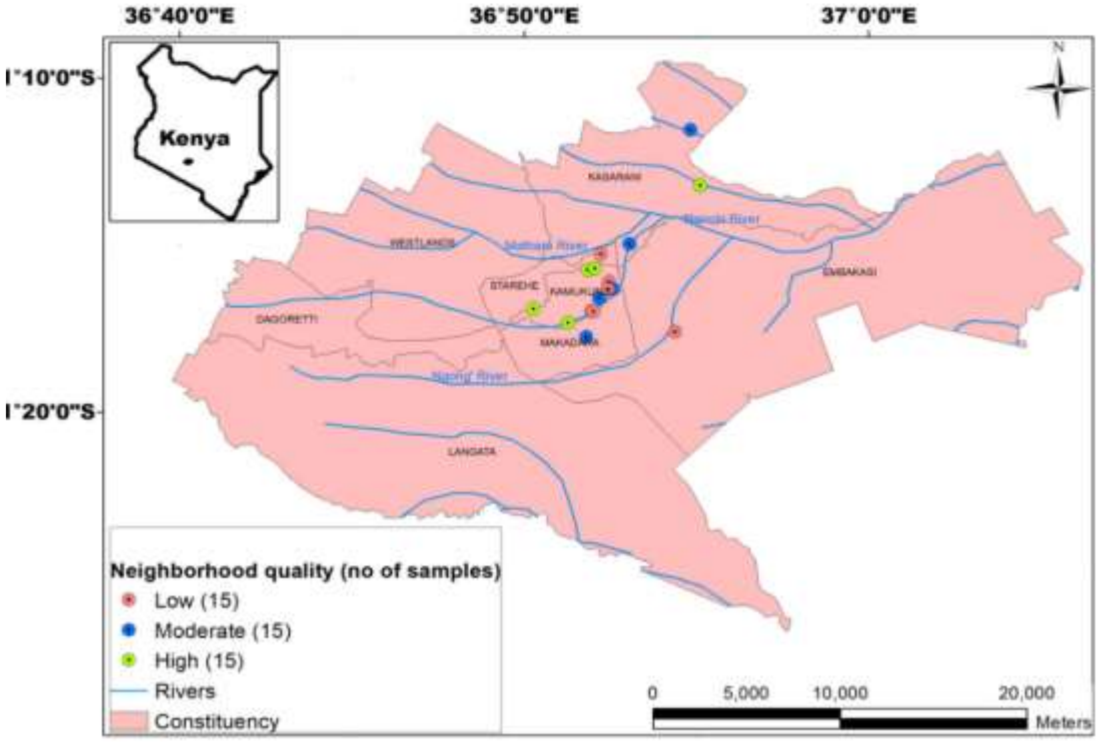


**Figure 3.1: Location of Sampled Farm Plots within Nairobi City County and the Classed Categories of Neighborhood Quality**

## 3.2 Research Design

### 3.2.1 Sampling and Target Population

The research was conducted in two stages. The first stage involved sensitizing urban agriculture stakeholders through a stakeholder workshop. The second stage involved conducting a field survey on farm plots belonging to urban farmer actors. In the field survey study, the target population was active urban farmers in Nairobi's eastern zone.

### 3.2.2 Stakeholders Workshop

The research started by holding of a main stakeholders' sensitization workshop at the Nairobi City County Agricultural office in Nyayo House in December 2012. The key stakeholders invited included officers from the Ministry of Agriculture, Livestock and Fisheries, Nairobi City Council Planning department, Ministry of Public Health and Sanitation, County Administration, Ministry of Environment, the National Environmental Management Authority (NEMA), Nairobi City County Trade and Industry and two farmer representatives from each of the nine sub-counties of Nairobi. The City County Director of Agriculture provided the link to all the sub-county agricultural officers. The stakeholders deliberated on the status of Agriculture in Nairobi city and members were sensitized on the aims and objectives of the intended research. The information collected during the workshop was collated and informed the development of an interview schedule for understanding issues related to urban agriculture in Nairobi City County.

### 3.2.3 Field Sampling of Farm Plots for Urban Agricultural Practitioners

The target population was represented by active farmers who spent most of their time, over 60% of their time, in agriculture for their income and livelihood. A quasi-comparative study design among farm plots in three locations (Kasarani, Starehe, and Kamukunji) was applied. Inclusion criteria of sample farm plots for the survey were having at least three of the target edible crops: tomatoes (Solanum lycopersicum), kales (Brassica oleracea var. Acephala), and arrowroots (*Colocasia esculenta*), growing in the farmed section. Sub-county agricultural officers (SCAOs) helped identify producers who met the requirements.

Farm plots were categorized according to the environmental quality of their immediate surroundings as low, moderate, or high. The environmental quality status of the sites was assessed by drawing on approaches commonly used in urban visual inspection protocols that evaluate the harmony of spatial elements, identifying degradation and pollution based on visual blight and the clutter of visual pollution objects (VPOs) (Wakil *et al.*, 2019). In this study, the visual assessment of site pollution was applied as a foundational component of environmental site assessment (ESA) that helps to quantify the environmental quality status of a site based on visible, sensory, and physical indicators (Novacek *et al.*, 2021; Latipov & Komilova, 2022). The process categorizes urban areas from 'no problem' to 'high pollution' based on the density, intensity, and maintenance of various visual pollution objects (VPOs). Among the different types of VPOs used for urban environmental audits, five indicators were selected that relate to the agricultural context of the study area to evaluate the sites. Methodology for assessment involved i) field inspection by site walkthrough and observing directly, noting 'red flags'; ii) review of historical records and storylines from residents and sub-county agricultural officers (SCAO). The VPO categorization criteria and the key indicators applied for the assessment are shown in Table 3.1, while Table 3.2 shows the results of the environmental quality classification of the study sites.

**Table 3.1: Results of Visual Pollution Assessment and Distribution of the Farm Plots (study sites) within the Sub- County. (Fx represents farm plot number)**

| | Final categorization of environmental quality of the farm sites | | |
|---|---|---|---|
| Sub-county | Low quality (3) | Moderate (2) | High (1) |
| Kasarani | F4 | F1, F2 | F15 |
| Starehe | F5, F6, F7 | | F3 |
| Kamukunji | F9 | F8, F10, F14 | F11, F12, F13 |

**Table 3.2: The Visual Pollution Objects (VPO) Categorization Criteria and the Key Indicators for Assessment Applied to Classify and Group the Study Sites According to Environmental Quality Status**

| Scale | Visual pollution objects (VPO) categorization scale | No. | Key Criteria for Visual Assessment |
|---|---|---|---|
| 0 | No Problem: Negligible impact on the landscape | i | Solid Waste and Litter: Uncollected garbage, illegal dumping, and neglected spaces (industrial by-products, hazardous waste |
| 1 | Insignificant Occurrence: Problem affects less than 10% of the surveyed area | ii | Green Space Quality and Availability: Lack of vegetation, poorly maintained green spaces |
| 2 | Moderate Occurrence: Problem affects 10–40% of the area. | iii | Infrastructure Condition: Aging or damaged infrastructure, leaking pipes, mis-managed wastewater discharge points. |
| 3 | Increasing Occurrence: Problem affects 40–80% of the area | iv | Surface Water Anomalies: Discoloured, cloudy, foamy, or oily-looking water in ponds, drains, or streams bordering the site. |
| 4 | Severe Pollution: Problem affects over 80% of the area | v | Odours: Strong, unusual, or pungent smells (chemical, petroleum, or sewage). |

### 3.3 Data Collection

#### 3.3.1 Stakeholders' Workshop

Participants took part in filling out a questionnaire that related to their engagement with urban and peri-urban agriculture activities. Issues of concern were presented, and perception was rated either by the count of individual respondents or by rating according to scores. Information sought included time spent on UPA, plot size, type and prevalence of crops grown, issues related to growth media, irrigation water, laws and regulations and marketing (Appendix i).

#### 3.3.2 Farmer Field Survey, Produce and Media Samples Collection

Fifteen farmers who grew at least two of the three crops targeted were chosen from three sub-counties with high urban agriculture activities, chosen with the help of agricultural extension officers, from Kasarani, Starehe, and Kamukunji. Samples of the three edible crop produce, irrigation water, and soil were collected in triplicate from each farm plot, giving a total of fifteen samples per farm. Recently matured leaves of kales were harvested from three randomly selected plants within the farm plot and put in brown paper to constitute one sample. Similarly, three ripe-to-harvest tomato fruits were harvested from three randomly selected plants. Arrow roots were dug out from a mature plant without inflicting injury to the tuber and put in punctured sealable transparent polythene bags and labelled (Figure 3.2). Soil samples were obtained from each farm plot in at least 5 different points by scooping with a trowel about 100g of the top 10 cm depth of soil in each point. The samples were then bulked by mixing thoroughly and delivered to the laboratory in sealed plastic bags. The closest source of irrigation water for each farm plot was identified and collected into one-litre screw capped glass bottles. All the samples, the three edible products and the two media samples were labelled according to the farmers' name code, sample number, type of environmental neighbourhood and the locational geographical coordinates obtained with a Global Positioning Satellite (GPS) receiver. The samples were stored in an ice-cooled box to minimise deterioration of the produce. The samples were delivered to the laboratory within six hours of collection and stored in a cold environmental room awaiting further analysis. The list of sampled farm plots is shown in Appendix vi.

**Figure 3.2: Initial Preparation Steps for the Delivered Crop, Water and Soil Samples Preparation Steps including Ashing in a Muffle Furnace Prior to Acid Digestion**

### 3.3.3. Laboratory Analysis

#### 3.3.3.1 Sample Preparation

Sample preparation and analysis were performed according to the procedure of Gupta (2017). Each of the three edible crop produce samples was chopped into small pieces using a laboratory cutter and then oven-dried at $70^0$ for 72 hours. They were then ground using a pestle and mortar after the removal of any soil contamination. A gram of each ground sample was weighed on an analytical balance (Model Chyo JL-180, manufacturer Chyo Balance Cooperation, Japan, Serial No.301272, readability 0.1mg-180g) and put into a crucible, which was then labelled with the farmer's code and sample number. The samples were charred on the Bunsen flame and later ashed in a ceramic muffle furnace at 500 °C for 8 hours. Six normal hydrochloric acids (one normal = $86cm^3$) were prepared. The 516 $cm^3$ hydrochloric acid was transferred to a one-litre volumetric flask and topped up with distilled water. The diluted acid was used to digest each sample's ash in a volume of 50 ml. The samples were filtered into 50ml plastic bottles, and the filtrate was labelled and stored in a cold room. Soil from the field was air-dried on the laboratory bench, ground using a pestle and mortar, and then sieved using a 2mm sieve (Figure 3.2). Soil acid digestion entailed mixing nitric and hydrochloric acids at a ratio of 2:1 and covering the mixture lightly with aluminium foil to avoid fumes. A soil of mass 2 g was measured and put into labelled flasks, and 20ml of the acid mixtures was added within the fume cupboard. These were boiled on the hearth for 30 minutes and let to cool while covered with aluminium foil. The mixture was put into a 50ml volumetric flask, topping up to the 50ml mark using distilled water. Filtering was done using a 125 mm filter paper and a funnel. The filtrate was put into labelled bottles with the farmer's code and sample numbers. The bottles were stored in a cold room ready for atomic absorption spectrophotometer analysis. Each of the three irrigation water samples per plot was filtered into labelled 50 ml plastic bottles and stored in a cold room.

#### 3.3.3.2 Heavy Metal Analysis

For all the samples, analysis for heavy metals (zinc, manganese, lead, and cadmium) was done using the Atomic Absorption/Flame Emission Spectrophotometer (AAS) (Japanese model SHIMADZU AA-630-12). The authors performed the AAS machine calibration as per the handbook by Gupta (2017) on the analysis of heavy metals/elements. This was done by preparing a working stock solution of 50 ppm from the original manufacturer's 1000 ppm stock solution. The following dilution formula was used;

$C_1V_1=C_2V_2$ where:

$C_1$=original stock solution, i.e., 1000ppm

$V_1$=Unknown

$C_2$=Working stock solution, i.e., 50ppm

$V_2$=100ml container

A series of standards was used to draw a linear calibration curve on Excel, where the curve of absorbance versus concentration was drawn. The curve was used together with a heavy metal (Cd, Pb, Zn, and Mn) specific cathode ray tube to read the absorbencies (wavelengths) in the AAS machine. Parts per million (ppm) readings were converted to mg/kg or mg/l, depending on whether it was for crops, soil, or water. Absorbance readings (in nanometers) were done directly from the machine, and the average of the two closest readings was recorded and later input into an MS Excel spreadsheet.

Crop plants were further assessed on their capacity to transmit metals from soil to plant tissues using the transfer factor (TF) index. TF was calculated as the ratio of the concentration of a specific metal in plant tissue to the concentration of the same metal in soil (Equation 1)

$$TF = \frac{Ccrop}{\mathrm{Csoil}} \qquad (1)$$

where Ccrop and Csoil represent the concentration of metal in the crop and soil, respectively.

#### 3.3.3.3. Pathogen Analysis

**Produce and irrigation water**

The one hundred and eighty samples from the fifteen farmers were analyzed for microbial presence of salmonella *(Salmonella tymphi/tymphimurium*), shigella and *Escherichia coli* bacteria. Microbial analysis on irrigation water and the three produce was commenced before 6 hours after field sampling. *Escherichia coli* analysis started with making sample pepton water dilution at a ratio of 1:1000, that is 1gm pepton broth to 1000 ml distilled water. 10gm of produce or 10 ml irrigation water were put into 90 ml pepton water in conical flasks. These were labelled using the farmer code and sample number. Serial dilution was done in three test tubes in concentrations of $10^1$,$10^2$ and $10^3$. A 0.1 ml of each dilution were innoculated on violet red bile agar (ratio 41.53gm: 1000ml distilled water and boiled) and introduced into petri dishes through surface spreading. These were incubated at 37 $^{\circ}$C for 24 hours. At the end of 24 hours, bacterial count was done and recorded as colony-forming units per gram (for produce samples) or colony-forming units per millilitre (for irrigation water samples).

Salmonella analysis required five steps;

- Pre-enrichment was the first step, during which 5 g (produce) or 10 ml (irrigation water) were loaded into 50 ml of nutrient broth media (mix ratio: 13 g nutrient broth dissolved in 1000 ml distilled water, autoclaved at 121 °C for 15 minutes). Pre-enrichment (a non-selective enrichment stage) is the process where the test sample is inoculated into a non-inhibitory liquid medium to favour the repair and growth of stressed or sub-lethally-injured salmonellae arising from exposure to heat, freezing, desiccation, preservatives, high osmotic pressure, or wide temperature fluctuations. Incubation at 30-37 °C for 24 hours was done.
- The second step, known as selective enrichment, entailed preparation of tetrathionate broth (mix ratio 77 g in 1000ml distilled water, boiled and cooled to 460 °C). Six grammes of potassium iodide and 5gm of iodine premixed in 20 ml of distilled water were added to the tetrathionate mix. This was dispensed in test tubes and covered with cotton wool to avoid contamination. Selective

enrichment favours the proliferation of Salmonella through a selective repression of the inhibition of the growth of competing micro-organisms.

- Thirdly selective plating where enrichment cultures are inoculated onto differential agars (salmonella-Shigella agar) for isolation of salmonella and shigella bacteria.
- The fourth stage of purification was not done since the research was only concerned with pathogen presence or absence.
- The fifth stage was biochemical screening, where isolates were screened using determinant biochemical reaction on Triple Sugar Iron agar (mix ratio 64.52 TSI in 1000ml dilute water heated to boiling point, 10ml distributed into test tubes and slanted). Isolates were streaked and stabbed into TSI slants.

**Figure 3.3: (A) Laboratory Preparation of Tetrathionate broth on an Electric Stove for use in Produce and Irrigation Water Bacteria (pathogen) Analysis. (B) Produce and Irrigation Water Bacteria after Incubation of Samples for their Count *(E.coli)* and Presence or Absence (*Salmonella* or *Shigella*)**

Observation was performed to determine the presence or absence of the two bacteria, using a microbiology atlas (Hart & Shears, 2004; Moshtaq, 2016). Detection of *Escherichia coli* (coliforms) by the plate count method was done conventionally. The liquid samples were plated, 1ml of undiluted sample per plate (in duplicate) for $10^0$ dilutions, and 0.1ml per plate for $10^{-1}$ dilution. For the solid, a 1:10 dilution was made. 10 ml of this dilution was distributed among 3 plates (i.e., 3.3 ml per plate). Two sets of 3 plates were made in this manner. These gave a $10^0$ dilution ($10^{-1}$ dilution x 10ml plated). One millilitre of this dilution was put into each of 2 plates. These were $10^{-1}$ dilution plates. Violet red bile agar was added to all plates and allowed to solidify. All plates were "capped" with enough violet red bile agar to form a complete overlay. These were incubated at 370 °C for 24 hours. During day two, typical coliform colonies: dark red at least 0.5 ml in diameter on uncrowded plates were seen (Figure 3). *Escherichia coli* count per gram was calculated to give colony-forming units per gram for produce samples or colony-forming units per milliliter for irrigation water samples.

## 3.4. Data Analysis

### 3.4.1 Stakeholders' Workshop

The questionnaire on UPA activities was analyzed according to the type of stakeholder that participated in the workshop. Descriptive analysis was conducted on the MS Excel software. The results of the analysis were summarized in bar charts to show respondent characteristics and their general practice in urban and peri-urban agriculture activities.

### 3.4.2 Heavy Metal Data Analysis

Data for the four heavy metal variables were analyzed for means and ranges. One-way ANOVA was conducted to test mean differences for the contents of heavy metals in crop, soil, and water samples, and for the transfer factor in the edible crops. Prior to ANOVA, the homogeneity of the variances was verified using Levene's test. Significant treatment differences were tested at $\alpha = 0.05$ using the Tukey HSD test. The Kruskal-Wallis test was used to assess the significance of differences in neighbourhood quality and heavy metal content. Statistical analyses were conducted using SPSS Version 25.0 (Statistical Package for Social Sciences for Windows, IBM Corporation). The maximum allowable limits for heavy metals set by the FAO, WHO, and other regulatory bodies (Table 3.3) were used as a reference to calculate the factor by which the metal content exceeded safe limits. Kenyan standard organic fertilizer specifications were also referred to, (Appendix iv and v).

**Table 3.3: Element's Concentration (mg/kg) Limits of Different Agricultural Samples by Different Regulatory Organisations**

| Item | Regulatory organization | Elements concentration (mg/kg) | | | |
|---|---|---|---|---|---|
| | | Cd | Mn | Pb | Zn |
| Soil | (FAO/WHO, 2023) | 3.00 | 210.00 | 300.00 | 300.00 |
| Soil | (FAO/WHO, 2023) | 3.00 | 75.00 | 300.00 | 300.00 |
| Water | (FAO/WHO, 2011) | 0.02 | 0.20 | 5.00 | 2.00 |
| Arrowroots | (FAO/WHO, 2011) | 0.10 | 2.00 | 0.10 | 47.40 |
| Kales | (FAO/WHO, 2011) | 0.20 | 2.00 | 0.30 | 60.00 |
| Tomatoes | (FAO/WHO, 2011) | 0.05 | 2.00 | 0.10 | 47.40 |

### 3.4.3 Pathogen Data Analysis

Data was input into an Excel spreadsheet. Columns comprised farmers' code with replicates of bacteria (Salmonella, Shigella, and *Escherichia coli*). Data on Salmonella and Shigella were on presence or absence (binomial), while that of Escherichia coli was recorded as colony-forming units per gram for produce and colony-forming units per millilitre for irrigation water. ANOVA was used to test for significant differences in *Escherichia coli* counts between the sub-county and environmental quality groups for the edible produce and irrigation water. The hypothesis tested was that the means across groups were equal. In case of rejecting the null hypothesis, post-hoc testing was conducted through a pair-wise comparison by running independent sample T-tests between groups, assuming unequal variances. To account for the increase in type 1 error due to repeated tests, a Bonferroni correction was applied to the p-value to compare the test results. Kruskal-Wallis (Non-parametric data ANOVA) was conducted for the presence/absence of Salmonella and Shigella grouped according to sub-county and environmental quality for the edible produce and irrigation water. Chi-square tests and a 95% confidence level were used to indicate measured dependencies. The Kenyan standard organic fertiliser specification for microbial contaminants was used as a reference for soil health (Appendix iii). Statistical analyses were conducted using SPSS Version 25.0 (Statistical Package for Social Sciences for Windows, IBM Corporation). Microsoft Excel 12 software was used for data entry and also for ANOVA tests. The results were presented in tables, graphs, and plates. Levels from the

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

## 4.1 Stakeholder Response on the Status of Urban and Peri-urban Agriculture in Nairobi

### Participants and Farming Characteristics

The composition of participants who attended the stakeholder workshop is shown in Figure 4.1A. The majority were UPA farmers, comprising about 50% (30% male and 20% female), followed by agricultural extension officers, comprising about 30% (all female). Age-wise, a large proportion of the stakeholders were in the age bracket of 50-65 years (67%) (Figure 4.1B). The frequency of participants who spent more than 60% of their time on UPA activities was the highest at 62.5%, while about 25% spent 20-40% of their time on UPA activities (Figure 4.1A). To a large extent, this would imply that the participants were well acquainted with UPA issues in Nairobi City County, thereby enhancing the reliability of the information derived from the workshop proceedings. The majority of the participants, about 80% owned the farm plots, while 20% worked on leased farm plots. The most common land size was the 1/8-1/4 acre, represented by about 30% of the respondents, while the large land size of > 1 acre was the least common among the urban farmers, with only 10% of the participants (Figure 4.2 B). Space for agricultural activities is limited in urban areas, and in rapidly urbanizing cities such as Nairobi, the challenge of open space availability is expected to intensify in the future, thus calling for space-saving technologies (such as vertical/storied gardens) for agricultural production adaptable to urban conditions.

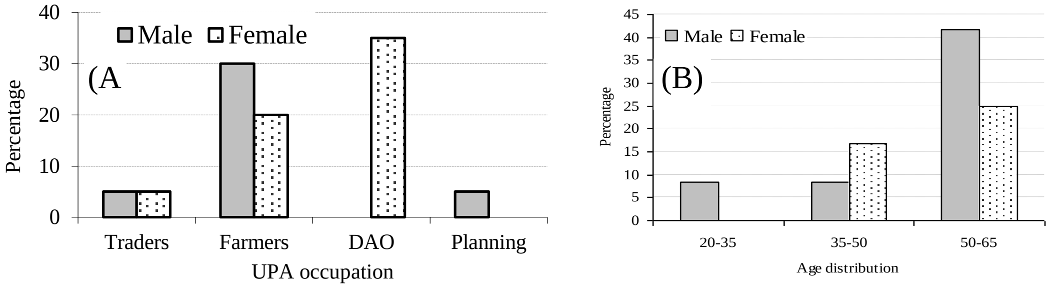


**Figure 4.1: The Gender Distribution of the Participants (A) and the Age Distribution by Gender of the UPA Farmers (B).**

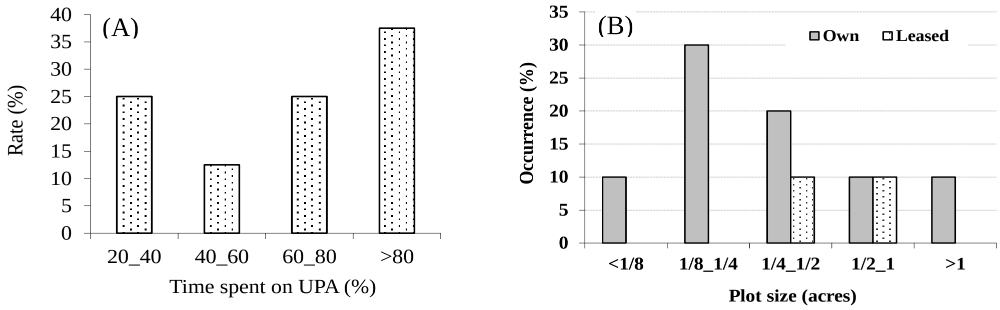


**Figure 4.2: The Percentage of Time Spent on Urban A and Peri-urban Agriculture Activities Daily by Farmers (B); the Size of Land Space Based on Land Sizes**

## 4.2 Occurrence Level of Heavy Metals

### 4.2.1 Occurrence Level of Heavy Metals between Localities

#### 4.2.1.1 Soil and Water

All four heavy metals were detected in soils with wide variation between farm plots (Table 4.1). Compared with FAO/WHO standards, the contents of Cd, Pb, and Zn were within the allowable limits, except for Mn, which was 8 times the allowable limit (Table 4.1), suggesting that the soils may be contaminated with Mn. The highest level of Mn was measured in a farm lot within an informal settlement of Kasarani location. There was no significant difference ($p>0.05$) in the level of Cd, Mn, Pb, and Zn between the localities (Kasarani, 4 farm plots, n = 12; Starehe, 4 farm plots, n =12; and Kamukunji, 7 farm plots, n =21) (Table 4.2, along column for soil).

**Table 4.1: Heavy Metal Occurrence Levels in Soil and Water Samples from Sampled Urban farm Plots in Eastern Zone of Nairobi (n = 15)**

| | Element concentration (mg/kg) | | | |
|---|---|---|---|---|
| Analysis item | Cd | Mn | Pb | Zn |
| Soil | | | | |
| mean±sd | 2.15±1.11 | 607.48±261.22 | 0.27±0.10 | 240.21±87.65 |
| range | 0.88 - 5.47 | 202.55 - 1022.6 | 0.16 - 0.45 | 75.41 - 389.19 |
| Factor of allowable | 0.716 | 8.100 | 0.001 | 0.801 |
| Water | | | mg/l | |
| mean±sd | 1.69±0.62 | 21.74±36.32 | 0.171±0.030 | 1.96±1.44 |
| range | 1.17 - 3.12 | 1.1 - 136.86 | 0.16 - 0.27 | 0.44 - 4.95 |
| Factor of allowable | 16.922 | 108.684 | 0.034 | 0.982 |

The contents of the four heavy metals were lower in water than those recorded for soils. Cadmium and manganese were above allowable limits by factors of 16.9 and 108.7, respectively (Table 4.1). The high levels of Cd and Mn observed in the water were from a similar estate in Starehe. The observed levels of lead and cadmium in water in this study are close to those reported for studies in Kibera and Maili Saba, slum estates in Nairobi (Kaluli *et al.*, 2011). Due to water scarcity in urban and peri-urban regions, industrial effluents and wastewater from sewerage systems are often used to fertigate crops, which can be a major source of heavy metals that accumulate in plants (Sharma *et al.*, 2015). Higher concentrations of the heavy metals were recorded in Starehe than in Kasarani or Kamukunji in all cases (Table 4.2, along the water column), although the differences were not statistically significant.

**Table 4.2: Results of ANOVA for Means of Heavy Metal Contents Grouped by Location of the Urban Farm Plots for Soil, Water and Crop Samples in Eastern Region of Nairobi. Mean Values Assigned with Different Letters Indicate Significance Difference (p < 0.05; Tukey HSD test**

| Element | Locality | Test sample element concentration (mg/kg, (ml/ltr for water)) | | | | |
|---|---|---|---|---|---|---|
| | | Soil | Water | Arrowroots | Kales | Tomatoes |
| Cadmium | Kasarani | 2.34±0.81 | 1.61±0.56 | 1.78±0.68 | 2.86±0.96 | 2.44±0.86a |
| | Starehe | 2.44±02.07 | 1.90±0.93 | 1.95±0.73 | 4.00±1.72 | 2.15±0.69ab |
| | Kamukunji | 1.86±0.49 | 1.61±0.51 | 2.26±1.10 | 2.87±1.24 | 1.45±0.22b |
| | mean±s.d. | 2.14±1.11 | 1.69±0.62 | 2.05±0.88 | 3.17±1.30 | 1.90±0.70 |
| | p-value | 0.69 | 0.757 | 0.699 | 0.481 | 0.041 |
| | Tukey HSD | 0.74 | 0.777 | 0.717 | 0.522 | 0.055 |
| Manganese | Kasarani | 675.24±245.18 | 16.67±12.68 | 74.70±12.82 | 10.10±3.98 | 7.94±2.44 |
| | Starehe | 611.68±227.98 | 40.77±64.83 | 69.28±2.64 | 17.08±7.52 | 7.72±4.03 |
| | Kamukunji | 566.36±313.26 | 7.54±10.95 | 70.09±5.04 | 16.37±9.07 | 7.12±4.75 |
| | mean±s.d. | 607.48±261.22 | 21.74±36.32 | 71.11±7.26 | 14.88±7.73 | 7.50±3.82 |
| | p-value | 0.824 | 0.477 | 0.540 | 0.374 | 0.943 |
| | Tukey HSD | 0.823 | 0.481 | 0.526 | 0.378 | 0.950 |
| Lead | Kasarani | 0.25±0.08 | 0.16±0.00 | 0.31±0.16 | 0.24±0.12 | 0.42±0.36 |
| | Starehe | 0.22±0.06 | 0.19±0.05 | 0.24±0.08 | 0.21±0.06 | 0.17±0.00 |
| | Kamukunji | 0.31±0.12 | 0.17±0.02 | 0.31±0.13 | 0.18±0.03 | 0.34±0.14 |
| | mean±s.d. | 0.27±0.10 | 0.17±0.03 | 0.29±0.12 | 0.21±0.07 | 0.32±0.19 |
| | p-value | 0.307 | 0.454 | 0.640 | 0.384 | 0.459 |
| | Tukey HSD | 0.334 | 0.398 | 0.671 | 0.382 | 0.391 |
| Zinc | Kasarani | 240.22±110.26 | 2.09±1.77 | 34.44±1.84 | 26.85±13.30 | 20.08±18.34 |
| | Starehe | 275.38±100.21 | 2.17±1.86 | 74.56±62.68 | 30.26±9.85 | 24.35±13.79 |
| | Kamukunji | 220.11±74.35 | 1.77±1.20 | 98.09±46.30 | 36.50±20.90 | 56.61±45.61 |
| | mean±s.d. | 240.21±87.65 | 1.96±1.44 | 74.84±49.98 | 32.26±16.26 | 38.27±36.37 |
| | p-value | 0.637 | 0.904 | 0.123 | 0.648 | 0.192 |
| | Tukey HSD | 0.823 | 0.521 | 0.526 | 0.378 | 0.950 |

### 4.2.1.2 Arrowroots

All the mean value contents for the four heavy metals in arrowroots were above allowable limits, with cadmium and manganese exceeding up to 20 and 35 times, respectively (Table 4.3). The contents varied widely across farm plots, irrespective of locality; for instance, the maximum and minimum contents of Cd and Mn were recorded in the same localities, Kamukunji and Kasarani, respectively. Results of ANOVA showed no significant difference in mean contents of the metals between the locations (Table 4.3 along the arrowroots column).

#### 4.2.1.3 Kales

In kales, Cd and Mn registered higher mean values of 15 and 7 mg/kg, respectively, above the allowable limits, compared with Pb and Zn, which were below unity (Table 4.3). ANOVA test returned no significant difference between localities ($P>0.05$) for all the heavy metals (Table 4.3) along the Kales column. However, among the three crops, Cd content was highest in kales, a common occurrence for leafy vegetables. The highest mean values for Cd and Mn were observed in Starehe. The main Kale varieties encountered in the survey were Collard Mfalme and the Thousand Headed variety.

#### 4.2.1.4 Tomatoes

In all cases except for Zn, the measured contents in tomatoes were above allowable limits, with cadmium exceeding by up to 38 times (Table 4.3). ANOVA test showed a high significance difference between localities in the content of Cd (Tukey HSD = 0.055, $p \leq 0.05$) but none for Mn, Pb, and Zn (Table 4.3). The highest mean Cd content recorded in Kasarani was not statistically different from that in Starehe but was different from that in Kamukunji. This showed that tomatoes from Kasarani and Starehe, around Soweto and Kiamaiko villages, respectively, were likely contaminated with cadmium during the survey season due to the use of water loaded with industrial effluents and animal slurry. Farm plots from Kasarani also recorded the highest amounts of Mn and Pb in tomatoes, while Zn was highest in Kamukunji (Table4.3). In Nigeria, the following ranges were found on river water irrigated tomatoes: *Cd (0.070=0.110), Mn (4.220=5.510), Pb (0.180=0.270),* and Zn (4.590=5.820), respectively (Rapheal & Adebayo, 2011). A study on the phytoremediation potential of *Amaranthus hybridus* and *Eichhornia. Crassipes plants along the* Nairobi River reported cadmium levels of between 1.81 - 3.45 mg/kg (Orwa *et al.,* 2014). The study also reported here for our test crops. The commonly grown tomato varieties were Money Maker, RomaF1, Anna F1, and Terminator.

**Table 4.3: The Overall Heavy Metal Occurrence Levels in Arrowroots, Kales and Tomatoes from the Sampled Urban Farm Plots in Eastern Nairobi (n = 15)**

| | Element concentration (mg/kg) | | | |
|---|---|---|---|---|
| Analysis item | Cd | Mn | Pb | Zn |
| Arrow root | | | | |
| Mean±sd | 2.5±0.88 | 71.12±7.26 | 0.29±0.13 | 74.84±49.98 |
| Range | 1.17 - 4.49 | 62.54 - 89.15 | 0.161 - 0.56 | 0.44 - 4.95 |
| Factor of allowable | 20.50 | 35.55 | 2.94 | 1.58 |
| Kales | | | | |
| Mean±sd | 3.18±1.30 | 14.89±7.73 | 0.21±0.07 | 32.26±16.26 |
| Range | 1.76 - 5.27 | 3.65 - 26.86 | 0.16 - 0.43 | 12.86 - 69.77 |
| Factor of allowable | 15.13 | 7.44 | 0.48 | 0.68 |
| Tomatoes | | | | |
| Mean±sd | 1.90±0.70 | 7.50±3.82 | 0.32±0.19 | 38.27±36.37 |
| Range | 1.17 - 3.51 | 2.38 - 13.52 | 0.17 - 0.68 | 8.70 - 136.84 |
| Factor of allowable | 38.01 | 3.75 | 3.17 | 0.81 |

### 4.2.2 Heavy Metal Incidences between Neighborhood Classes

#### 4.2.2.1 Soil and Water

Results of the Kruskal-Wallis test showed that there was no significant effect of neighbourhood quality of farm plots on the content of the four heavy metals in soil (H'(2), $p > 0.05$), (Table 4.4). In water, there was a significant effect of neighbourhood quality on the content of Zn (H' (2) = 6.388, $p < 0.05$), being highest in a moderate quality class. These results showed that although neighbourhood environmental conditions could portray a polluted environment, farm practices at the individual farm plot, such as using clean manure and precaution measures on using contaminated water, could guarantee the safety of crop produce.

#### 4.2.2.2 Crops

For arrowroots, only Mn, Pb, and Zn were low in the high-quality neighbourhood, consistent with our classification, but no significant difference ($p > 0.05$) between classes (Table 4.3). In kales, the distribution of Mn content agreed with the neighbourhood quality classification, while in tomatoes, although there was no significant effect of neighbourhood class on metals (H’ (2), p > 0.05), the contents of Cd, Pb, and Zn were low in the high-quality neighbourhood, consistent with the classification. For all the crops, the Kruskal-Wallis test showed no significant effect of neighbourhood quality on the level of Cd, Mn, Pb, and Zn (H' (2), p > 0.05) (Table 4.4). Our criteria for classifying allocation of vicinities such as high, moderate or low quality relied on visual observations and working experience of agricultural staff and researchers. However, heavy metal occurrence contents fluctuated between the neighbourhood qualities. This implied that agricultural practices at the farm level were more critical in influencing the quality of food produced than the nature of the surrounding environment.

**Table 4.4: Heavy Metal Content in soil and Water Samples from Urban Farm Plots of Nairobi Classed by Environmental Quality of the Vicinity. (L, M and H = Qualities of Low, Medium and High; n = 15). H’= Kruskal-Wallis test Statistics, for the four Heavy Metals in Arrowroots, Kales and Tomatoes. (Critical chi-square value, p = 0.05, 2df = 5.99)**

| Env. quality class | Metal element concentration (mg/kg) | | | |
|---|---|---|---|---|
| | Cd | Mn | Pb | Zn |
| Soil | | | | |
| L | 2.44±1.71 | 659.13±315.64 | 0.235±0.06 | 186.76±122.76 |
| M | 2.52±0.62 | 577.21±185.47 | 0.35±0.09 | 280.30±44.66 |
| H | 1.48±0.44 | 586.09±315.84 | 0.22±0.10 | 253.58±302.90 |
| mean | 2.44±1.71 | 607.48±261.22 | 0.27±0.10 | 240.21±87.64 |
| *H'* | 5.028 | 0.38 | 5.721 | 3.38 |
| *p* | 0.081 | 0.827 | 0.057 | 0.185 |
| Water | | | | |
| L | 1.29±0.26 | 10.35±11.23 | 0.17±0.02 | 0.84±0.35 |
| M | 1.95±0.53 | 19.84±12.40 | 0.16±0 | 2.57±1.15 |
| H | 1.84±0.83 | 58.25±73.12 | 0.18±0.05 | 2.48±1.84 |
| mean | 1.28±0.26 | 18.84±34.48 | 0.17±0.03 | 1.96±1.43 |
| *H'* | 3.913 | 1.055 | 1.086 | 6.388 |
| *p* | 0.141 | 0.59 | 0.581 | 0.041 |

### 4.2.3 Transfer Factor Index

Results of transfer factor index (TF) analysis, also called the bioaccumulation factor for the four heavy metals in the three crop types, are shown in Figure 4.3. Significant differences were found in the TFs of Mn and Pb in the edible parts of the surveyed crops; arrowroots, chi-square, Mn (H' (2) =31.08 and Pb (H' (2) =6.82, $p<0.05$). Overall, the mean TF index for the heavy metals decreased in the order Cd>Pb>Zn>Mn. The mean TF of Mn in arrowroots was significantly higher than in kales and tomatoes (Figure 4.3). Similarly, the TF of Pb in arrowroots was significantly higher than in kale and tomatoes. When the TF ratio is >1, the plants have accumulated elements; ratios around 1 indicate no influence by the elements, and ratios <1 show that plants exclude the elements from uptake (Mirecki & Agi, 2015). A transfer factor index of > 1 for cadmium was recorded in arrowroots, kales and tomatoes, while the other TF above 1 for lead was in arrowroots only (Figure 4.3). This indicated a high likelihood for bio-accumulation of Cd and Pb in the surveyed sites. The mean TF index in crops decreased in the order of arrowroots>kales>tomatoes.Thus, arrowroots had a high capacity taccumulate heavy metals, especially Cd and Pb.

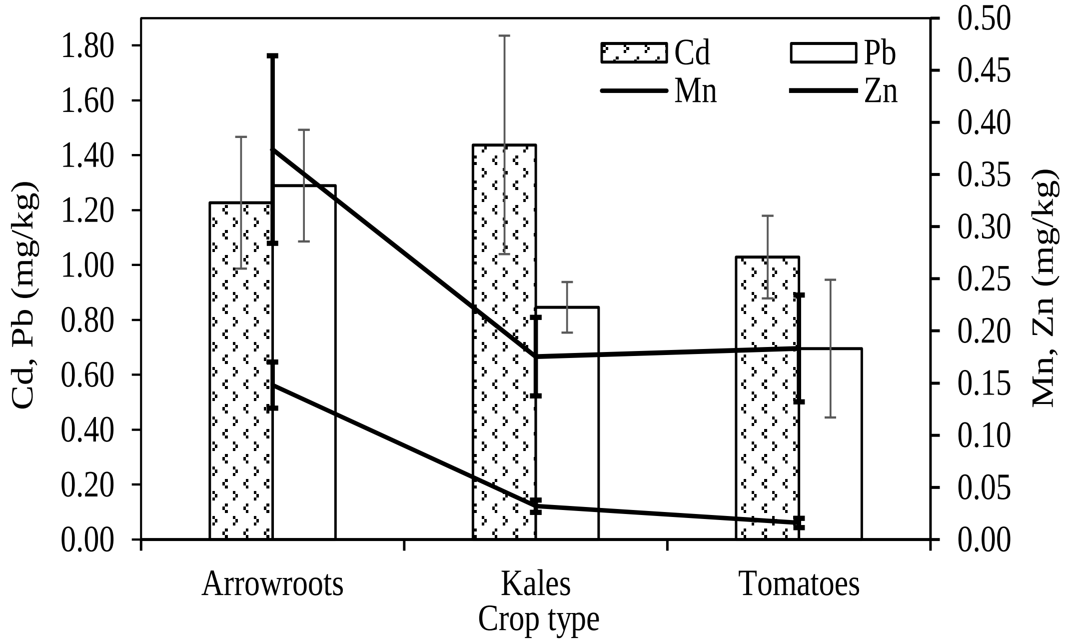


**Figure 4.3: Transfer Factor Index of Heavy Metals in Three Vegetable Crops Sampled from Urban Farm Plots of Eastern Nairobi. Error Bars Indicate Standard Error of Fifteen Replicates**

### 4.2.4 Conclusion

Participation in urban agriculture impacts dietary adequacy (Zezza & Tasciotti, 2010), implying that engagement in farming by urban households allows them to consume better, more nutritious diets. However, the urban farmer grows plants under strong stresses caused by the character of the city environment, such as being near industrial areas, dumping, and exposed municipal refuse sites that contaminate air, soils, and water (Chaoua *et al.*, 2019). This study indicates heavy metal pollution in growing media, irrigation water, and produce, particularly cadmium. Soils had higher contents of heavy metals, so it is likely that most of the contamination occurred through the soils or soil amending materials from where it accumulates in crops, posing a risk to human health when consumed (Kumar *et al.,* 2015; Olowoyo & Lion, 2016).

The concentration of heavy metals was found to be crop-specific, attributable to variations in uptake efficiency and transfer factor among species. Cadmium was high in kales (sukuma wiki), a leafy vegetable widely grown in urban neighbourhoods and indispensable in the daily diet of many urban households, especially in the low-income informal settlements of Nairobi. Production of arrow roots in marshy areas of the city is a common practice, irrespective of water source, yet it showed a high tendency to accumulate heavy metals. Although urban dwellers in this part of the city may be aware of health risks posed by unsafe farming practices (Lee-Smith, 2006), they are forced by low incomes and socio-economic status to overlook them. Techniques and measures to mitigate health risks need to be scaled up, such as wastewater treatment (NEMA, 2012), community self-regulation (Metro Atlanta Urban Farm, 2022), and building on good-practice frameworks (Cole & Jones-Otazo, 2006).

Crops with low transfer factors of heavy metals should be proposed for production in such environments. For Nairobi, technical, organizational, and financial support to urban farmers is needed to reduce risks and promote a positive perception of urban agriculture. Through research and implementation of relevant policies, the Nairobi City County government, through the Departments of Agriculture, Public Health, and Urban Planning, can improve the competitive status and level of participation of the urban farmer in the wider economic web of the urban food system.

## 4.3 Pathogen Levels on Crop Produce and Irrigation Water

The laboratory analysis aimed to determine the presence or absence of Salmonella and Shigella. No distinction was made between the two species of Salmonella, namely S. typhimurium and S. typhi. However, *Escherichia coli* involved bacterial count as colony-forming units per gram for produce or colony-forming units per milliliter for irrigation water. When Salmonella–Shigella Agar (M108) was used in the analysis, and the bacteria were viewed against a dark background, Escherichia coli appeared as pink colonies. Both Salmonella and Shigella appeared as black colonies due to their production of hydrogen sulfide ($H_2S$) gas.

### 4.3.1 *Escherichia coli* Levels between Localities

Table 4.5 shows the levels of *Escherichia. coli* for the sample materials of water, and the three crop products from the three localities. Overall, the highest mean of *E. coli* bacterial counts was recorded in arrowroots (Figure 4.4. There was no significant difference between the sub-counties in levels of *E. coli* for water, kales, and tomatoes, but a highly significant difference was apparent when it came to arrowroots, the highest observed being in Kamukunji sub-county ($p<0.005$). Probably arrowroot had the highest levels because it is an edible produce nearest to the soil and irrigation water compared to the leaf (kale) and the fruit (tomato).

**Table 4.5: The Levels of Escherichia coli as Observed for Substrates of Water, Arrowroots, Kales and Tomatoes between the Sampled farms of the Sub-counties of Nairobi City County**

| Locality | *Ecoli* concentration ($\log_{10}$ CFU 100 $ml^{-1}$) | | | |
|---|---|---|---|---|
| | Water | Arrowroots | Kales | Tomatoes |
| Kasarani | 4.29±0.63 | 4.55±1.01$^{b}$ | 3.70±0.77 | 3.44±1.09 |
| Starehe | 4.57±1.55 | 4.73±0.60$^{ab}$ | 3.38±0.95 | 4.00±0.91 |
| Kamukunji | 4.38±0.99 | 4.77±0.90$^{a}$ | 3.43±1.27 | 3.44±1.43 |
| mean±s.d. | 4.41±0.14 | 4.68±0.12 | 3.50±0.17 | 3.63±0.32 |
| p-value | 0.31 | 0.002 | 0.930 | 0.38 |

### 4.3.2 *Escherichia coli* levels between Neighbourhood Environmental Quality

The levels of *E. coli* based on differences between the environmental quality of the neighbourhood are shown in Table 4.6. The null hypothesis that farm plots in neighbourhoods classified as low or high in environmental quality record similar levels of *E. coli* was tested. For irrigation water, *E.coli* was significantly high in the low environmental quality neighbourhood compared to the moderate and high quality neighbourhoods, thus rejecting the null hypothesis. Among the crop samples, *E.coli* levels in arrowroots were significantly high in the low environmental quality neighbourhood compared to the high quality neighbourhood, but not significantly different between the low and the moderate quality neighbourhood. In kales and tomatoes, although the levels of *E.coli* were high in the low environmental quality neighbourhood compared to the moderate and high quality neighbourhoods, statistically, they were not significantly different (Table 8). Microbial contamination of fresh produce with *E.coli* has been widely reported (Michino *et al.,* 1999; Alegbeleye *et al.,* 2018; Miceli *et al.,* 2019), with contamination sources being related to various stages of the farm-to-fork chain, during cultivation of fresh produce, at harvest, within distribution chains, and even at the consumer kitchen level. Rain and irrigation water droplets have been shown to splash soil particles onto plant surfaces, leading to plant contamination (Girardin *et al.,* 2005; EFSA Panel on Biological Hazards (BIOHAZ) *et al.,* 2017; Alegbeleye *et al.,* 2018). Water sources of poorer microbiological quality, such as surface water, municipal water, or reutilised wastewater, can contaminate fresh crops. In this study, farm plots classified under low-environment quality neighbourhoods were commonly irrigated with surface water sourced from contaminated streams, the only cheaply available water sources. It was observed that the common irrigation method was by splashing water on the leaves of vegetables, which potentially increased the chance of microbes landing on plant leaves and hence the risk of contamination of fresh produce (Alegbeleye *et al.,* 2018; Gurtler & Gibson, 2022).

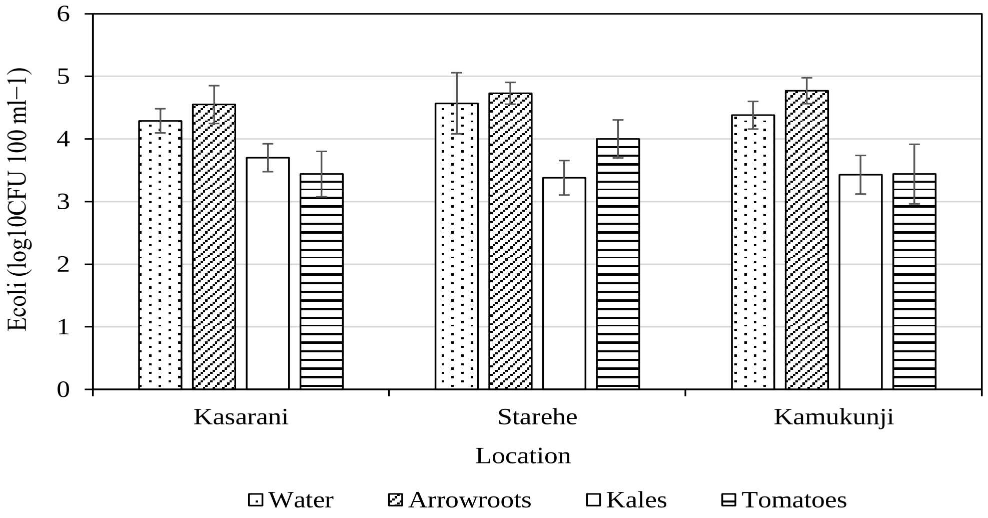


**Figure 4.4: Levels of *Escherichia coli* as Observed for Substrates of Water, Arrowroots, Kales and Tomatoes for the Sampled Farms of the Sub-counties of Nairobi City County. (n=15)**

**Table 1. 6: The Levels of *Escherichia coli* as Observed for Substrates of Water, Arrowroots, Kales and Tomatoes between the Sampled farms Classified by Neighbourhood Environmental Quality of Low, Moderate or High. (n=6 – 15).**

| Neighbourhood quality | *Ecoli* concentration ($log_{10}$CFU 100 $ml^{-1}$) | | | |
|---|---|---|---|---|
| | Water | Arrowroots | Kales | Tomatoes |
| Low | $4.10 \pm 0.66^{a}$ | $4.20 \pm 0.69^{a}$ | 2.94±1.21 | 2.94±0.76 |
| Moderate | $3.18 \pm 0.80^{b}$ | $3.36 \pm 1.20^{ab}$ | 2.16±0.90 | 2.66±1.42 |
| High | $2.77 \pm 1.40^{b}$ | $3.46 \pm 0.86^{b}$ | 2.37±0.81 | 2.51±1.18 |
| mean±s.d. | 3.34±0.68 | 3.67±0.46 | 2.49±0.40 | 2.70±0.22 |
| p-value | 0.003 | 0.038 | 0.119 | 0.773 |

### 4.3.3 Salmonella on Produce and Irrigation Water

Table 4.7 shows that Salmonella bacteria were more present, at a rate of 82.2%, than absent in the irrigation water of the sampled farms, irrespective of the sub-county. Kamukunji sub-county had the highest number of farms, 40%, that recorded the presence of Salmonella in irrigation water. However, there was no significant difference in the pattern of Salmonella distribution between the sub-counties. In the case of arrowroots, the same distribution of Salmonella was observed as that of irrigation water, with no significant difference between the sub-counties (Table 4.7). However, the overall rate of prevalence was much higher at a rate of 91.1 %. The distribution of Salmonella in kales and tomatoes showed significant differences between the sub-counties, $p = 0.004$ (kales) and $p = 0.042$ (tomatoes), and thus rejected the null hypothesis. The overall rate of occurrence in kales and tomatoes was at rates of 44.4% and 53.3%, respectively. Compared to the other sub-counties, Kamukunji had much higher cases of absence of Salmonella than Kasarani and Starehe (Table 4.7).

**Table 4.7: The Levels of Salmonella as Observed for Substrates of Water, Arrowroots, Kales and Tomatoes between the Sampled Farms Classified by Locality (n= 12, 12 and 15 for Kasarani, Starehe and Kamukunji**

| | Location sub-county | | |
|---|---|---|---|
| | | **Water** | |
| | Kasarani | Starehe | Kamukunji |
| Absent | 4.4 | 6.7 | 6.7 |
| Present | 22.2 | 20.0 | 40.0 |
| Statistic | $\chi^2(2) = 0.614, P = 0.736$ | | |
| | | **Arrowroots** | |
| Absent | 2.2 | 2.2 | 4.4 |
| Present | 24.4 | 24.4 | 42.2 |
| Statistic | $\chi^2(2) = 0.020, P = 0.990$ | | |
| | | **Kales** | |
| Absent | 4.4 | 15.6 | 35.6 |
| Present | 22.2 | 11.1 | 11.1 |
| Statistic | $\chi^2(2) = 11.009, P = 0.004$ | | |
| | | **Tomatoes** | |
| Absent | 4.4 | 13.3 | 28.9 |
| Present | 22.2 | 13.3 | 17.8 |
| Statistic | $\chi^2(2) = 6.352, P = 0.042$ | | |

### 4.3.4 Salmonella Levels between Neighborhood Environmental Quality

The prevalence level of Salmonella in water for the different neighbourhood qualities was highest in the low-quality neighbourhood and lowest in the high-quality neighbourhood (Table 4.8); however, there was no significant difference between the neighbourhood qualities ($p > 0.05$). The prevalence pattern for arrowroots was inconsistent with the neighbourhood quality, with no significant difference between the three classes. For kales and tomatoes, the prevalence of Salmonella recorded was higher in the high-quality environmental neighbourhood than in the low-quality neighbourhood, contradicting the expectation as per assigned class. However, there was no significant difference in prevalence pattern (presence, absence) between the three classes for kales and tomatoes, p= 0.181 and p = 0.343, respectively (Table 4.8), and so we accept the null hypothesis.

**Table 4.8: The Incidence Level of Salmonella as Observed for Substrates of Water, Arrowroots, Kales and Tomatoes between the Sampled Farms Classified by Neighborhood Environmental Quality of Low, Moderate or High. (n= 15).**

| | Envionmental quality | | |
|---|---|---|---|
| | **Low** | **Moderate** | **High** |
| | | **Water** | |
| Absent | 2.2 | 6.7 | 8.9 |
| Present | 31.1 | 26.7 | 24.4 |
| Statistic | $\chi^2(2) = 2.128$, $P = 0.345$ | | |
| | | **Arrowroots** | |
| Absent | 2.2 | 4.4 | 2.2 |
| Present | 31.1 | 28.9 | 31.1 |
| Statistic | $\chi^2(2) = 0.549$, $P = 0.760$ | | |
| | | **Kales** | |
| Absent | 24.4 | 17.8 | 13.3 |
| Present | 8.9 | 15.6 | 20.0 |
| Statistic | $\chi^2(2) = 3.420$, $P = 0.181$ | | |
| | | **Tomatoes** | |
| Absent | 20.0 | 11.1 | 15.6 |
| Present | 13.3 | 22.2 | 17.8 |
| Statistic | $\chi^2(2) = 2.143$, $P = 0.343$ | | |

### 4.3.5 Shigella on Produce and Irrigation Water

The mean prevalence rate for Shigella in irrigation water was 17.0 %, being highest in Kamukunji (20.0%) and followed by Kasarani sub-county (17.8%) (Table 4.9). The main source of contamination of irrigation water could be the faecal-oral route, which was evident from the observed cases of usage of sewage water for watering crops in the study sites. There was no significant difference in the distribution of the Shigella bacteria in irrigation water between the three sub-counties (p = 0.419). In arrowroots, the overall mean prevalence rate was 13.3%, with an almost equal rate and no significant difference (P > 0.05) between the sub-counties. In kales and tomatoes, the overall mean prevalence rates were 17.0% and 15.6% (Table 4.9. The highest prevalence rate for kales was in Kasarani and Kamukunji sub-counties, while for tomatoes, it was highest in Kasarani sub-county. Water that is contaminated with *Shigella spp*. may be deposited on edible crop parts that may be consumed, causing direct transmission to humans (Lolić *et al.*, 2023).

**Table 4.9: The Levels of Shigella Observed for Substrates of Water, Arrowroots, Kales and Tomatoes between the Sampled Farms Classified by Locality. (n= 12, 12 and 15 for Kasarani, Starehe and Kamukunji Respectively).**

| | **Location sub-county** | | | **Overall mean rate** |
|---|---|---|---|---|
| | | **Water** | | |
| | **Kasarani** | **Starehe** | **Kamukunji** | |
| Absent | 8.9 | 13.3 | 26.7 | 16.3 |
| Present | 17.8 | 13.3 | 20.0 | 17.0 |
| Statistic | $\chi^2(2) = 1.741, P = 0.419$ | | | |
| | | **Arrowroots** | | |
| Absent | 13.3 | 13.3 | 33.3 | 20.0 |
| Present | 13.3 | 13.3 | 13.3 | 13.3 |
| Statistic | $\chi^2(2) = 2.413, P = 0.343$ | | | |
| | | **Kales** | | |
| Absent | 8.9 | 11.1 | 28.9 | 16.3 |
| Present | 17.8 | 15.6 | 17.8 | 17.0 |
| Statistic | $\chi^2(2) = 2.836, P = 0.242$ | | | |
| | | **Tomatoes** | | |
| Absent | 2.2 | 17.8 | 33.3 | 17.8 |
| Present | 24.4 | 8.9 | 13.3 | 15.6 |
| Statistic | $\chi^2(2) = 13.383, P = 0.001$ | | | |

### 4.3.6 Shigella Levels between Neighbourhood Environmental Quality

Based on the environmental quality classes, the distribution of prevalence of Shigella in irrigation water was inconsistent with the neighbourhood quality classification, and the overall mean rate for presence and absence of Shigella was less varied, with no significant difference between the classes (Table 4.10). In arrowroots, there was a significant difference between the quality classes ($p < 0.05$), and so we rejected the null hypothesis. However, a low prevalence rate was recorded in the neighbourhood designated as low quality, which was in contrast to the categorisation set for the specific sites. In kales and tomatoes, the distribution pattern for Shigella remained the same between the quality classes, again with the low-quality class recording the lowest prevalence, but no significant difference between the classes, p>0.05 (Table 4.10).

**Table 4.10: The Levels of Shigella as Observed for Substrates of Water, Arrowroots, Kales and Tomatoes between the Sampled Farms Classified by Neighborhood Environmental Quality of Low, Moderate or High. (n= 15)**

| | Environmental quality | | | Overall mean rate |
|---|---|---|---|---|
| | | Water | | |
| | Low | Moderate | High | |
| Absent | 17.8 | 20.0 | 11.1 | 16.3 |
| Present | 15.6 | 13.3 | 22.2 | 17.0 |
| Statistic | $\chi^2(2) = 2.312, P = 0.315$ | | | |
| | | Arrowroots | | |
| Absent | 26.7 | 11.1 | 22.2 | 20.0 |
| Present | 6.7 | 22.2 | 11.1 | 13.3 |
| Statistic | $\chi^2(2) = 7.222, P = 0.027$ | | | |
| | | Kales | | |
| Absent | 20.0 | 13.3 | 15.6 | 16.3 |
| Present | 13.3 | 20.0 | 17.8 | 17.0 |
| Statistic | $\chi^2(2) = 1.245, P = 0.537$ | | | |
| | | Tomatoes | | |
| Absent | 24.4 | 13.3 | 15.6 | 17.8 |
| Present | 8.9 | 20.0 | 17.8 | 15.6 |
| Statistic | $\chi^2(2) = 3.750, P = 0.153$ | | | |

**Conclusion**

Overall, the highest mean of *E coli* bacteria count was recorded on arrowroots at Kamukunji subcounty (p<0.005). Between neighbourhoods, *E.coli* was highest in the irrigation water in the low-quality neighbourhood. Kamukunji had the highest occurrence of Salmonella bacteria at 40% and Shigella with a mean of 20% in irrigation water. The highest prevalence rate for kales was in Kasarani and Kamukunji sub-counties, while for tomatoes, it was highest in Kasarani sub-county. The hypothesis that farms plots in neighbourhoods classified as low in environmental quality record similar levels of *E. coli* as those of moderate and high quality was tested.

For irrigation water, *E.coli* was significantly high in the low environmental quality neighbourhood ($p<0.005$) compared to the moderate and high quality neighbourhoods, thus rejecting the null hypothesis. For kales and tomatoes, the prevalence of Salmonella recorded was higher in the high-quality environmental neighbourhood than in the low-quality neighbourhood, contradicting the expectation as per the assigned class, and so we accept the null hypothesis.

# CHAPTER FIVE

# OVERALL CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

This study indicated the presence of heavy metal pollution in growing media, irrigation water, and produce of urban agriculture in Nairobi City County, particularly of cadmium and manganese. The level of Cd and Mn in irrigation water was several-fold higher than levels permissible under FAO and WHO regulations. Higher concentrations of the heavy metals were recorded in farm plots from Starehe than in Kasarani or Kamukunji in soil and water, although the difference was not statistically different. All crops' edible parts recorded heavy metal contents above permissible levels, especially for Cd, Mn, and Pb to a lesser extent. The level of Cd was significantly different between the localities, being highest in Kasarani sub-county, which could be linked to tomatoes from around Soweto and Kiamaiko villages, likely due to usage of water loaded with industrial effluents and animal slurry.

Although in some cases there was a positive match between the level of heavy metal and classified environmental quality of a site, there was no significant effect of neighbourhood quality on the level of Cd, Mn, Pb, and Zn. This implied that agricultural practices at the farm level were more critical in influencing the quality of food produced than the perceived nature of the surrounding environment.

Transfer factor index of > 1 for cadmium was recorded in arrowroots, kales, and tomatoes, while the other TF above 1 for lead was in arrowroots. The study showed a high likelihood for bio-accumulation of Cd and Pb in the surveyed sites. The mean TF index in crops decreased in the order arrowroots>kales>tomatoes. Thus, arrowroots had a high capacity to accumulate the heavy metals, especially Cd and Pb. Similar observations have been recorded for cocoyam grown in urban wetland areas, a root crop similar to arrowroots (Mongi & Chove, 2020).

There was no significant difference between the sub-counties in levels of *E. coli* for water, kales, and tomatoes, but a highly significant difference was apparent when it came to arrowroots, the highest observed being in Kamukunji sub-county ($p<0.05$). In all the test samples (soil, water, arrowroots, kales, and tomatoes), E.coli was consistently higher in low-quality neighbourhoods than in high-quality neighbourhoods, thus rejecting the null hypothesis.

Salmonella was detected in all the test samples of water, arrowroots, kales, and tomatoes. The pattern of distribution was the same in all the sub-county localities except for kales and tomatoes, where the incidence of Salmonella in Kasarani was significantly higher than in Starehe and Kamukunji. There was no significant difference in prevalence pattern (presence, absence) between the three environmental quality classes (low, moderate, and high) for water, arrowroots, kales, and tomatoes, and so we cannot reject the null hypothesis.

Shigella was detected in all the test samples with varied prevalence rates but not significantly different between localities according to chi-square tests ($P> 0.05$), except for tomatoes ($p = 0.001$), where the Shigella distribution pattern was significantly different, with high prevalence values recorded for Kasarani than the other localities. Compared between environmental qualities, only in arrowroots was there a significant difference in distribution pattern ($P=0.027$) with high prevalence in the moderate class.

The practice of using water from sources of poorer microbiological quality, such as surface water, municipal water, or reutilised wastewater, was common in the study areas. Splashing water on the leaves of vegetables potentially increases the chance of microbes landing on edible plant parts and hence increases the risk of contamination of fresh produce, as also observed in other studies (Miceli & Settanni, 2019; Gurtler & Gibson, 2022).

Despite the myriad of issues facing urban agriculture, it continues to thrive, being driven by several motivations, which include food security strategies for the urban poor, emerging food marketing systems, and policies on urban farming (Kirkpatrick

& Davison, 2018; Ninsheka *et al.*, 2024; Thomas *et al.*, 2021a). The results of this study call for concerted efforts by all stakeholders, from farmers, input suppliers, agricultural officers, urban planning officers to regulatory bodies, towards ensuring a safe and healthy urban agriculture system. With the burgeoning of the urban population, space for agriculture will be more constrained, which affects the type of agriculture a farmer can practice (Vågsholm *et al.,* 2020), often pushing the majority of the poor farmers to resort to unsafe agricultural practices. The research demonstrated the disconnect between risk perception and actual risk of urban agriculture. The farms, which were previously perceived to be of low quality (contaminated), did not show much difference from farms in areas perceived as low risk. Adaptive farming techniques, continuous education, and communication can greatly transform farmer behaviour (Rossini-Oliva & Nuñez, 2024) and quality of produce, and help change the ambivalent perception towards urban agriculture by urban dwellers and city authorities. There is a dire need, therefore, to re-focus on technologies that maximise space, resources such as water, and guarantee the provision of healthy and nutritious food from urban agriculture. Supported by a strong policy and regulatory framework, the urban agriculture industry in Nairobi city can be directed towards attaining the internationally acceptable standards to benefit the socio-economic well-being of many urban dwellers, especially in the low-income neighborhoods.

## 5.2 Recommendations

The following recommendations are proposed

i) Any future study to extend the diversity of localities to cover urban neighborhoods, both from low- and high-income areas

ii) To widen the scope of the study to measure the implications of heavy metal contamination on human health risk, such as through the hazard quotient for carcinogenic diseases. This aspect can be followed by designing studies that include in-depth studies by conducting medical tests on human subjects, especially those exposed to urban agriculture practices.

iii) Development and updating of records related to all aspects of urban agriculture in Nairobi City County that are accurate, retrievable, and easily accessible.

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# APPENDICES

## Appendix I: Research questionnaire

Research questionnaire

JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY.

FACULTY OF AGRICULTURE.

Questionnaire for: Study on 'Safety and management of urban and peri-urban agricultural processes and products'

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Introduction: This is academic research being conducted by a research scientist who is a member of JKUAT in the Department of Horticulture. The researcher invites you to participate in the exercise, whose objective is to determine safety and management of urban and peri-urban agricultural processes and products within Nairobi County for improved income and health of producers and consumers.

Informed consent: As a good gesture to research ethics, I find it prudent that I ask for your consent to participate in the survey. Consequently, I am bound by the following:

• Your responses will be treated with **CONFIDENTIALITY.**

• The study **DOES NOT** intend to associate any of the responses in this questionnaire with you, your associates or your farm.

•**ANY** divulgence occurring will be my responsibility.

I agree to participate in this survey;

Signature of participant: ________________________ Date: _____________________

| | | |
|---|---|---|
| Please return the filled questionnaire to: | JKUAT, Department of Horticulture | E-mail: |

| | | |
|---|---|---|
| | P.O. Box 62000-00200, Nairobi, Kenya | |

This questionnaire is being administered by enumerators. Please respond to only one questionnaire.

SECTION A: FARMER'S PERSONAL DETAILS

1.Name……………………………………………………………………………..

2. Subcounty…………………………Ward………………………………………..

Location……………………………Sublocation……………………………………

3. Gender a. Male[ ] b.Female[ ].

4. Age bracket in years.

a.18-25 [ ] b.26-35 [ ] c.36-45 [ ] d. Over 60 years[ ]

5. Marital status a. Single [ ] b. Married [ ] c Any other…………………..

6. House hold size a [2 ] b [3] c [4] d [>4]

7. Highest completed level of education

a.Primary level[ ] b.Secondary level[ ] c.Certificate[ ] d.Diploma[ ] e. Degree [ ] f. Any other(specify)……………….

8. What is your main occupation?

a,Public sector-Permanent[ ] b.Private sector-Permanent[ ] c.Short term contracts [ ] d. Casual[ ] e. Business[ ] f.Any other……………

9. Time (%) spent in urban agriculture a.0-10 [ ] b.10-50 [ ] c.50-75 [ ] d.75-100 [ ]

10. Level (%) of Urban Agriculture contribution to total income a.10 [ ] b. 30 [ ] c. 50 [ ] d. 100 [ ].

SECTION B: FARMING CHARACTERISTICS.

11. How did you acquire the land? a. Personal [ ] b.[ ] Institutional c. Unscheduled land [ ] d. Any other (specify)…………………………………………………………

12. Land size.

A. (Less than 1/32 acres) [ ] b, (1/32-1/16 acres) [ ] c. (1/16-1/8acres) [ ]

d.(1/8-1/4acres)[ ] e.(1/2-1acre) [ ] f.>1acre [ ]

13. Where do you get your irrigation water?

a,Roof catchment[ ] b.Water pan [ ] c. River [ ] d. piped [ ] e. Any other (specify)………….

14. Type(s) of inorganic fertilizers used.

| | |
|---|---|
| D.A.P. | |
| C.AN. | |
| Compound | |
| A.S.N. | |
| Foliar | |

15. Sources of manure.

| | |
|---|---|
| Livestock (from the same farm) | |
| Livestock(bought, e.g. from elsewhere) | |
| Compost (specify sources) | |

| | |
|---|---|
| a.Farm waste | |
| b. Industrial waste | |
| c. Organic garbage | |
| d. Slaughterhouse waste | |
| Any other (e.g.Sewage sludge) | |

16. Crop enterprises……………………………………………………………………

17. What is the destination of your crop produce? a. Sale [ ] b. Self consumption [ ] c Both sale and consumption [ ].

18. What is your most limiting factor to farming? a. Water [ ]. b. Nairobi city by-laws [ ].

c. Space [ ]. d. Produce security [ ]. e. Any other (specify)……………………………

19. How do you manage agricultural waste? a, Feeding to livestock [ ]. b. Burning [ ]. c. Throw away [ ]. d. Sell [ ]. e. Compost [ ]. f .Any other (specify)…………………

**Appendix II: Potential Survival of Faecal Pathogens in the Environment**

| **Material** | **Duration of survival** | | | |
|---|---|---|---|---|
| | *Cryptosporidium* | *Salmonella* | *Campylobacter* | *E.coli* |
| Water-Frozen | >1yr | >6months | 2-8weeks | >300days |
| Water-cold | >1yr | >6months | 12days | >300days |
| Soil-Frozen | 10weeks | >6months | 4days | 84days |
| Soil-cold | >1yr | >12weeks | 2-8 weeks | >300days |
| Soil-warm | 8weeks | 12-28 | 1week | 2days |
| Cattle Manure | 4weeks | >1year | 2-8weeks | >100days |
| Composted | 4weeks | 7-14days | 7days | 7days |

Source: Human and Animal Pathogens in Manure, Olsen, M.E

**Appendix III: Microbial limits for organic fertilizers**

**Description of fertilizer contaminant Limits**

| | |
|---|---|
| ***Escherichia Coli*** | **1000cfu/g** |
| **Salmonella Species** | **Nil** |
| **Shigella species** | **0** |
| **Faecal streptococci** | **<500 cfu/g** |
| **Infective parasites** | **Nil** |

Source: Kenyan Standard organic fertilizer specification KS2290:2018, ICS65080

**Appendix IV: Heavy metal contaminant limits for organic fertilizers**

| Parameter (heavy metal) | Limit (mg/kg) |
|---|---|
| Cadmium (maximum) | 5 |
| Lead | 30 |
| Zinc | 300 |
| Manganese | 200 |

Source: Kenyan Standard organic fertilizer specification KS2290:2018, ICS65080

## Appendix V: International standards for heavy metals in food

| Metal | Description of food | Max permitted concentration in ppm |
|---|---|---|
| Cadmium (Cd) | Cereals and vegetables | 0.1 |
| Lead (Pb) | All foods in solid form | 6 |
| | All foods inliquid form | i |
| Zinc (Zn) | All foods | 100 |
| Manganese (Mn) | All foods | 500 |

Source: Codex Alimentarius Commission General Standards for Contaminants and Toxins in food and feed. CODEX STAN 193-1995

## Appendix VI: Sampled farm plots and their GPS coordinates

| Farmer's name | Village | Neighborhood | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|
| Muigai Njoroge | Kariadudu | 2 | S 01,14,58.0 | E36,53,03.7 | 1595 |
| James Kirangi | Soweto | 2 | S 01,11,33.3 | E 36,54,49.7 | 1563 |
| Simon Odhiambo | Kiamaiko | 1 | S 01,15,16.6 | E 36,52,14.5 | 1615 |
| Charles Kioli | Luckysummer | 3 | S 01,13,13.7 | E36,55,07.6 | 1576 |
| Eliud Muriu | Ziwani | 3 | S01,16,54,8 | E36,50,16.8 | 1667 |
| Stanslous Akoi | Mabatini | 3 | S 01,15,45.7 | E36,51,51.5 | 1623 |
| Kevin Uduny | Huruma | 3 | S 01,15,41.9 | E36,52,04.1 | 1628 |
| Ndonga | Makadara | 2 | S 01,17,45.8 | E3651,48.8 | 1636 |
| Joseph Gichuki | Bahati | 3 | S 01,17,19.9 | E36,51,17.1 | 1626 |
| Fred Nyangalwa | Kiambiyu | 2 | S 01,16,35.6 | E36,52,10.9 | 1623 |
| Victor Onyango | Kiambiyu | 1 | S 01,16,05.8 | E36,52,28.8 | 1534 |
| Paul Ng'ang'a | Bahati | 1 | S 01,16,59.0 | E36,51,58.1 | 1623 |
| Pauline Wambere | Bahati | 1 | S 01,17,00.3 | E36,52,01.2 | 1628 |
| Tom Kaiganira | Uhuru | 2 | S 01,16,19.1 | E36,52,34.9 | 1601 |
| Geofry Kimani | Savannah | 1 | S 01,17,36.2 | E36,54,23.1 | 1612 |
| Maina Karis | City cotton | 1 | S 01,16,19.1 | E36,52,25.9 | 1607 |