HEALTH AND ENVIRONMENTAL RISKS OF USING WASTEWATER IN VEGETABLE PRODUCTION IN URBAN AND PERI- URBAN AREAS OF NAIROBI CITY, KENYA

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DECLARATION

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DEDICATION

Nobody has been more important to me in the pursuit of this Degree than my immediate family. I sincerely thank my wife Mrs. Winrose Rono, and my children Kevin Kirui, Ian Kirui and Adeline Chebet for their profound encouragement.

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ABSTRACT

The use of wastewater for farming results in excessive accumulation of heavy metals in soils leading to elevated levels of metal uptake by crops, which in turn affects food safety. The identified knowledge gap in vegetable production using wastewater in urban and peri-urban areas of Nairobi City relates to inadequate awareness concerning associated health and environmental risks occasioned by quality of wastewater used for irrigation and vegetable produce, which the study sought to fill. Cross-sectional, correlational and evaluation research designs were used based on the research objectives. Qualitative and quantitative data was collected using interview guide, questionnaire, observation checklist and visual aids. Quantitative data was also generated by carrying out laboratory analysis of wastewater and vegetable samples. Generated data was analysed using descriptive and inferential statistics. The study findings were presented using tables, pie charts and graphs. The findings showed vegetable farmers use raw influent, the treated effluent, and wastewater-polluted Nairobi River. Farmers used wastewater for irrigation because it is the only source of water, contain plant nutrients, reliable and without restrictions of access. Irrigation methods used are surface irrigation (basin and flood), and spray. Petrol-powered water pump generators are used for pumping and applying wastewater. The most challenging source of wastewater is the raw influent in view of the bad odour and need for dilution to facilitate flow in the channels leading to farmlands. Wastewater used for vegetable production did not meet the Environmental Management and Coordination (Water Quality) Regulations 2006 standards for irrigation water and microbiological quality guidelines for wastewater use in irrigation. Titanium, zinc, lead, chromium, cadmium, cobalt and copper concentrations in the sampled vegetables exceeded the FAO/WHO safe limits in leafy vegetables. Total coliforms and *Escherichia coli* in the wastewater samples exceeded <1000/ 100ml recommended for total coliforms and nil/ 100 ml recommended for *Escherichia coli*. Health risks associated with wastewater use in vegetable production include breeding grounds for mosquitoes, bioaccumulation of heavy metals and illnesses such as skin and waterborne diseases like typhoid and cholera. Environmental risks are bad odour, river bank erosion, and resultant pollution. In order to mitigate risks of using wastewater in irrigation, the study recommends sensitization of farmers on the potential risks of using wastewater, carrying out periodic assessment of wastewater to confirm its suitability for irrigation, development and implementation of policy guidelines for safe use of wastewater in irrigation. Theoretical significance of the study is the added body of knowledge on the potential of wastewater reuse in urban and peri-urban areas. The generated data can provide baseline information for the proposed further research, namely; carrying out a similar study in both seasons for comparison purposes; monitoring contamination levels in vegetable produce before and after harvest; and gathering large data set of farmers and consumers and where possible their blood samples and other health indicators be taken to see the impact of wastewater.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS:	Atomic Absorption Spectrometer
Al:	Aluminum
BOD:	Biological Oxygen Demand
CBOs:	Community based organisations
Cd:	Cadmium
Co:	Cobalt
Cr:	Chromium
Cu:	Copper
FAO:	Food and Agriculture Organization
FBO:	Faith-based organisation
g/kg:	gram/kilogram
Ha:	Hectares
Hg:	Mercury
IJPAES:	International Journal of Plant, Animal and Environmental Sciences
IWMI:	International Water Management Institute
KEBS:	Kenya Bureau of Standards
KI:	Key informants
Km:	Kilometers
KNBS:	Kenya National Bureau of Statistics
L:	Litre
Mg/l:	Milligrams per litre
Mpn:	Minimum probable number

NACOSTI:	National Commission for Science, Technology and Innovation
NEMA:	National Environment Management Authority
NWSC:	Nairobi Water and Sewerage Company
Pb:	Lead
pH:	Measure of hydrogen ion concentration
PTEs:	Potentially toxic elements
ROK:	Republic of Kenya
SPSS:	Statistical Package for Social Sciences
TDS:	Total Dissolved Solids
Ti:	Titanium
UA:	Urban Agriculture
UNWWDR:	United Nations World Water Development Report
UPA:	Urban and Peri- Urban Agriculture
WB:	World Bank
WHO:	World Health Organization
WRA:	Water Resources Authority
Zn:	Zinc

OPERATIONAL DEFINITION OF TERMS

BOD: The amount of oxygen required by organisms to decompose organic matter in wastewater.

Direct use of untreated wastewater from a sewage outlet: occurs when it is directly disposed of on land where it is used for cultivation.

Direct use of treated wastewater: occurs when wastewater has undergone treatment before it is used for agriculture or other irrigation or recycling process.

Environmental risk: actual or potential threat of adverse effects on living organisms and the environment by effluents, emissions, wastes, resource depletion etc.

Hazard: A potentially damaging physical event, phenomenon or human activity that can cause loss of life or injury, damage of property, environmental degradation or social and economic disruption.

Health risk: Something that could cause harm to people's health.

Heavy metals: Any metallic element that has a relatively high density and is toxic at high concentration.

Indirect use of treated or untreated urban wastewater: occurs when water from a river receiving treated or untreated urban wastewater is abstracted by farmers downstream of the urban centre for agriculture.

Household size: All persons occupying a housing unit.

MDAs: Ministries, departments and agencies.

NCWSC: Nairobi City Water and Sewerage Company

Peri- urban: Embraces both urban and rural setting located anywhere in-between the urban and the rural landscape.

pH: A measure of hydrogen ion concentration in the water ranked on a scale of 1.0 to 14.0.

Planned use of wastewater: refers to the conscious and controlled use of wastewater either raw (i.e. untreated) or diluted (i.e. treated)

Polluter pays principle: the cost of cleaning up any element of the environment damaged by pollution, compensating victims of pollution, cost of beneficial uses lost as a result of an act of pollution and other costs.

Reclaimed water or recycled water: Is treated wastewater that can officially be used under controlled conditions for beneficial purposes, such as irrigation.

Research design: Is a comprehensive plan for data collection in an empirical research. It is a blueprint for empirical research aimed at answering specific research questions or testing specific hypotheses. It involves three processes viz. data collection, the instrument development and sampling.

Risk: A probability or threat of damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal exposures.

Social risk: Refers to a series of unfavourable events (loss of income, incapacity for work, etc.) which involve income discontinuity; the total or the partial loss of income.

Sustainable development: Development that meets the needs of the present, without compromising the ability of future generations to meet their own needs.

Total dissolved solids (TDS): All inorganic and organic substances contained in water that can pass through a 2 micron filter.

Treated wastewater: Is wastewater that has undergone treatment process in a wastewater treatment plant and subjected to one or more physical, chemical and biological processes to reduce its contamination by hazardous substances.

Urban agriculture: Involves cultivating crops, breeding and keeping livestock as well as aquatic animals and plants, and using land for gardens, nurseries, or agro-forestry.

Urban wastewater: Is usually a combination of one or more of the following:

1. domestic effluent
2. effluent from commercial establishments and institutions, e.g. hospitals
3. industrial effluent
4. storm water and other urban runoff.

Vegetables: Mainly annual plants cultivated as field and garden crops and used almost exclusively for food.

Wastewater: Used water from either domestic, industrial, commercial or agricultural activities; surface runoff or storm water; and any sewer inflow or sewer infiltration.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The effects of industrialization, mordenization, and inadequate resource management techniques on freshwater resources' quality and quantity are tremendous. Increased population worldwide and decrease in clean water supply limit human activities, in particular enterprises. The majority of industrial processes necessitate a large amount of water, which is virtually equally discharged as wastewater. (Matheyarasu, *et al*., 2015).

The composition of wastewater varies greatly and can include organic particles, pathogens such as viruses, bacteria, and parasitic worms, organic particles such as feces, hair, food, and plant material, inorganic materials such as salts, sand, grit, heavy metals, metal particles, and ceramics, and pesticides and other toxins (FAO, 2012).

Concerns about climate change and ensuring food security in urban areas have boosted the popularity of urban agriculture (UA). UA can help reduce hunger and poverty (SDG 1.1, 1.4, 1.5, 2.1, 2.3, 2.4, and 2.c); create sustainable food production patterns (SDG 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, and 15.9); and promote the integration of environmental values in development (SDG 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, and 15.9). (SDG 15.9). The main issues in UA are figuring out how to monitor, control, and eliminate hazards in the physical, economic, and social environment, as well as figuring out how it can be a long-term part of global urban food systems (Game and Primus, 2015).

With population, urbanization, better living conditions and economic development, the volume of wastewater generated by home, industrial and commercial sources has increased. As millions of urban and peri-urban (UPA) small-scale farmers of the developing countries rely on wastewater or wastewater-polluted sources of water to irrigate high value edible crops on the urban market, they are not often provided with alternatives to irrigation water. Unwanted wastewater components can adversely affect the environment and human health. Waste irrigation is therefore an issue for government entities in charge of public health and environmental quality (Qadir, *et al*., 2010).

The major benefits of residential water reuse are nutrient supply, water provision reliability, urban food supply contribution, income production and livelihoods. These features are particularly relevant for small farmers who can enjoy improved water and food safety through the use of recycled or raw irrigation water (D'Andrea, *et al*., 2015).

The use of urban wastewater in agriculture has been done for almost 100 years and is recognized in most arid and semiarid locations by decreasing freshwater resources. In numerous developing countries, potentially unstructured urban lands along the urban drainage systems include prospective sites for the production of various agricultural goods, such as vegetable, which are highly demanded by villages and cities. In general, raw urban wastewater irrigated vegetables is the critical pathway to exposure of urban populations. Non-built urban lands, particularly those along the urban drainage systems, are sometimes seen as producing grounds for some agricultural items like vegetables which are highly sought after by urban people in many developing regions (Ruma and Sheikh, 2010).

Wastewater is a resource as well as an issue. Wastewater and its fertilizer content may be successfully implemented for irrigation and other services to the ecosystem. It can provide farmers, society, and municipalities positive benefits. However, reusing wastewater also affects human beings and natural systems, which need to be discovered and evaluated (Hussain, *et al*., 2002).

Wastewater in several developed and middle-income nations such as France, the United States of America, Spain, Tunisia, Jordan and Israel is applied to agricultural fields after it is fully treated. The practice is recognized, well-regulated and controlled by agencies that are well-established. In most developing countries large volumes of urban wastewater generated remain untreated due to inadequate resources for effective wastewater treatment facilities (Drechsel, *et al*., 2010).

A survey conducted between 2006 and 2007 by Kaluli, *et al* (2011) showed nearly half of the wastewater generated in Nairobi ended up being treated in the treatment facilities, while raw sewage was used for irrigating more than 720 hectares of cropland. The crops grown included vegetables such as kales (*Brassica* sp.), spinach (*Spinacia oleracea*) and the African vegetables like Amaranthus (*Amaranthus* sp.). Approximately 75% of the vegetables produced was sold for income, while the rest was consumed.

1.2 Statement of the problem

Since the untreated wastewater is released into the environment, most of Nairobi City's freshwater resources are polluted. The raw municipal and industrial wastewater is routed into the rivers via natural drainage canals, thus helping to pollute the sources of freshwater. Urban farmers use untreated wastewater for irrigation of plant products in the city (Ndunda and Mungatana, 2013). According to Kanyoka and Eshtawi (2012), negative features of wastewater reuse include soil salinity, farmer and consumer health, public acceptability, marketability of produce, and economic feasibility and sustainability of wastewater irrigation.

The wastewater generated in Nairobi (Kaluli *et al*., 2011) is within the National Environment Management Authority (NEMA) quality guidelines except biological oxygen demand (BOD) and coliform bacteria in raw sewage. Biological Oxygen Demand is an important water quality parameter used for assessing the effect discharged wastewater will have on the receiving environment. The higher the BOD value, the greater the amount of organic matter available for oxygen consuming bacteria. Nairobi City's untreated wastewater (Ndunda and Mungatana, 2013) is discharged through natural drainage waterways, hence most freshwater resources are polluted to varying degrees. Urban and peri-urban farmers in the City irrigate their farms with the untreated wastewater.

Sewage water farming is associated with too much buildup of heavy metals in the soil that result in increased heavy metal uptake by crops, which affects food safety. Kale (*Brassica* sp.*)* popularly known as 'sukuma wiki' is one of the most preferred green leafy vegetables that is consumed by most households in Nairobi. Unfortunately, a reasonably large proportion of this vegetable retailed in urban areas pose several food safety risks to consumers. Some of the potential risks are contamination by microbial pathogens, heavy metals, pesticides and residues of chemical fertilizer. Some retailers do sprinkle the vegetables with unclean and often polluted water to maintain freshness and make it look attractive to the customers' eyes (Ngigi, *et al*., 2011).

Apart from potential benefits as a valuable resource (Hussain *et al.,* 2002), wastewater can also have harmful effects in agriculture, with potential cost accompanying its use. For instance, its use in agriculture is likely to increase exposure of farmers, farmworkers, consumers and people neighbouring wastewater irrigated farmlands to infectious diseases. It is also potential of causing groundwater contamination; impacting the soil negatively through accumulation of salts and heavy metals if used for considerably long time; having negative impacts on value of neighbouring properties; as well as having other negative impacts on socio-ecological systems.

Heavy metal contamination of food (Gupta *et al.*, 2013) is one of the key aspects of determining food quality assurance. They rank high among the chief food contaminants of leafy vegetables. Intake of heavy metal contaminated vegetables poses a risk to human health. Thus the extended ingestion by humans of insecure heavy metal concentrations in foodstuffs causes various biological and biochemical processes in the human body that are disrupted. Diverse chronic disorders cause dietary consumption of heavy metals through contaminated plants. Regular monitoring of these metals is crucial to prevent excessive growth of the food chain metals (Gupta *et al.*, 2013).

The Environmental Management and Coordination (Water Quality) Regulations, 2006 provide standards for irrigation water and wastewater, while the Food and Agriculture Organisation together with the World Health Organization do have safe limits for heavy metals in green leafy vegetables. The objective of these standards is to safeguard human and environmental health. Awareness about the existence and compliance levels of the standards is poorly understood in the country.

It is against this background that the current study was undertaken to better understand the health and environmental risks of using wastewater in vegetable production by establishing the physicochemical characteristics and microbiological composition of wastewater used as well as the concentrations of selected heavy metals in vegetables produced using wastewater in Ruai ward, Nairobi City, Kenya.

1.3 Research objectives

The general objective of the study was to determine health and environmental risks associated with wastewater use in vegetable production in urban and peri-urban areas of Nairobi City, Kenya.

The specific objectives of the study were to:

i) Establish vegetable types, sources and reasons for using wastewater in production as well as irrigation methods used in urban and peri- urban areas of Nairobi City, Kenya,

ii) Examine physicochemical characteristics and microbiological composition of wastewater used in vegetable production in urban and peri-urban areas of Nairobi City, Kenya,

iii) Determine titanium, zinc, lead, chromium, cadmium, cobalt and copper concentrations in vegetables produced using wastewater in urban and peri-urban areas of Nairobi City, Kenya, and

iv) Examine health and environmental risks associated with wastewater use in vegetable production in urban and peri-urban areas of Nairobi City, Kenya

1.4 Research questions

Samples of wastewater used in vegetable production and samples of vegetables produced using wastewater were analysed in the laboratory. Since there was no control experiment, research questions instead of hypotheses provided guidance towards achieving the study objectives. The following were the research questions:

i) What are the types of vegetables, sources and reasons for using wastewater in their production in urban and peri- urban areas of Nairobi City, Kenya?

ii) What are the physicochemical characteristics and microbiological composition of wastewater used for vegetable production in urban and peri- urban areas of Nairobi City, Kenya?

iii) What are the concentrations of selected heavy metals in vegetables produced using wastewater in urban and peri- urban areas of Nairobi City, Kenya? and

iv) What are the health and environmental risks of using wastewater in vegetable production in urban and peri- urban areas of Nairobi City, Kenya?

1.5 Significance

New findings from this study will be useful to the State Department for Agriculture for considering review of relevant policies, legislation and regulations in a participatory approach to guide in implementation of guidelines for safe use of wastewater for crop irrigation. It will also be of help in designing appropriate programs for monitoring contamination levels of vegetable produce along the food chain. Nairobi county government and non- state actors with an interest in urban agriculture will use the findings in designing programs for raising awareness on the potential risks of using wastewater for urban and peri-urban agriculture.

Further, proposed policy and technical interventions will inform decisions aimed at improving efficiency of the Ruai domestic wastewater and industrial wastewater treatment plant to handle present and foreseeable volumes of raw influent. The treated effluent released could be made available for reuse at an agreed fee by interested farmers. Lastly, apart from adding to the existing knowledge, the findings will be used by researchers and scholars since the collected data will potentially provide a starting point for further research.

1.6 Scope

The study was conducted in Ruai ward, erstwhile Ruai Division, Njiru sub- County, Nairobi City where farmers use wastewater for vegetable production. Data covering sources of wastewater, reasons for use, types of vegetables produced, as well as social and environmental risks of using wastewater in vegetable production was obtained from the interviewed farmers. In addition, physicochemical characteristics and microbiological composition of wastewater used, and concentrations of heavy metal contaminants in vegetables produced using wastewater were determined in the laboratory. Further, four medical personnel-in-charge of four different health facilities (out of eight) in the study area were interviewed with a view to triangulate information obtained from the interviewed farmers. Lastly, a structured questionnaire was administered on key informants from State and non-state organisations relevant to the study to get their organizational views on the study and proposed policy and technical interventions for safe use of wastewater for crop irrigation in urban and peri-urban settings.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents literature review guided by aim and objectives of the study. It gives the global perspective of urban and peri-urban farming using wastewater; reasons (drivers) for using it and mode of application; physicochemical characteristics and microbiological composition of wastewater; concentrations of heavy metals contaminants in the vegetables produced using wastewater; and health and environmental risks associated with wastewater use in vegetable production.

2.2 Urban and Peri-urban agriculture using wastewater: Global perspective

2.2.1 Introduction

The use of wastewater for agricultural purposes (World Bank- WB, 2010) is the most established application with the longest history compared to other applications. In general, irrigated lands are located within urban areas because it is in such places where a lot of wastewater is generated. According to Mokhtari *et al* (2012), wastewater irrigation is expanding in lower income countries and in arid and semi-arid high-income countries. The practice involves direct use of untreated wastewater or the indirect use of polluted waters from rivers and streams.

In most developing nations, wastewater is used in untreated form and in many other countries because of limited treatment facilities it is generally discharged into waterbodies with either partial or no treatment. In this respect the untreated wastewater end up being used for irrigation in urban or semi-urban farming, which accounts for approximately 13% of all irrigated croplands globally (Dickin *et al*., 2016).

In developing countries such as Mexico, Vietnam., China, India, Peru, Lebanon, Egypt and Morocco, agricultural use of untreated wastewater as a source of crop nutrients has for centuries been linked with land application and crop production. However, over the years this practice has become less popular in developed countries owing to advancement in wastewater treatment technologies and increased awareness about environmental and health issues. Farmers in developing countries use wastewater extensively to sustain their livelihoods (IWMI, 2006).

In developing nations, consumers of agricultural produce grown under wastewater irrigation whereby a greater percentage of them consume raw produce and salad greens, do often face health complications because a large proportion of wastewater does not undergo adequate treatment (Drechsel and Evans, 2010).

Metals contaminate the soil and enter into the plant parts and have the potential to accumulate at high concentrations in the edible parts of vegetables. They get ingested into the human body when such vegetables are consumed. Heavy metals can be hazardous to the human body even in low concentration. Examples of hazardous effects of heavy metals are central nervous system breakdown and damage to renal system (Latif *et al*., 2018).

Although urban agriculture seems to have benefits, it also has public health concerns and environmental issues as pointed out by Mougeot (2000). Public health issues that are of concern are contamination contributed by producers, handlers, consumers and people living in the neighbourhood of production areas as well as those contributed by crop and husbandry inputs, products and byproducts, which can be grouped as nuisances and safety hazards. On the other hand, environmental issues that are of concern include visual untidiness, pollution of soil and water resources, and soil erosion.

The purpose of the WHO (2006) guidelines is to safeguard human health when wastewater is used for agriculture. It is a multi-barrier approach that is advised for nations that use untreated wastewater and focuses on health protection measures at several points of entry along the food chain. In the guidelines, however, it has been slowed down by attitudes and perceptions of farmers, retailers and consumers when the planned non-wastewater treatment protection measures have been adopted. Moreover, in low to middle-income countries, there is insufficient evidence for the success of risk reduction strategies aimed at farming measures, marketing for hygienic food and preparing food in markets, homes and kitchens (Antwi-Agyei *et al*., 2016).

2.2.2 Reviews from outside Africa

Agricultural use of wastewater, slurry and excreta (IWMI, 2012) is widely spread with a long history in several nations. For many years farmers in China used human and animal excrements as fertilizers, while the Northern European and Mediterranean societies used not only the wastewater but also sewage sludge as manure. Prior to the introduction of wastewater treatment technologies, several North American and European cities disposed of wastewater in agricultural fields to prevent pollution of waterbodies. In Paris, France, use of partly treated wastewater was common until the second part of 1900s.

Wastewater irrigation is widespread in the Near East owing to severe water scarcity and large populations. For instance, the Kuwait's agriculture is dependent on reclaimed wastewater, while Iran uses close to 70 million M^3 of wastewater for agricultural irrigation annually (Hamilton *et al*., 2007). Sewage farms (WB, 2010) began declining in urbanized industrialized countries around 1913 due to the development of biological wastewater treatment processes that required much less land. The decline of sewage farms and their almost complete abandonment in much of the western world was further contributed by odour and public health concerns regarding the likelihood of disease transmission from raw sewage irrigated vegetables.

A study conducted by Roy *et al*. (2013) on the effects of wastewater reuse for crop production in Tejgaon metropolitan area in Dhaka, Bangladesh showed the farmers' first impression was cost saving from fertilizer use and were not aware of toxicity associated with wastewater irrigation, which could affect their economic gains.

In agriculture, the problem of wastewater utilization is to discover practical and safe applications that do not jeopardize those people who are dependent upon it and take account of the importance it attaches to attaining food security in increasing metropolitan areas. It is not just a task, but also a chance. For example, nutrients can be used for farming; however, most localities have limited room to treat and dump on the ground. The employment of this technology can also bring beneficial benefits to farmers, society and towns and perhaps generate health hazards for farmers, their families and consumers, while severely affecting the environment. These are not often strictly complied with although they are established (UN- Water, 2013).

2.2.3 Reviews from Africa Continent

In Africa there are inadequate urban and rural water and sanitation facilities. Increased amounts of wastewater generate population expansion, improvements of livelihoods and socio-economic situations. In most cases, waste is dumped into the receiving environment unprocessed, which leads to downstream water sources being threatened by health and pollution. Urban or rural poor people often rely on untreated wastewater to meet their livelihoods and needs for food security, which not only threatens their health but also consumers and the environment (Bahri *et al*., 2016).

Households might spend up to 80% of their income on food demands in water-scarcity areas of Africa, where urban poor are engaged in agriculture with wastewater as a result of the lack of jobs. They consume part of their own produce and thereby enhance food safety and allow them to use their revenue for other purposes. It is not just a livelihood source, but also many cities depend on high quality foodstuffs generated in wastewater, notably vegetables (Raschid-Sally *et al.*, 2005).

Vegetables are grown in soils irrigated with wastewater having high concentrations of harmful metals and are accumulated in edible and inedible parts of the vegetables in sufficient quantities to provide potential health problems for the human and animals ingesting these metal-rich plants. Even at low amounts, heavy metals can be harmful and not biodegradable. They endure in different environments and can accumulate in plants and animals. Consumption of food crop from wastewater irrigated and partly treated farming effluents could expose consumers to a number of diseases that are often only visible after years of exposure (Edokyapi *et al*., 2017).

Despite the fact that several African countries face a water crisis, many of them have no regulations and thus wastewater reuse is practiced unregulated. However, countries like Tunisia have comprehensive guidelines that include physicochemical and biological parameters, as well as heavy metals (Navarro, *et al*., 2015).

2.2.4 Reviews from East Africa

In Tanzania, vegetables are cultivated along river valleys passing through cities. In the city of Dar es Salaam, for instance, urban agriculture is practiced along several river valleys where the rivers are recipient of toxic chemicals from industries (Sibomana *et al*., 2012).

2.2.5 Reviews from Kenya

In Kenya, close to 2,200 ha are irrigated with water of varying qualities by about 3,700 farmers within a radius of 20 km of Nairobi City, a practice that could result in public health and environmental risks (Njenga *et al*., 2011). Approximately 30% - 40% of households within the confines of Nairobi City (FAO, 2012), practiced agriculture, either as producers, processors or traders.

Farmers and farm workers can be directly exposed to pathogens, and consumers of the farm produce will be indirectly affected. In addition, the surrounding community can be further affected through the contamination of groundwater and runoff to surface water. Aerosols can be formed in farms where sprinkler irrigation is used, thus affecting nearby communities as well (Adegoke *et al.*, 2018).

2.3 Wastewater use in vegetable production

This section is about literature review on sources of wastewater, reasons for using and irrigation methods used in vegetable production.

2.3.1 Sources of wastewater

Municipal wastewater generally comprises of household wastewater, industrial wastewater, storm water and groundwater drainage that enter the municipal water system. The wastewater in families, institutions and commercial buildings is composed of wastewater, whereas industrial wastewater is the wastewater released by manufacturing facilities and food processing plants (Hussain, *et al*., 2002).

On average, countries with high incomes treat approximately 70 percent of their municipal and industrial wastewater. In countries with a high middle income, the percentage decreases to 38%, and in those with a lower middle income to 28%. Only 8 percent of low-income countries undergo any type of treatment. Either to preserve environmental quality or to give an alternative source in dealing with water shortages is the motive behind the improved wastewater treatment in high-income countries. The release of untreated wastewater is, however, very widespread in underdeveloped nations, particularly due to insufficient or lack of infrastructure, technical and institutional capabilities, and funding (UNWWDR, 2017).

A study conducted by Cornish and Kielen (2004) from 1998 to 2001 in Kumasi, Ghana and Nairobi to establish water sources, crop management and marketing, and contribution of informal urban and peri-urban irrigation practices to household income and expenditure, showed 3% each of the irrigators in both cities used urban potable water supply, while the majority used shallow groundwater that was polluted to varying degrees. Other irrigators used streams or rivers that were equally polluted. Majority (51%) of the farmers in Nairobi used water from rivers and streams, while in Kumasi, 46% of the farmers used shallow weir as source of irrigation water (Table 2.1).

Table 2. 1: Different sources of water and percentage of irrigators in Nairobi and Kumasi cities

Source	Nairobi (%)	Kumasi (%)
Stream/river	51	38
Main sewerage	34	0
Shallow weir	4	46
Urban potable water supply	3	3
Other (deep well, pool etc.)	8	13

Source: Cornish and Kielen (2004)

Whereas 34% of farmers in Nairobi used raw sewage from the sewerage main, none of the farmers in Kumasi used this source, hence signifying the extent of wastewater use in vegetable production in Nairobi City. Treated wastewater was not being used for irrigation in either city.

The use of wastewater for irrigation is mainly constraint by the concern for public health. Wastewater carries with it an array of pathogenic microorganisms that pose a risk to farmers, farmworkers, vendors of vegetable crop produce, and consumers. High levels of nitrogen in wastewater can cause nitrate pollution of groundwater resources used for drinking, which could lead to adverse health effects. Direct contact and use of sewage water in raw form for irrigation and indirect influence of such practice in contamination of food chain, and water sources is potential of inducing severe implications on the farmers' health (Radhika and Kulkarni, 2017).

The current study acknowledges the works of Cornish and Kielen (2004), Ngigi et al. (2011), and Ndunda and Mungatana (2013) with respect to sources of wastewater used for vegetable production by farmers in urban and peri-urban areas. However, the study sought to establish exact points where vegetable farmers draw wastewater they use for irrigation in the study area.

2.3.2 Reasons for using wastewater in vegetable production

Farmers that need irrigation water commonly use wastewater in urban and peri-urban regions in most developing countries (Gweyi-Onyango and Osei-Kwarteng, 2011). Drivers for wastewater use include increasing pressure on freshwater resources, in part due to climate change, increasing urbanization and growing wastewater flows, and more urban households engaged in agricultural activities (WB, 2010). Farmers prefer wastewater because it provides not only the soil moisture, but also the nutrients necessary for plant growth (Kaluli *et al*., 2011).

Wastewater users from several social and economic backgrounds use wastewater for irrigation purposes in diverse ways. In semi-arid and dry regions, it is often the only water source available in adequate amount for irrigation. Unlike fresh water from precipitation, which is concentrated in frequently brief and intermittent rainy seasons, it is also available throughout the year. It is also an affordable source of water as well as vegetable nutrients (Buechler *et al*., 2006).

Rising water scarcity, degradation of freshwater resources, and increasing population growth with corresponding demand for food has resulted in increased untreated wastewater irrigation in vegetable production in Africa's urban areas (Owusu *et al*., 2012).

The water supplies are constantly being used as irrigation and are becoming the only water for several farmers in areas with water stresses where fresh water caused by population growth, urbanism, and climate change are increasingly scarce and water supplies are being maintained, untreated or partially treated. 10 per cent of the world's population is projected to depend on food produced with contaminated wastewater (UN- Water, 2013).

A study conducted in Imo State, Nigeria by Emenyonu *et al* (2010) showed more than 50% of the farmers preferred wastewater because of plant nutrient content, while close to 25% of them used it due to unavailability or high cost of freshwater. The profit after the introduction of wastewater use surpassed the profit before, which led to the conclusion that wastewater use in vegetable production was a profitable venture. The study further revealed some of the respondents took precautionary measures whenever they were in contact with wastewater.

Although wastewater is beneficial because of essential plant nutrients, its use for crop irrigation is associated with sanitary, environmental and health risks due to presence of toxic contaminants and microbiological organisms (Khalid *et al*., 2018). Whereas reuse of treated wastewater is a coping strategy during periods of water scarcity (Drechsel and Evans, 2010), untreated wastewater (Emenyonu *et al*., 2010) often becomes the only source of irrigation water particularly in areas lacking reliable sources of freshwater supply.

As opposed to fresh water, the flows of wastewater do not differ with season, climate or precipitation, thus farmers can cultivate crops year round. Irrigation of wastewater, however, poses health and environmental problems. Diseases can most likely spread by presence of parasite worms and heavy metals in food. Flood irrigation can also lead to soil durability, enrichment of heavy metals and low groundwater contamination, when applied without preparation immediately (Zhang and Shen, 2017).

It is against this background that the current study which sought to establish the health and environmental risks of using wastewater in vegetable production in an urban and peri-urban setting in Nairobi City in Kenya will therefore fill the identified gap.

2.3.3 Irrigation methods

Application of water to plants can be through surface and localized irrigation. In surface irrigation, water flows under gravity without pumping and can be performed as furrow, flood or border strip irrigation. When water is applied to each plant with the help of connected pipes, it is called localized irrigation. In this irrigation method, water can be supplied through drip irrigation, spray or micro-sprinkler irrigation or bubbler irrigation (Alam, 2014). The surface irrigation, irrigation and drip irrigation are three primary irrigation technologies under the FAO (2001). Surface irrigation requires water to be applied to the field surface by gravitational flow. The whole field is flooded (water irrigation) or the water is supplied to tiny channels (furrows) or land strips (border irrigation).

The preferred method of irrigation is dependent on the condition of water supply, climate, soil, crop, cost and the farmer’s capacity to manage the selected system. Other factors such as contamination of farm workers, crop and the harvested produce, the environment, salinity, and toxicity hazards will have to be taken into consideration when wastewater is used (Valipour and Singh, 2016).

One of the factors influencing the microbial quality of farm produce is the type of irrigation used (Keraita *et al*., 2007). According to the WHO (2006), localized irrigation techniques like drip irrigation presents the lowest hazard to farmers, while at the same time causing minimal transfer of pathogens to crop surfaces as water is directly applied to the root.

Consideration must be given to the environmental dangers connected with irrigation of wastewater. Untreated irrigation of wastewater can readily lead to accumulation of heavy metals in soils. Appropriate irrigation technologies can effectively reduce the negative impact of water irrigation on the environment. Flood irrigation may pollute a complete field, as is the most environmentally beneficial strategy, depending on the technology utilized (Zhang and Shen, 2017).

In Lima, Peru farmers using treated and untreated wastewater in vegetable production channel it to the farming land using furrows and watering cans. Most wastewater irrigators in many parts of the world including Sub-Saharan Africa (IMWI, 2006) use watering cans. Although this requires minimal investment, probability of contamination of mainly leafy vegetables through spraying of droplets on the leave surface increases with the use of watering cans (Roman *et al*., 2007).

Surface irrigation (furrow) is used at La, Accra, Ghana, where the farming area is a moderately larger open field with a topography that allows for furrow irrigation. A drain to the treatment facility is used for water supply. Farmers drain water into sewers from which they may water with green vegetables. Furrow irrigation can lessen crop pollution since crops are planted on ridges, but the farmers' exposure is as high as water fetching from rivers and drains (Obuobie *et al*., 2006).

In Kenya, surface irrigation represents 67% of irrigated area, while drip irrigated area is about 2% of irrigated area, while sprinkle irrigated area represents 31% of irrigated area. The most commonly irrigated crops are vegetables such as *Brassica* sp. *Spinacia oleracea*, cabbage and onions (Monteiro *et al*., 2010). Assessment of risks associated with urban wastewater irrigation and production of traditional African vegetable seeds in Nairobi by Njenga *et al* (2011) revealed farmers used surface irrigation (furrow and flood), and ground seepage irrigation methods as well as watering cans.

Safe irrigation methods in wastewater irrigation have to be complemented with other practices to ensure safety of others involved in the value chain (FAO, 2012). The safer irrigation options (Owusu *et al*., 2012), are safer technologies during fetching, transportation and application in order to mitigate against potential environmental and public health hazards that are associated with the use of untreated wastewater. In case wastewater is used, factors that have to be taken into consideration are contamination of farm workers, crop and the harvested produce, the environment, salinity, and toxicity hazards (Valipour and Singh, 2016).

In view of the nature of wastewater, the current study sought to establish irrigation methods used by vegetable farmers in the study area. In addition, precautionary measures put in place by farmers to ensure safety while in contact with wastewater will be observed and documented.

2.4 Physicochemical characteristics and microbiological composition of wastewater

The characteristics of recycled water and classification according to its physicochemical and biological aspects is determined by its source, level of treatment and geographical location.

The physicochemical characteristics are crucial for understanding the environmental effects, while the biological aspect of recycled water is important when health effects are considered (Maheshwari, 2016). Water quality is determined by its physical, chemical and microbiological properties. Hence, the quality of natural water sources used for different purposes should be established in terms of the specific water-quality parameters that most affect the possible use of water (Shah, 2017).

2.4.1 Physicochemical characteristics of wastewater

The main physicochemical characteristics of wastewater include pH, oxygen demand, suspended and dissolved solids, phosphate and metals Akpor and Muchie (2011). One of the factors that lower crop productivity (Poyen *et al*., 2019) is the quality of irrigation water. Vegetables and crops grow well if the soil pH level falls between 5.5 and 7 to a maximum of 8 with best conditions of 6.5.

Wastewater irrigation affects crops based on water compositions and crop physiological mechanisms. Untreated wastewater irrigation leads to accumulation of heavy metals in crops (Zhang and Shen, 2017). Trace elements according to (Jeong *et al.*, 2016) are essential for crop growth but when the amount of heavy metals in irrigation water is excessive, it can cause harm. For instance, Pb and Cd when dissolved in water or soil, they can be accumulated in the crop and become harmful to the human body.

Metals are non-biodegradable because of long biological life and are hazardous contaminants in the environment and food (Tasrina *et al*., 2015). Heavy metals (Naser *et al*., 2012) have a tendency to bio-accumulate in plants and animals, and bio-concentrate in the food chain and attack specific body organs. Heavy metal contamination (Bagdatlioglu *et al*.,

2010) can be triggered by irrigation with contaminated water, application of fertilizers and metal-based pesticides, industrial emissions, transportation, harvesting process, and storage and /or sale.

Key sources of chemical pollutants that pose risk to human health are municipal and industrial wastewater (Buechler *et al*., 2006). Using effluents discharged from manufacturing industries, wastewater irrigation systems and municipal sewerage for irrigation results in increased accumulation of heavy metals in food crops and vegetable plants thereby compromising food safety (Verma and Kaur, 2016).

Through food, drinking water and air, heavy metals enter the human body. Consumers are raising demand for improved vegetables. Some unpolluted, dark green and large leaves have good quality leafy vegetables. However, exterior vegetable morphology cannot ensure pollution protection. The main pollutants of leafy vegetables include heavy metals. Vegetables absorb metals from contaminated soils and contaminated habitats. Vegetables growing on heavy metal contaminated medium can accumulate high concentrations of trace elements and cause health risk to consumers (Ali and Al-Qahtani, 2012).

In low concentrations, many metals are essential to life. For instance, trace quantities of certain heavy elements like Co, Cu and Zn are essential micronutrients for plants and higher animals. However, excessive accumulation in agricultural soils through wastewater irrigation not only result in soil contamination, but also affects food quality and safety (Naser *et al*., 2018).

The presence of heavy metals, which are introduced into the municipal sewer by discharging untreated industrial wastewater is among the most restrictive factors for agricultural wastewater utilization. The repeated use of sewage effluent in agricultural areas could also contribute to metal accumulation in soil, because the high retention capacity of this waste is an essential sink for heavy metals (Bashir *et al*., 2009).

Impact from wastewater on agricultural soil is mainly due to the presence of high nutrient contents, high total dissolved solids (TDS) and other constituents such as heavy metals, which are added to the soil overtime (Hassan *et al*., 2015). Investigation of water quality in Nairobi River by Mbui *et al*. (2016) showed values for TDS were below the acceptable NEMA limits of 1200 mg/l for natural water and the range was 176-438 mg/l. The range observed for pH, TDS, Cu, Zn, Pb and Cr was 6.89-7.77, 176-438 mg/L, < 0.01- 0.1799 mg/L,<0.005-0.0197 mg/L, < 0.05-0.4415 mg/L and < 0.02- 0.0846 mg/L, respectively

It is against this background that the current study investigated the physicochemical properties viz. pH, total dissolved solids (TDS), Al, Cd, Cr, Co, Cu, Zn and Pb in samples of wastewater used for vegetable production in Ruai ward, Nairobi City, Kenya; and evaluated their concentration status with recommended limits for corresponding parameters in the Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water.

2.4.2 Microbiological composition of wastewater

Municipal wastewater as a medium consisting of water, and organic and mineral substances characterized by negligible temperature variations, provides favourable conditions for the development, existence and survival of fungi, viruses and bacteria as well as pathogenic organisms (Bawiec *et al*., 2016). Pathogenic microorganisms in wastewater that are potential of causing disease are bacteria, viruses and parasites (Hussain *et al*., 2002).

Wastewater comprises a vast variety of discharged organisms whose types and quantities fluctuate according to population background levels. Many diseases can persist in soil or on crop surfaces for long enough time to be transmitted to humans or animals. Helminth eggs are known to be the greatest health concern for the use of wastewater for irrigation as the most environmentally resistant pathogens. Helminthiasis is prevalent and endemic in Africa, Latin America and the Far East. Ascariasis can occur with different types. Cholera, typhoid, stomach ulcers caused by *Helicobacter pylori* and Amebiasis are further diseases linked to the usage of wastewater (Jiménez, 2006).

Although coliforms commonly occur in water they are generally not harmful to human. Their presence is used as an indicator for water contamination with diseases causing germs and pathogens (Abbas *et al*., 2015). Levels of faecal coliforms in water used for irrigation often exceed the WHO (2006) wastewater irrigation guidelines. Irrigation with untreated water and wastewater is one source of microbial contamination of vegetables along the production chain. Other sources include pathogens in the soil, application of contaminated manure, and cleaning the vegetable produce with polluted water. In the case of vegetables produced in urban areas the main microbial contamination occurs during primary production thereby suggesting post-harvest processing and handling do not necessarily increase contamination levels (Magnusson and Bergman, 2014).

Escherichia coli is a non-spore-forming gram-negative bacterium and it is the most common cause of acute urinary tract infections. It also cause acute enteritis in human beings and animals and is a general cause of a dysentery-like disease affecting human beings, and haemorrhagic colitis often referred to as ‘bloody diarrhoea’ (Percival and Williams, 2014).

In Njenga *et al* (2011), 82% and 66% of vegetable farmers involved in wastewater irrigation in Kibera and Maili Saba tested positive for parasitic larvae respectively. There was also no significant difference in parasitic loads found in faecal samples that were collected from the farmers using wastewater and the non-farmers at Maili Saba meaning that parasite levels were due to environmental contamination and exposure to the wastewater. Amongst the interviewed households, 34% reported that at least one member of their families had health problems caused by wastewater.

Non-pathogenic components in municipal wastewater varies in their composition over time, sites and regions. For instance, the composition of typical raw wastewater depends on the residential communities' socioeconomic characteristics and population size as well as types of industrial and commercial units (Kanyoka and Eshtawi, 2012).

The Standard Newspaper article *'Waste management, the new challenge for property developers'* of 22nd February, 2018 reported that:

> 'The Ruai sewage treatment plant in Nairobi, the 3rd largest in the region collects and treats an equivalent of up to 80% of wastewater generated from the city of Nairobi. The rest ends up in rivers or other disposal means that could expose residents to harm'.

It is against this background that the current study sought to determine concentrations of total coliforms as an indicator for water contamination with disease causing germs and pathogens, and *Escherichia coli* in the samples of wastewater used for vegetable production in Ruai ward, Nairobi City, Kenya; and evaluated status of their levels with respect to corresponding parameters in Environmental Management and Coordination (Water Quality) Regulations, 2006 microbiological quality guidelines for wastewater use in irrigation.

2.5 Heavy metals in wastewater- irrigated vegetables

Heavy metals (Engwa *et al*., 2019) naturally occur in the environment and their exposure to human beings is through various anthropogenic activities. They reach the soils and water bodies through erosion, run-off and acid rain. Metals such as Pb, Cd and manganese (Mn) enter human body via gastrointestinal route when eating food, fruits, vegetables or drinking water or other beverages. It can also be through inhalation, while others such as Pb can be absorbed through the skin. Sources of some heavy metals are shown in Table 2.2.

Table 2.2: Main toxic metals in industrial effluents

Heavy Metal	Source
Cadmium	Emitted through industrial process (e.g. paints, batteries and plastics) into sewage sludge, fertilizers and groundwater and taken up by plants. Human exposure can be by ingesting contaminated leafy vegetables.
Chromium	Present in petroleum, chromium steel, fertilizers, and metal plating. Used in wood preservation.
Copper	Used in production of copper pipes, cables, wires, copper cookware etc. It can accumulate in the soil and up taken by plants.
Lead	Released into the atmosphere from industrial processes and vehicle exhausts and can eventually get into the soil and flow into waterbodies, which can then be taken up by plants hence human exposure through food or drinking water.
Zinc	Plating, galvanizing, iron and steel

Source: Engwa *et al*., 2019

Natural and anthropogenic sources are responsible for increasing levels of heavy metals in the environment. Anthropogenic sources include sewage sludge, pesticides, organic matter, compost, fertilizer supplements, industrial waste, smelting and metallurgical industries, and use of treated or untreated industrial and municipal effluents for irrigation purposes (Engwa *et al*., 2019). The heavy metals contribute to the soil from where they are translocated via root absorption to various plant components. The accumulation and absorption of heavy metals from various plant parts rely on the levels of accessible heavy metals in soil and the shape of metals (Agrawal *et al*., 2007).

Although vegetables form an important part of human diet, they contain both essential and toxic elements at varying concentrations on the surface and in the tissue of fresh vegetable (Bigdeli and Seilsepour, 2008). Leafy vegetables (Asdeo and Loonker, 2011) are capable of accumulating heavy metals than other vegetables.

Soil acts as a medium for plant growth which can recycle nutrient and resources that plants need. It will absorb heavy metals in the polluted river as well as ground water causing side effect for vegetable growth. As roots grow in the soil, they will absorb water and nutrients in solution. Heavy metals that are attached with soil water and soil particles will be absorbed by plant roots and accumulated in vegetables. Using water which is contaminated by heavy metals for irrigation is another pathway through which heavy metals get into vegetables (Aweng *et al*., 2011).

Heavy metals also enter into vegetables through manure, sewage sludge, fertilizers and pesticides (Yusuf and Oluwole, 2009). Heavy metals that are essential plant nutrients include Cu, Zn, Mn and iron (Fe), while some like Cd and Pb do not play any major role in plant physiology and are often found as contaminants in vegetables (Tasrina *et al*., 2015). Transfer of heavy metals from water to soil and finally uptake from soil and accumulation in edible parts of vegetative tissue represents a direct pathway through which they get incorporated into the human food chain (Bashir *et al*., 2009).

Vegetable plants growing on a medium contaminated with heavy metal have the potential to accumulate trace elements in high concentration to cause health risk to consumers (Ali and Al-Qahtani, 2012). Heavy metals such as Cr, Zn and Cu (Shakya and Khwaounjoo, 2013) though essential for biological activities in the body, their presence in high concentration can be a health risk.

Assessment of leafy vegetables viz. *Amaranthus* sp. and *Solanum villosum* grown in Thika town by Inoti *et al* (2012), revealed the two vegetable species accumulated Pb in their stems and edible leaves but the stems accumulated the highest concentration. The concentration of heavy metals on the surface and within plants are influenced by several factors including climatic conditions, atmospheric deposition, application of fertilizers, type of soil on which the plant is grown, and irrigation with wastewater (Shakya and Khwaounjoo, 2013).

All living organisms accumulate in their system substantial amount of Zn without any damaging effect as it is essential for carbohydrate metabolism, protein synthesis and inter nodal elongation. Zinc deficiency causes loss of appetite, growth retardation and immunological abnormalities. However, Zn can be toxic when exposures exceed physiological requirements (Shakya and Khwaounjoo, 2013).

Lead is a toxic element that can be harmful to plants, although plants usually show ability to accumulate large amounts of Pb without visible change in their visible appearance or yield (Tasrina *et al*., 2015). Excessive accumulation of Pb in plant tissue impairs various morphological, physiological and biochemical functions in plants often with deleterious effects. Elevated levels of Pb in the blood is potential of causing kidney dysfunction and brain damage (Gupta *et al*., 2013). There is relationship between Pb in the human body and the increase of blood pressure of adults as pointed out by Ametepey *et al* (2018). Lead also causes mental retardation in young children (Mutune *et al*., 2014).

Cadmium is non-essential and has no nutritional value to plants, animals and human beings because it is toxic, while Cu is an essential micronutrient which functions as a biocatalyst required for body pigmentation (Latif *et al*., 2018). According to Gezahegn *et al* (2017), Cu works with many enzymes like those involved in protein metabolism and hormone synthesis. Excessive intake can cause vomiting and nervous system disorder, while its deficiency causes low white blood cell count and poor growth.

Cobalt is essential to human because it forms part of vitamin B_{12} but exposure to elevated levels results in lung and heart diseases, and dermatitis (Oladeji and Saeed, 2015). Symptoms of Co deficiency (Gezahegn, 2017) include loss of appetite, emaciation, weakness and anemia. Chromium (Ametepey *et al*., 2018) is crucial for insulin activity and deoxyribonucleic acid transcription in living organism particularly human beings. However, an intake < 0.02 mg per day could lower cellular responses to insulin.

Human beings get exposed to heavy metals like arsenic (As), Cd, Pb and mercury (Hg), which are linked to several health effects through prolonged consumption of contaminated foodstuff or inhalation of irrigated soil. For instance, exposure to Cd cause renal damages and osteoporosis in children (Al Osman *et al*., 2019). Apart from toxicity, deficiencies of heavy metals also occur and hence, knowledge about their concentration in vegetables for dietary supply is vital (Mutune *et al*., 2014).

The uptake of heavy metals by leafy vegetables (Akan, 2013) is an avenue of their entry into the human food chain with deleterious effects on health. Examples of heavy metals that are essential plant nutrients (Tasrina *et al*., 2015) are Cu, Zn, Mn and iron (Fe), while those which do not play any major role in plant physiology and are often found as contaminants in vegetables include Cd and Pb.

Soil absorbs heavy metals and ground water into a polluted river, which will have a negative influence on the growth of vegetables. As soil roots grow, water and nutrients are absorbed into a solution. Heavy metals connected to soil and soil particles are absorbed and incorporated into vegetation by plant roots. The irrigation water that is contaminated with heavy metals is another way to enter vegetables heavy metals (Aweng *et al*., 2011). Plants growing in metal-polluted environments often do not show visible signs of intoxication even if they contain elevated concentrations of toxic metals (Abaidoo *et al*., 2010).

It is against this backdrop that the current study determined the concentrations of selected heavy metals viz. Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of vegetables produced using wastewater in Ruai ward, Nairobi City, Kenya; and evaluated their status with FAO/ WHO safe limits for corresponding heavy metals in green leafy vegetables. The FAO/ WHO (2011) safe limits for Zn, Pb, Cr, Cd, Co and Cu in green leafy vegetables are 0.099, 0.0003, 0.0023, 0.0002, 0.005 and 0.073 g/kg, respectively.

2.6 Risks of using wastewater in vegetable production

The interest in wastewater use for agricultural purposes (Jaramillo and Restrepo, 2017) increased in 1990s in many countries as a result of huge demands for water in the sector. During the period, reuse of wastewater received a global attention due to associated public health and environmental hazards prompting the WHO to draft the *'Reuse of effluents: methods of wastewater treatment and health safeguards'* in 1973 to protect public health and facilitate rational use of wastewater and excreta for agriculture and aquaculture. Example of good practice in wastewater irrigation (Roman *et al*., 2007), is in Lima, Peru where farmers are required to fulfill certain precautions such as maintaining a buffer zone of between 50 and100 metres.

Wastewater use in agriculture can be both a benefit, providing water and nutrients for the cultivation of crops and ensuring food security in the cities, as well as a source of pollution, a threat affecting the health of users, consumers and the environment depending upon its composition, the treatment it has undergone, the extent to which it is irrigated and the regulations and principle guidelines under which it is being utilized, (UN Water, 2013).

Although wastewater is a source of plant nutrients and organic matter, it contains harmful chemical constituents and pathogens that pose health and environmental risks. Whereas some risks are short term impacts like microbial pathogens, others such as salinity effects on soil have longer-term impacts that increase with continued use of wastewater. Apart from microorganisms, household sewage contains salts, hence irrigation with treated wastewater causes land salinity, which in turn can cause land sealing and sodium accumulation which could cause increased runoff and land erosion (Shakir *et al*., 2016).

Potential toxic elements like Zn, Cr, Cu, Cd, Pb, and parasitic worms in wastewater (Khalid *et al*., 2018) are capable of inducing environmental and human health risks. The untreated wastewater crop irrigation can also cause soil hardening and groundwater contamination. There can also be chemical risks to plant health through soil and groundwater pollution (WB, 2010). Untreated wastewater irrigation is a major threat to public health, food safety, and environmental quality (Muneri, 2011).

A study conducted in Pakistan by Buechler *et al* (2006) on the impact of wastewater irrigation on health, environment and income showed farmers and farmworkers using wastewater for irrigation had higher hookworm infections compared to the farmers who did not. This led to the conclusion that consumption of raw vegetable or salad crops grown with untreated wastewater exposed consumers of wastewater-irrigated produce to high risk from diseases like cholera, typhoid and dysentery. In Dakar, Senegal (Amoah *et al*, 2016) prevalence of amebiasis and ascariasis is 60% amongst farmers using wastewater for irrigation.

Investigation of public health and environmental hazards associated with wastewater irrigation in Nairobi's urban agriculture by Mutua *et al* (2010) revealed the presence of heavy metals mainly in the stem and leaves, which raised health concerns as the plant parts were harvested for human consumption.

2.6.1 Health risks of using wastewater in vegetable production

The health effects of irrigating with wastewater can be both beneficial and negative. The beneficial effects are related to food security especially amongst disadvantaged communities, whereas the negative effects are due to the presence of pathogens and hazardous chemical compounds in wastewater. Groups that are at risk are agricultural workers and their families, crop handlers, consumers of crops and persons living near the areas irrigated with wastewater particularly children and the elderly (Jiménez, 2006).

The disadvantages of using wastewater include health risks it poses on farmers, persons in contact with untreated wastewater for a reasonably long time and the consumers of vegetables irrigated with wastewater. Another disadvantage is the creation of favourable conditions for disease vectors like mosquitoes in peri-urban areas (Raschid-Sally *et al*., 2001). Treated wastewater irrigation represent a range of potential concerns for human health, through consumption or exposure to pathogens, heavy metals and organic compounds (Shakir *et al.*, 2016).

A comparison of helminth infections amongst farmers (Qadir *et al*., 2010) showed farmers irrigating with wastewater had higher rates than farmers using freshwater although there were exemptions Farmers using wastewater for irrigation can also experience skin and nail problems (Akhtar *et al*., 2018).

In developing nations, many farm households irrigating with wastewater are unaware of the risks or environmental impacts. Household members may be illiterate, lack sufficient information and resources and have suffered most of their lives from terrible sanitary conditions. In the broader context of their living conditions where wastewater contact through irrigation can be merely one among a number of sanitary issues, many farmers therefore accept these health risks. The primary risk groups are, however the consumers of wastewater-irrigated produce such as fresh vegetables.

Often, untreated wastewater (Dickin *et al*., 2016) comprises a wide spectrum of municipal, agricultural and industrial contaminants. The health risk of farmers and their families and agricultural workers, their families, communities living in the proximity of wastewater irrigation as well as consumers of wastewater irrigated crops is caused by excreta-related infections, skin irritants and toxic compounds from these sources.

Viral, bacterial, and protozoan diseases such as salmonellosis, shigellosis, cholera, giardiasis, amebiasis, hepatitis A, viral enteritis, and other diarrhoeal disorders have been associated with wastewater exposure. Helminth infections such as ascariasis, are frequently associated with wastewater exposure and are linked to anemia, as well as physical and cognitive development problems. Agricultural labourers also develop skin disorders such as dermatitis and rashes as a result of frequent contact with untreated wastewater (Dickin *et al*., 2016).

Microbial diseases (Jaramillo and Restrepo, 2017) can be transmitted by water either directly or indirectly and have been implicated globally for premature mortality. Other compounds present in wastewater that pose potential risks to human health are emerging contaminants like pain relievers and antibiotics.

In most developing nations faced with rapid urbanization and inadequate wastewater treatment facilities (Yadav *et al*., 2016), peri-urban farmers are often compelled to use wastewater either from the sewage drains or wastewater-polluted sources, which can pose a significant occupational and public health hazard. For instance, peri-urban vegetable production in Pakistan (Kouser *et al*., 2009), is mainly dependent on untreated wastewater, which increases the agricultural labourers' probability of falling ill.

The main concern associated with wastewater reuse is related to public health and infection risks, either real or potential. Infection rate can be high, low or minimal, depending on the type of pathogen, the infective dose, and the susceptibility of the affected person. Thus, risks of reusing water in agriculture are minimal as long as its biological quality meets established criteria. Epidemiological studies over 20 years, revealed when wastewater is applied to land for crop production, there exist real infection risks caused by pathogens (Navarro *et al*., 2015).

Human health risks posed by wastewater crop irrigation can either be occupational or consumption-related. Ascaris and hookworm infections are more critical than infections from bacteria, virus and protozoa. Exposed groups include farmers and workers because of long time spent in contact with wastewater and contaminated soils. Consumption-related risks relate to eating uncooked vegetables such as salads (Abaidoo, *et al*., 2010).

Of health concern in wastewater use is the chemical content. If present in small quantities most chemical compounds are biologically useful but become harmful at high concentrations. Although Co, Zn and Cu are not likely to be absorbed by plants in sufficient quantities to prove harmful to consumers, they are toxic to plants far before reaching a concentration that is toxic to human beings. Cadmium poses the greatest risk (Shakir *et al*., 2016).

Soil contamination with potentially toxic elements (PTEs) is the main route of their exposure to human beings via consumption of food crops. Should the concentration of PTEs exceed the safe limits, it can result in various health complications in the human body. Long-term use of vegetables contaminated with PTEs can cause toxic metals accumulation in the body organs such as the liver and kidneys (Khalid *et al*., 2018).

Repeated application of treated and untreated wastewater in vegetable production could result in enormous accumulation of heavy metals in soil and in vegetables, which are transferred to food chain with potential health risk to consumers (Perveen *et al*., 2010).

One of the health protective actions of reducing health risks in wastewater-irrigation is through education and awareness creation. Prior to which, it is important for the producers and consumers to understand various food safety issues and perceptions that concern them (Antwi-Agyei *et al*., 2016).

Excess nutrients, pathogens, heavy metals and pesticides are frequent in wastewater and detrimental to human beings and the environment (UN-Water, 2013). Table 2.3 shows the major health dangers to farmers and consumers, as is common in most parts of Africa, when the vegetables are watered with improperly treated effluent.

Table 2. 3: Examples of health risks associated with consumption of wastewater irrigated vegetables

Risk type	Health risk	Exposed population	Exposure pathway
Contact-related risks (occupational)	• Parasitic worms (helminths) e.g. intestinal roundworms and hookworms • Diarrhoeal diseases amongst children • Skin infections causing itching and blisters on the hands and feet as well as dermatitis (eczema)	Farmers/ farmworkers Children playing on the farm Market vendors	Contact with irrigation water and contaminated soils Contact with wastewater used for irrigation and contaminated soils • Exposure to contaminated soils while harvesting • Washing vegetables with wastewater
Risks related to consumption	• Mainly bacterial and viral infections such as cholera, typhoid, hepatitis A, viral enteritis which mainly cause diarrhoea • Parasitic worms e.g. ascaris	Vegetable consumers Children playing on the farm	Eating contaminated vegetables, especially those eaten raw like green salads Licking soil

Source: UN- Water (2013)

Health risks connected with partially treated and untreated wastewater recycling are dependent on the combination of exposure and the presence and concentrations of hazards such as pathogens. For example, excreted pathogens vary according on pathogen type and strain, the individual in question and the stage of the cycle of infection and are therefore dependent upon the population's health and pathogens' susceptibility to environmental stressors (Adegoke *et al*., 2018).

In countries with perennial freshwater scarcity especially in light of increasing volumes of urban wastewater, wastewater irrigation is expected to grow, a scenario that requires a thorough understanding of the major health risks and exposure pathways in order to make relevant risk management decisions for different wastewater use situations (Dickin *et al*., 2016).

2.6.2 Environmental risks of using wastewater in vegetable production

Wastewater from various sources including industries transport considerable amounts of toxic heavy metals that are likely to contaminate agricultural soil. Continued application of municipal or industrial wastewater for irrigation result in the buildup of trace elements such as cadmium, copper, zinc, chromium and lead in the soil surface. Excessive accumulation of such elements not only contaminates the soil but also affects the quality and safety of food (Gezahegn *et al*., 2017).

Using wastewater for irrigation has adverse effects on the environment, particularly soil. Thus, prolonged use can alter physicochemical parameters and microbial composition of soil, which in turn affects soil fertility and productivity. Amongst the leading potential pollutants in wastewater are Cd, Zn, Cr, Pb, and Cu (Jaramillo and Restrepo, 2017). Wastewater irrigation also has the risk of polluting ground water resources as pointed out by Radhika and Kulkarni (2017).

Treated wastewater irrigation causes land salinity, land sealing, and sodium buildup, which could cause increased runoff and land erosion. The most important negative effect on the environment caused by irrigation with wastewater is the increase in soil salinity, which can decrease productivity in the long term. Other potential environmental effects are strong odour nuisances and decreased yields often caused by improper control of treated wastewater irrigation, which in turn cause a decline in yield and poor quality crops (Shakir, 2016). Despite improved removal efficiencies during wastewater treatment in activated sludge systems, the remaining nutrients are harmful to aquatic ecosystems and could cause eutrophication (Raschid-Sally, 2013).

> Part III regulation 13 (1) of the Environmental Management and Coordination (Water Quality) Regulations, 2006 on 'discharge into public sewers' compels 'every owner or operator of a trade or industrial undertaking issued with a license by a local authority or sewerage service provider to discharge effluent into any existing sewerage systems shall comply with the standards set out in the Fifth Schedule of the Regulations'.

The study is justified because the findings will be of use to Nairobi county government in developing policies that promote safe use of wastewater for households' economic development. In addition, the findings will inform development and implementation of educational and public awareness programs for mitigating potential public health and environmental risks associated with wastewater irrigation.

2.7 Multiple-barrier Model relevant to the current study

In countries devoid of adequate resources and technology to effectively operate wastewater treatment facilities, the WHO guidelines (2006 Ed.) for safe wastewater irrigation recommends a 'multiple-barrier' approach (Figure 2.1) for health risk reduction. The guidelines' salient features are good agricultural, manufacturing and hygienic practices as a cost effective approaches of enhancing food safety at all stages of food chain where wastewater is used for irrigation (Drechsel *et al*., 2010).

Good practices for risk reduction

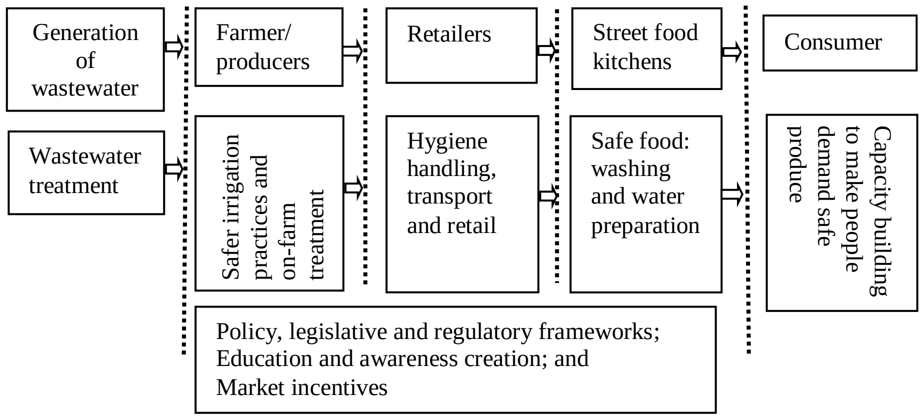

Figure 2.1: Multi-barrier approach in wastewater food chain

Source: Modified from Drechsel *et al*. (2010)

Vegetables often act as a media for carrying poisonous materials like heavy metals and other toxicants from either irrigation water or from land where they are grown. Contamination can be caused by factors like irrigation water contaminated by effluents or waste, contaminated soil, inorganic fertilizers or pesticides. Vegetables tend to absorb and accumulate higher concentration of heavy metals when grown on metal contaminated soils than those grown on uncontaminated soil. The heavy metals are absorbed alongside other plant nutrients. Contamination of soils and crops with heavy metals have adverse effects on soil, plants, animals and human beings (Danjuma and Abdulkadir, 2018).

Pathogenic microorganisms in wastewater that are potential of causing disease are bacteria, viruses and parasites (Hussain *et al*., 2002). In the soil or on crop surfaces pathogens may live long enough, and are passed on to people or animals. Helminth eggs are identified as the greatest health risk in the use of wastewater for irrigation (Jiménez, 2006). Irrigation with untreated water and wastewater is one source of microbial contamination of vegetables along the production chain. Other sources include pathogens in the soil, application of contaminated manure, and cleaning the vegetable produce with polluted water (Magnusson and Bergman, 2014).

The 'multi-barrier' approach for health-risk reduction in the wastewater food chain is relevant to the current study because it presents the exposure routes in the food chain through which consumers of foodstuff including vegetables produced using partially treated or untreated wastewater are exposed to pathogenic and non-pathogenic threats. The approach's good practices for risk reduction, which is aimed at enhancing food safety is a clear demonstration of allocating responsibility of risk reduction along the food chain starting with the farmer, as the producer followed by the handlers and finally the consumers.

2.8 Methodological approaches relevant to the current study

The current study used research questions instead of hypotheses since a theoretical hypothesis was not defined neither the samples of wastewater nor the vegetables were subjected to any particular experimental conditions before analysing. The study therefore followed a social approach. The inclusion and exclusion criteria for choosing which parameters to analyze in the samples of wastewater used in vegetable production and vegetables produced using wastewater in the study area was based on the existing respective set standards viz. Environmental Management and Coordination (Water Quality) Regulations 2006 microbiological quality guidelines for wastewater use in irrigation and FAO/ WHO permissible limits for heavy metals in leafy vegetables. Thus, the status of the analysed parameters was compared with allowable limits for corresponding parameters in these two national and international standards.

After determining the sample size for the study area, random selection of the respondents was done across the vegetable plots, where every farmer found on the farm involved in wastewater farming was interviewed using an interview guide. The idea of using an interview guide was borrowed from Woldetsadik *et al*. (2018) who used it in evaluating farmers' perceptions on irrigation water quality, health hazards and corresponding mitigation measures in four wastewater irrigated urban vegetable farming sites in Addis Ababa, Ethiopia.

Similarly, Ndunda and Mungatana (2013) used the same approach in assessing farmers' perception and knowledge risks in wastewater irrigation amongst farmers in Kibera slum, Nairobi City, Kenya. The only difference, however is that the current study did not use focus group discussions after an attempt to conduct one through a farmers' association did not take place. The Association's leader linked the failure to a negative publicity given to the practice of using wastewater in vegetable production by the media. In addition, Njenga *et al* (2011) used interview method when they investigated community-based wastewater farming and its contribution to livelihoods of the urban poor with particular focus on Nairobi, Kenya.

Semi-structured questionnaires was administered on twelve purposively sampled key informants on behalf of relevant State and non-state actors. The purpose was to gather information and views of their respective institutions regarding wastewater management in urban and peri-urban areas of Nairobi City, knowledge about its use in vegetable production and why farmers used it for irrigation, technical assistance given to the wastewater irrigators, general perception about wastewater use in vegetable production, potential health and environmental risks of using wastewater in vegetable production, and proposed policy and technical interventions to make wastewater safe and available for reuse in urban and peri-urban farming in the country.

The idea of using questionnaires in data collection was adopted from various workers. For instance, Njenga *et al* (2011) administered questionnaires on farmers using wastewater for irrigation in Kibera and Maili Saba to gather quantitative data on types of crops grown, land sizes, inputs used, management of community-based irrigation systems, and benefits and constraints faced in wastewater farming. Emenyonu *et al* (2010) also used structured questionnaires to obtain information on socioeconomic characteristics while studying the effects of wastewater use on vegetable production in Imo State Nigeria. Further, De Leeuw (2014) used semi-structured questionnaires in conducting key informant interviews among three key informants from the Department of Horticulture, the Health Centre and the Sewerage Department on multiple perspective on the use of wastewater in agriculture, a study among farmers and customers on the use of wastewater in irrigated vegetable cultivation in the Kathmandu Valley, Nepal.

Observation checklist and visual aids were used concurrently to observe and record farmers' activities with a focus on sources of wastewater and methods of irrigation used in vegetable production in the study area. That which was observed was recorded in the checklist and photographed using the phone's camera. This approach reinforced what the respondents described in interviews. The quality of data collected was not affected in any way because individual farmers were not involved in observation. During interviews, de Leeuw (2014) recorded observations with a view to understand processes of social scenery and insights regarding the various water sources used for irrigation.

The collected wastewater samples were transported to the laboratory for analysis of physicochemical properties in accordance with the standard method for examination of water and wastewater described by Eaton (2005). The analysed are pH, total dissolved solid (TDS), aluminium (Al), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), zinc (Zn) and lead (Pb). The pH was immediately determined at the sampling points using pH meter, while Al, Cd, Cr, Co, Cu, Zn and Pb concentrations were determined in the laboratory using Atomic Absorption Spectrometer (AAS). Their status were compared with the values for corresponding parameters in the Environmental Management and Coordination (Water Quality) Regulations, 2006 microbiological quality guidelines for wastewater use in irrigation.

The method used in investigating wastewater samples had been used by Hassan *et al* (2015) in assessing the quality of wastewater for irrigation purposes. The only difference, however, is that Hassan *et al* (2015) investigated soluble cations (Na^+, Mg^+, Ca^+, K^+); soluble anions (CO_3^{2-}, HCO_3^-, chloride Cl^- and NO_3^-); heavy metals (Cd, Ni and Pb); and biological oxygen demand (BOD) and chemical oxygen demand (COD). Shakir *et al* (2016) also used the same approach in evaluating environmental and health risks associated with reuse of wastewater for irrigation.

Another set of wastewater samples from georeferenced sites were transported to the laboratory for analysis using the method described by Eaton (2005) to determine water quality parameters viz. total coliforms and *Escherichia coli*. During inoculation of the samples in the laboratory, coliforms organisms were determined using substrate enzyme defined technique method (Colilert -18), which simultaneously detected both total coliforms and *Escherichia coli* in a 250 mL format, and the status compared with the values for corresponding parameters in the Environmental Management and Coordination (Water Quality) Regulations 2006 microbiological quality guidelines for wastewater use in irrigation. The same Colilert system for determining total coliforms and *Escherichia coli* in the samples of water had been used by Edberg *et al* (1989) in enumerating total coliforms and *Escherichia coli* from source water using the defined substrate technology.

The samples of *Brassica* sp., *Spinacia oleracea*, *Solanum* sp. and *Amaranthus* sp. under investigation were transported to the Directorate of Mining laboratory for further treatment and analyses following the standard method for examination of heavy metals in vegetables. The selected heavy metals viz. Ti, Zn, Pb, Cr, Cd, Co and Cu were analysed using flame atomic absorption spectroscopy (model Varian Spectr AA-10) described by Eaton (2005). The resultant values were compared with the FAO/ WHO allowable limits for corresponding heavy metals in green leafy vegetablest.

The method used in determining the concentrations of selected heavy metals in samples of vegetables produced using wastewater in the study area had been used by Njenga *et al* (2011) in studying risks associated with urban wastewater irrigation and production of traditional African vegetable seeds in Nairobi, Kenya.

2.9 Conceptual Framework

There are various definitions of conceptual framework. Adom *et al* (2018) define conceptual framework as a structure which can best explain the natural progression of the phenomenon to be studied. It is the researcher's explanation of how the research problem would be explored and makes it easier for the researcher to easily specify and define the concepts within the problem under study.

According to Tamene (2016), conceptual framework is a network/interlinked system or relationship of assumptions, expectations and beliefs. It is a tentative theory that guides the research. It is the essential and central element of the research design that guides not only the researcher to what is going on, but also guides a reader to what has been done and how. In reference to both definitions and reviewed literature, the conceptual framework model (Figure 2.2) was generated to guide the study.

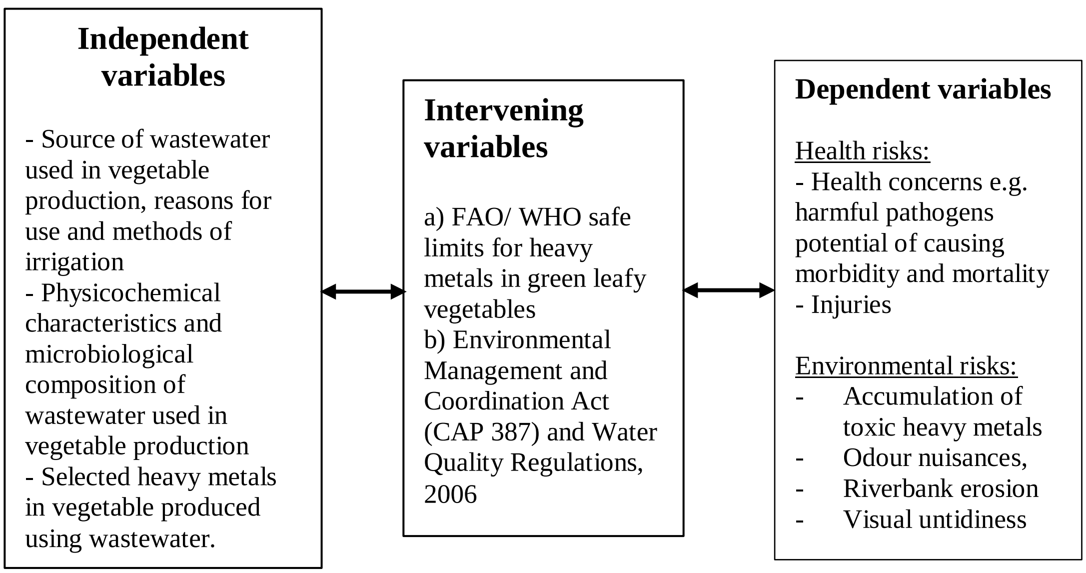

Figure 2.2: Conceptual framework model showing interaction of variables in wastewater use in vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

The dependent variables also called outcome variables are the researcher's predicted potential risks arising from wastewater use in vegetable production, reflecting the influence of the independent variables. The identified independent variables viz. sources of wastewater, reasons for using it and methods of wastewater irrigation; physicochemical characteristics and microbiological composition of wastewater used in vegetable production;

and heavy metal contaminants in the vegetables produced using wastewater might influence the identified dependent variables viz. health risks caused by harmful pathogens that cause morbidity and mortality, and environmental risks as a result of accumulation of toxic heavy metals, which in turn accumulate in the soil and subsequently enter into human body via uptake by plants including vegetables.

Crossman (2019) defines an intervening variable as something that influences the relationship between an independent and a dependent variable. Generally, the intervening variable is caused by the independent variable, and is itself a cause of the dependent variable. The intervening variables in the study viz. international conventions relevant to the study such as the FAO/ WHO permissible limits for heavy metals in green leafy vegetables, and the national laws and regulations viz. Environmental Management and Coordination Act (CAP 387) of 2015 together with the Water Quality Regulations, 2006 influence the direction of relationships between independent variables and dependent variables. Thus, weak enforcement of identified intervening variables would give the farmers a leeway to use free and reliable sources of water in the form of wastewater to produce vegetables for their households' consumption and economic gains in terms of sales.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the methods used in conducting the research and covers the study area, study population, research designs, sampling strategy, survey tools, methodology, ethical considerations, validity and reliability of data collection tools, limitations, assumptions, data processing, analysis and presentation.

3.2 Study area

The study was conducted in Ruai ward between Njiru Township and Ruai domestic wastewater and industrial wastewater treatment plant in Nairobi City, Kenya. The site was chosen because vegetable farmers predominantly use wastewater for irrigation. It was chosen also because it is an urban and peri-urban setting in the City and is accessible from the Nairobi-Kangundo Road. Nairobi has a population of 4.3 million people (KNBS, 2019). It is located $1^{o}16'$ South and $36^{o}48'$ East, 148 Km south of the Equator. It is located at an altitude of 1,680 metres above the sea level, and covers an area of 689 km^2 (Figure 1). It has a warm tropical highland climate with daily temperatures ranging from $29^{o}C$ in the dry season to $24^{o}C$ during the rest of the year and the mean rainfall of 875 mm annually (Omwenga, 2011). There are two rainy seasons, short and long which occur in October-December and March-May, respectively.

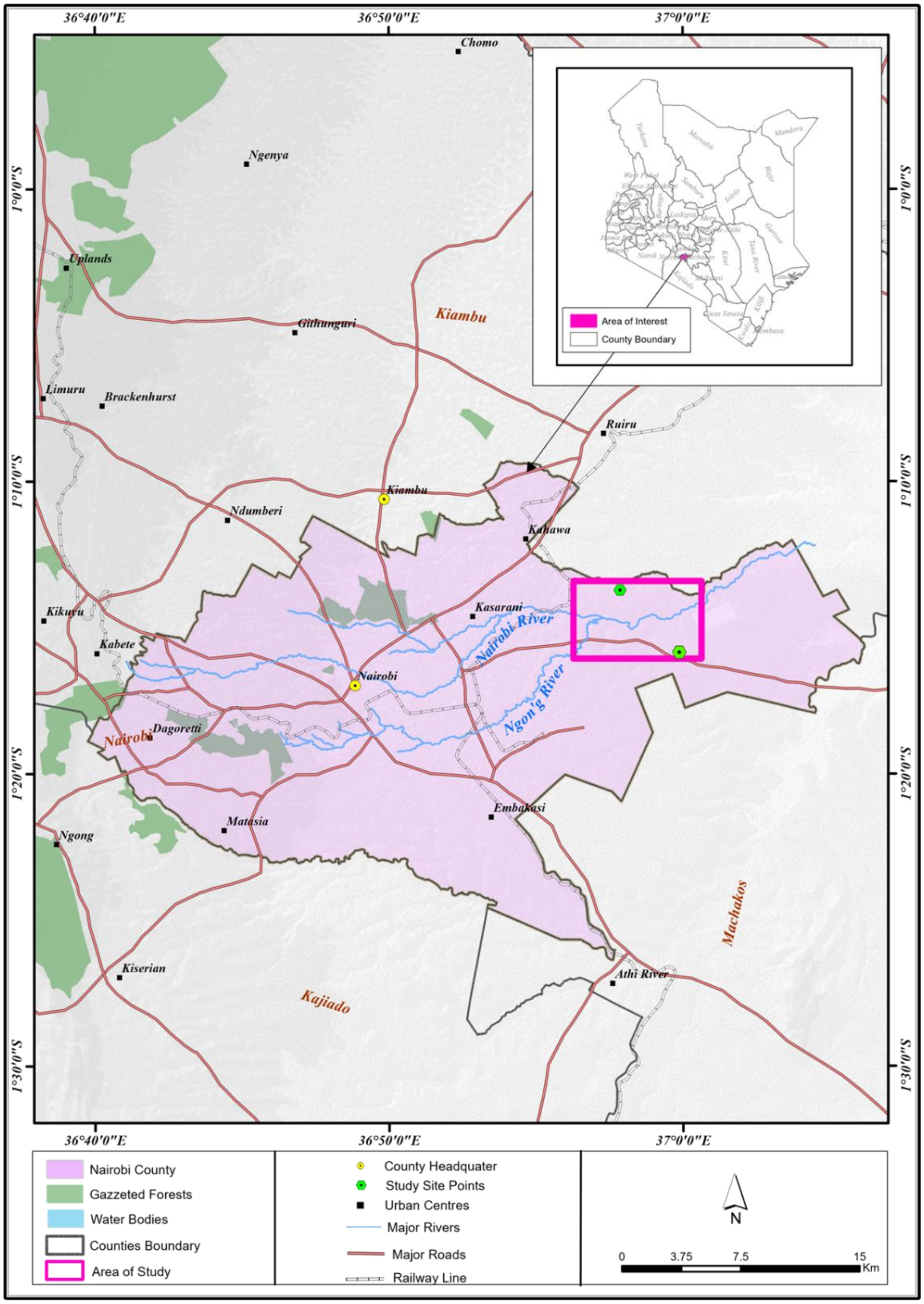

Figure 3.1: Map of Kenya showing the study area

Source: Directorate of Resource Surveys and Remote Sensing

The Nairobi River is used downstream by close to 4 million people for irrigation and domestic purposes. It traverses through Nairobi City and has three tributaries viz. Mathare, Nairobi and Ngong rivers which pass through numerous informal settlements such as Mathare valley, Korogocho, Majengo, Dandora and Kariobangi South whose sewerage and solid waste disposal systems are inadequate. The tributaries are surrounded by small-scale farms producing fresh vegetables (Njuguna *et al*., 2017).

3.3 Research designs

During proposal development, two categories of study population were envisioned. The first one comprised of farmers using wastewater in vegetable production in the study area, farm workers, vegetable retailers and consumers. The second category comprised of the key informants representing Government ministries, departments and agencies (MDAs) at the National level and Nairobi County Government as well as non-state actors relevant to the study.

Research design (Bhattacherjee, 2012) is a comprehensive plan for data collection in an empirical research. It is a plan aimed at answering specific research questions or testing specific hypotheses. It involves three processes viz. data collection, the instrument development and sampling. Research questions were used in the current study. Cross-sectional studies are characterized by collection of data at a given point in time and may be either descriptive or analytical in nature (Kesmodel, 2018). Such studies according to Cherry (2019), are observational in nature and are known as descriptive research and not causal or relational.

In view of its exploratory nature, multiple research designs involving both qualitative and quantitative approach using correlational survey and evaluation designs were used in the current study. Cross-sectional survey was used because data was collected from a subset of the study population comprising of 177 respondents as the sample size that was computed in accordance to Kothari (2004).

The study also used correlational research design in the case of the second and third specific research objectives. Thus, samples of wastewater and selected vegetables produced using it in the study area were randomly harvested and transported to the laboratory for analysis using the method described by Eaton (2005). The wastewater samples were analysed for chemical characteristics and microbiological composition, while concentration of selected heavy metals were determined in the vegetable samples. The quantitative data generated represented the state of wastewater and vegetables in the study area at the time of sampling.

Further, descriptive design was used to solicit for information from the respondents concerning the practice of using wastewater in vegetable production and to describe the existing phenomenon. The degree of association in descriptive design was measured using the Chi-square statistics. The design helped in answering the research questions of where, how and what.

Lastly, observational design was used to record in the observation checklist and photograph using the phone camera that which was observed in the immediate and surrounding environment. Research designs used in the study are shown in Table 3.1.

Table 3.1: Research designs used in studying health and environmental risks of using wastewater in vegetable production in the study area

Entry	Specific objective	Measurable variable/ indicator	Research Design
1.	To establish vegetable types, sources and reasons for using wastewater in production as well as irrigation methods used in urban and peri- urban areas of Nairobi City, Kenya	- Types of vegetables - Categories of sources of wastewater - Reasons for using wastewater - Mode of wastewater application	Cross-sectional (observational and descriptive) (n = 177)
2.	To determine physicochemical characteristics and microbiological composition of wastewater used in vegetable production in urban and peri-urban areas of Nairobi City, Kenya	- Physicochemical characteristics - Microbiological composition	Correlational: Samples of wastewater from the study area.
3.	To determine titanium, zinc, lead, chromium, cadmium, cobalt and copper concentrations in vegetables produced using wastewater in urban and peri-urban areas of Nairobi City, Kenya	- Presence or absence of the heavy metals - Concentration in g/Kg of heavy metals in the samples of vegetables	Correlational: Samples of vegetables from the study area.
4.	To examine health and environmental risks associated with wastewater use in vegetable production in urban and peri-urban areas of Nairobi City, Kenya	Potential Health and Environmental risks	Evaluation Cross-sectional (observational and descriptive) (n = 177)

Source: Researcher (2021)

3.4 Sampling strategy

The study area being relatively small, purposive sampling strategy was used in selecting the farms where sampled farmers were drawn from. The sample size with finite population was obtained using the formula described in Kothari (2004):

$$n = \frac{Z^2 * p * q * N}{e^2(N-1) + Z^2 * p * q}$$

Where,

n = desired sample size

N = Population size

Z = standard normal deviate at the required confidence level of 95% (1.96)

P = proportion of farmers population having the defined criteria in the study

q = (1- p)

e = acceptable error (± 2%)

Applying the formula where (N) is 250 as number of farmers recognized by Njiru sub county Director of Agriculture, and where z = 95%, p = 1.96 % and e = + or - 2%, the computed sample size was 177. Each farmer doubled up as the household's head and farmer in the study area. The second category of the study population which consisted of key informants drawn from various relevant Government ministries, departments and agencies; Nairobi county government; non- state actors with an interest in urban and peri-urban agriculture using wastewater; and medical personnel-in-charge of health facilities in the study area were all sampled purposively in view of nature of information they were going to provide. Wastewater used in vegetable production together with the edible parts of mature leafy vegetables viz. *Spinacia oleracea*, *Amaranthus* sp., *Brassica* sp. and *Solanum* sp. produced using wastewater in the study area were sampled randomly while making sure the samples collected were representative enough.

3.5 Data collection

Both primary and secondary data were collected for the current study.

3.5.1 Primary data

During proposal development of the current study, two categories of research participants were envisaged viz. vegetable growers, farm workers, retailers and consumers in the first category, while the second category comprised of key informants drawn from relevant ministries, departments and agencies (MDAs) at the national level, Nairobi county government; non-state actors with an interest in urban and peri-urban agriculture using wastewater; and medical personnel-in-charge of health facilities in the study area.

After developing the data collection tools, viz. the household interview guide, questionnaire, data sheet and observation checklist and aligning them to the data requirements and the research questions they were given to the experts from agriculture and water sectors to check for content and errors. The experts' feedbacks were used to further correct the tools before they were shared with the supervisors whose feedbacks were also used to finalize the tools.

Prior to conducting the interviews, the interview guide was first tested on 10 farmers neighbouring the targeted participants in the study area to check for grammar, sentence construction, logical flow of questions, validity and reliability. It was also meant to check if the tool measured what was intended to measure. The tool was finalized after making several corrections with approval from the supervisors. The purpose of conducting a pilot study (Ghazali, 2016) is to check validity, reliability and practicality of a survey tool. Prior to the actual survey in the current study, the survey tools were pilot tested on 10 vegetable farmers selected randomly from outside the study area but producing vegetables using wastewater. This was deliberately done to avoid interfering with the study samples of the targeted first category of study population drawn from the study area.

The research assistants were taken through all the data collection tools and trained on how to use them. They were also trained on how to conduct the interviews and record the respondents' responses objectively._To confirm whether they clearly understood how to conduct and record responses in an interview and prior to using the corrected data collection tools, for instance, the research team piloted the tools to find if they would work in the real world.

The purpose of piloting the research tools was to also confirm that everyone in the sample clearly understood the questions. This enabled the research team to note if certain questions made the respondents feel uncomfortable. It was also during piloting when the researcher and the assistants got an opportunity to estimate how long the survey would last.

It was during piloting of interview guide when it was discovered that farmers apart from providing leadership in farm activities, they also did the farm chores just like the workers did and participated in vegetable vending as well. They also consumed at the household level the vegetables they produced using wastewater in the study area. The first category of research participants was thus reviewed which resulted in retaining the farmers alone, while the second category of research participants remained as earlier envisioned. The key informants represented ministries of Education (Nairobi county), Agriculture, Livestock and Fisheries Development (State Department of Crop Development/ Urban and Peri- urban Agriculture Project); State Department of Social Development (Njiru Sub county), Veterinary Services, Social Development, and Education, Health and Sanitation, Environment and Forestry; Water and Sanitation; Water Resources Authority; Kenya Bureau of Standards; and National Environment Management Authority. Non-state actors represented are Sustainable Environment Development Watch-Kenya, Elekea Kenya and Mazingira Institute.

After piloting the data collection tools, the researcher debriefed with the research assistants and made appropriate corrections by taking into account suggestions made by respondents who participated in piloting. Piloting also assisted in determining how well the questions and instructions were understood.

The researcher took note whenever the would-be respondents hesitated to respond to the questions asked or request for clarification, which was alluded to indicate either the respondents did not understand the question at hand or had more than one meaning. Once the interview was over, the research team inquired if the respondent was satisfied with the questions and the response made. This approach proved useful in subsequent interviews. Data collection activities were closely monitored to minimize and resolve missing and questionable data promptly.

The research assistants were first trained on how to conduct the interviews and record the respondents' responses objectively. This was subsequently followed up by the actual interviews under the supervision of the researcher who also conducted the interviews personally. The research assistants' participation during piloting of the survey tools further enhanced the skills acquired and prepared them for the task ahead.

Prior to the commencement of the actual survey, a brief tour of the study area was undertaken with the objective of familiarizing the research team and self with the actual situation on the ground, study population as well as the extent and mode of applying wastewater in vegetable production. In addition, the tour offered the team an opportunity to estimate the period the actual survey would last and the resources required.

Farmers and medical personnel-in-charge of health facilities in the study area were interviewed using semi-structured interview guides (Appendix 3 and 4, respectively). Further, structured questionnaires (Appendix 5) were self-administered by key informants on behalf of relevant State and non-state actors. A datasheet (Appendix 6) was used for recording identification details on the samples of wastewater and vegetables produced using wastewater before transporting to the laboratories for analysis to generate quantitative data. Lastly, an observation checklist (Appendix 7) was used to record that which was observed during data collection in the field. A summary of sampling strategies and tools for data collection are presented in Table 3.2.

Data was also generated through collection and laboratory tests of wastewater and vegetable samples. Data generated was analysed using inferential (Chi-squire test) and descriptive statistics, while pie charts, graphs and tables were used to present the results.

The study period was between 2015 and 2019. Data was collected during drought between 1st March and 20th August, 2018. Collection of data coincided with unexpected rainfall, which, however did not hinder the farmers from using wastewater for irrigation. Data was collected using an interview guide, questionnaires, data sheet, observation checklist and visual aids. Focus group discussions were not held in view of negative publicity given to the practice of using wastewater in vegetable production by the media.

Table 3.2: Sampling strategies and data collection tools in the current study

Entry	Study population unit	Sampling method	Sample size	Data collection tool	Appendix number
1.	Vegetable farmers	Systematic random	177	Interview guide	3
2.	Medical personnel-in-charge of health facilities in the study area	Random	4	Interview guide	4
3.	Key informants representing relevant MDAs and Nairobi City Government	Purposive	12	Questionnaire	5
4.	Key informants representing relevant non-state actors	Purposive	10	Questionnaire	5
5.	Laboratory material (samples of wastewater and vegetables)	Simple random	10	Data sheet	6
6.	Observation	Purposive	6	Observation checklist	7

Source: Researcher (2021)

a) Interviews

Interviews were conducted face-to-face at two levels viz. with the farmers and the medical personnel-in-charge of health facilities in the study area.

i) Farmer personal (face-to-face) interviews

Personal interviews were conducted on purposively selected farmers using wastewater in vegetable production found in their farms. The research team engaged with the participants by posing questions in a neutral approach, listening attentively to participants' responses, while asking follow-up questions and inquiries based on the responses. The characteristics observed were sources of water used and reasons for using them, methods of irrigation used, types of vegetable crops produced and the general environment. The interviews were conducted from March to June 2018 in a face-to-face situation using both Kiswahili and English languages.

The research assistants were prepared for the interviews by selecting, organizing and training them at the same time. They also maintained a conducive environment to gain confidence from the respondents. The individual interviewer asked the questions properly and recorded the responses appropriately. A total of 177 out of 250 vegetable farmers officially recognized by the office of the Njiru sub- County Agricultural Officer were interviewed between March and August 2018 and their individual responses recorded in the interview guide.

Interviewing the farmers while in their farms proved valuable. Firstly, the approach did not interrupt with the farmer's field activities. Secondly, it presented the research team an opportunity to have a general overview and make a record of that which was observed in the immediate and surrounding environment pertaining to wastewater application in vegetable production. Thirdly, interviews complemented the respondents' responses, which were recorded in the households' interview guide.

The research team convened meetings after concluding the day's interviews to confirm all the entries in the interview guides together with the observation checklists were properly entered. The meetings were also held to address issues that might have not been clearly understood by the enumerators.

Interview method of data collection facilitated ease of capturing more and in- depth information from the respondents and that the interviewer was able to detect and overcome any resistance from the interviewees. The interviewer had the flexibility of rephrasing the questions for clarity. The interviewees also had a full control over which person(s) answered the questions during interview process. In most cases, the interviewer interpreted the language of the interview to accommodate different respondents with varying abilities of understanding the questions. Generally, the interview method offered a good response.

ii) Medical personnel-in-charge of health facilities in the study area

Face to face interviews were also conducted using an interview guide on the medical personnel-in-charge of health facilities randomly visited in the study area. The purpose of the interview was to triangulate the information on health risks of using wastewater in vegetable production that was obtained from the interviewed farmers. The purpose of the study was explained to them by the researcher who subsequently posed questions in a neutral approach and recording responses. The interviews were conducted between March and June 2018.

b) Observation checklist and visual aids

Observation as one of the qualitative methods has been adopted by a number of groups within the social sciences including, sociologists, and anthropologists (Leicht, *et al*., 2010). There are two distinct types of observations viz. participant participation involves being in the setting as both observer and participant, while direct observation involves observing without interacting with the objects or people under study in the setting (Kawulich, 2012).

The current study used direct observation because observations were made without interacting with either the observed objects or the farmers themselves under study and the research questions guided the researcher on what to be observed. That which was observed was recorded in the observation checklist, while photographs were taken after interview session. The purpose of training the research assistants was to ensure they had a common approach to the assignment ahead. It was also aimed at eliminating subjective bias during observation and recording. The methods were independent of the respondents' willingness to respond since it did not require any active cooperation from their part.

Both observational and visual methods complemented the respondents' responses to the research questions regarding, for example, source and mode of applying wastewater in vegetable production. The study benefited from these methods because it made it possible for the researcher to appreciate the behaviour of not only the respondents using wastewater in vegetable production, but also the immediate and surrounding environment that was captured using a camera.

Additionally, observation checklist and visual aids facilitated development of a good rapport and fostered a free and open discussion between the respondent and the interviewer. They also provided an opportunity to appreciate the respondents' concerns in particular social and environmental dynamics of using wastewater in vegetable production driven by dense human population and a corresponding high demand for fresh vegetables.

c) Questionnaire

Self-administered structured questionnaires explaining purpose of the study with a request to process and return them to the researcher, were either hand delivered or sent through electronic mail to key informants on behalf of State and non-State actors with a stake in urban and peri-urban agriculture using wastewater. The questionnaires were used to gather information and views from the key informants on behalf of MDAs at the National level and Nairobi county government as well as non-state actors relevant to the study wastewater management in Nairobi City, knowledge about its use in vegetable production in urban and peri-urban areas of the City, why farmers use wastewater, potential health and environmental risks associated with wastewater use in vegetable production, and proposed policy and technical interventions for safe reuse in urban and peri-urban farming in the country. Twelve out of fifteen questionnaires administered on purposively samples key informants were processed and returned.

This method was chosen because it was cost-effective and easy to administer. It also had the advantage of reaching out to many respondents as well as increased validity of information provided. Sent questionnaires were followed up through constant telephone calls and electronic mails reminding the respondents to return the processed questionnaires for good response.

d) Collection and laboratory tests of samples

True experimentation was not used in the study because neither wastewater nor vegetable samples were subjected to any control of conditions that would potentially affect the parameters of interest.

i) Wastewater sampling and sample preparation for laboratory analysis of physicochemical characteristics

Five two-litre polyethylene bottles were cleaned with clean water and rinsed thrice with respective wastewater before filling with the sample. Each two-litre sample collected as discrete sample from five different geo-referenced sampling points was kept in respective bottle. Sampling points corresponded to the following five points where farmers draw wastewater used for vegetable production:

1. A canal discharging treated effluent into the Nairobi River from the Ruai wastewater treatment plant,
2. Discharge point (convergence of treated effluent and the Nairobi River),
3. Upstream of Nairobi River (convergence of Nairobi and Ngong rivers before receiving treated effluent),
4. Raw influent from a perforated inlet pipe, and
5. Downstream of Nairobi River (convergence of Nairobi and Ngong rivers, treated effluent and the raw influent).

Each sample was collected by dipping the sample bottle approximately 20-30 cm below the water surface, while directing the bottle's mouth against the flow direction. Care was taken to ensure nothing was in contact with the insides of the bottles and lids to avoid or minimize contamination. In collecting and preparing the samples for analysis, and noting the potential risks in handling wastewater consisting of domestic, industrial and medical wastes as well as microorganisms, precautionary measures were observed at all times. In this case, hand gloves were used to avoid bodily contact with the wastewater, while gumboots were used to avoid personal risk or injury from nature of the sample and location of sampling point.

Samples collected the same day were clearly marked with the date of collection and geographical location of each sampling point before delivering to the Directorate of Mining in the Ministry of Petroleum and Mining for further treatment and analysis of pH, total dissolved solids, cadmium, cobalt, copper, zinc and lead against corresponding parameters in Environmental Management and Coordination (Water Quality) Regulations, 2006 microbiological quality guidelines for wastewater use in irrigation. Detailed laboratory analysis is described by Eaton (2005). All samples were collected at points closest to where wastewater is either pumped or directed on to the farmlands.

ii) Wastewater sampling and sample preparation for laboratory analysis of microbiological composition

The samples of wastewater were collected once (grab samples) from five predetermined and geo-referenced sampling points. Eaton (2005) is of the view that sources such as large lakes, protected groundwater supplies, water supplies receiving conventional treatment and wastewater streams may be adequately represented by single grab samples. The research team therefore presumed each sample taken represented the composition of its source. The five sampling points were similar to the sampling points for wastewater samples for physicochemical characteristics analysis except for the coordinates. All samples were collected at points closest to where wastewater is either pumped or directed on to the farmlands.

All the samples were collected randomly to ensure their representativeness. The sampling bottles were clean and free from contamination before and after collecting the water samples. They were not opened prior to collecting the samples. Each bottle was individually examined for cracks, a missing seal, or other signs that would compromise sterility. None of these indications was found and therefore none of the bottles was discarded.

Holding sample containers at the base, the aluminum foil seal around the cap was removed using the free hand before attempting to open the bottles, while making sure the inside faced downwards. Approximately 100 ml of water was aseptically sampled using sterilized autoclaved sampling bottles for analyzing microbiological content viz. total coliforms *Escherichia coli* in the laboratory. In the process certain precautions were observed such as avoiding touching the interior of the caps or placing them down and filling the bottles to the fill line to avoid overflow.

Finally, the caps were carefully replaced and the laboratory requisition form filled with the following: a unique number, collector's name and contact, date, location coordinates and sample type to prevent sample misidentification. During sampling and sample handling, adequate safety precautions were taken because sample constituents were likely to be toxic. Thus, gloves and apron were worn. Samples were also collected safely by avoiding situations that would lead to accidents.

The collected samples of wastewater were transported in a cool box with ice packs to maintain a temperature of 4°C until they were delivered at the Water Resources Authority - Central Water Testing Laboratory within 6 hours. They were received and verified based on the information on the label by the laboratory attendant. The samples were analysed using the method described by Eaton (2005) for total coliforms and *E. coli* against the corresponding parameters in Environmental Management and Coordination (Water Quality) Regulations 2006 microbiological quality guidelines for wastewater use in irrigation.

iii) Vegetable sampling and sample preparation for laboratory analysis of selected heavy metals concentration

Four main types of leafy vegetables viz. *Brassica* sp., *Spinacia oleracea*, *Solanum* sp. and *Amaranthus* sp. produced using wastewater in the study area were randomly picked, each half a kilogram (½ kg) at their vegetative stage from five sites according to sources of wastewater used in their production. For example, site 1- treated effluent irrigated, site 2- discharge point irrigated, site 3- upstream of Nairobi River irrigated, site 4- raw influent irrigated, and site 5- downstream of Nairobi River irrigated. Site selection was informed by sources of wastewater used for irrigation.

From the five georeferenced sites, one sample each of four different types of vegetables (in total 20 samples) were randomly collected the same day from the owners who practised wastewater irrigation. Permission was first sought from the vegetable growers to pick the samples from their fields. Edible parts of target vegetables growing across each site were collected. Samples from the same field were separately wrapped together and packed in five separate biodegradable bags marked sample 1 to 5 to avoid mix-up during handling and subsequent preparation before delivering to the laboratory for further treatment and analysis. They were later unwrapped, clearly marked and spread on a clean surface for moisture loss overnight.

The following day the samples were pressed using a plant press. They were kept undisturbed except for regular turning to ensure all the samples more or less received the same treatment. The purpose was also meant to ensure the samples dried separately to eliminate excess moisture. Dried samples were removed from the plant press and crashed before packaging in clearly marked paper bags which were transported to the Directorate of Mining laboratory for further treatment and determination of Ti, Zn, Pb, Cr, Cd, Co and Cu levels.

3.5.2 Secondary data

Secondary data was sourced from books, records, newspapers, research works, Government statistics and reports. Supplementary relevant literature in scientific and peer-reviewed journals in the Internet and virtual library were further reviewed.

3.6 Validity and reliability of data collection tools

3.6.1 Validity

According to Middleton (2020), validity refers to how accurately a method measures what it is intended to measure. Thus, if research has high validity it means it produces results that correspond to real properties, characteristics, and variations in the physical or social world. Thus, if research has high validity, it means it produces results that correspond to real properties, characteristics, and variations in the physical or social world. Salimi and Ferguson-Pell (2017) are of the view that validity principles are applicable to studies based on questionnaires, observational studies, or other types of assessments, and therefore helps one to know how true the claims and propositions made in a study area.

The content validity of the research tools used in the current study was first tested to ascertain if it would generate relevant responses to the study. To undertake this, the researcher first developed the interview guide, questionnaire and the observation checklist then presented them to the supervisors to evaluate the content and adequacy of the items in the tools. The tools were appropriately corrected based on the feedback received.

3.6.2 Reliability

According to Middleton (2020) reliability refers to how consistently a method measures that which is indented to measure. A measurement is considered reliable if the same result can be consistently achieved by using the same methods. The reliability of an instrument is the measure of degree to which a research tool yields consistent results or data after repeated trials (Mugenda and Mugenda, 2003).

Test-retest reliability as a measure of consistency between two measurements of the same concept administered to the same sample at two different points in time (Bhattacherjee, 2012) was used in testing the reliability of the survey tools viz. interview guide, questionnaire and the observation checklist used in the current study. If the observations have not changed substantially between the two tests, then the measure is reliable. Based on these two similar definitions of reliability, the research tools in the current study were developed in consultation with the supervisors who also approved them after they were satisfied with the content.

3.7 Ethical Considerations

The study had ethical considerations. Thus, once the study proposal was approved by the Masinde Muliro University of Science and Technology, a research permit (Appendix 1) was sought and obtained from the National Commission for Science, Technology and Innovation (NACOSTI), and a letter granting authorization to conduct research in the study area (Appendix 2) was obtained from the State Department of Basic Education in the Ministry of Education.

To assist in gaining farmers' permission to conduct interviews, letters of introduction from the Masinde Muliro University of Science and Technology, State Department of Basic Education in the Ministry of Education were availed to the Njiru Sub-County Deputy County Commissioner during a courtesy call. A tour of the study area was subsequently made to familiarize the research team with what was to be expected in the actual survey.

Noting that the study involved human participants and therefore required ethical clearance, the researcher first gained informed consent from the study population before interviewing. The interviewees were also informed about the type of information solicited from them, reasons why it was being sought, purpose and what was expected from them, and how it was going to affect them either directly or indirectly. Photography was, in addition, taken with the permission of the respondents.

The research assistants and the researcher acting as the interviewers, first asked for the respondent's consent to be interviewed by introducing and explaining the purpose of the interview. The interview process was voluntary and only the willing participants were interviewed. The consent was voluntary and without pressure of any nature.

The research assistants avoided asking sensitive questions and whenever there were questions touching on income status, for example, the researcher informed the respondents the type of information required from them and that they were asked clearly and frankly, and they were given ample time to decide if they wanted to participate or not. Whenever it was discovered during interview session that the way information sought was creating harassment, the researcher took step to prevent it. The researcher also assured the participants their responses were going to be kept anonymous.

3.8 Limitations

The study had the following limitations:

i) Most respondents were skeptical in revealing sources and reasons for using wastewater in vegetable production for fear of losing customers for their vegetable produce. This was however, overcame through persuasion and by convincing them the purpose was solely for academic research and not for public information.

ii) Low response from a section of the study population which was addressed by constant reminders through phone calls and text messages, and electronic mails,

iii) Aware that using wastewater in vegetable production was prohibited and the negative publicity raised through media about wastewater-irrigated vegetables in the study area often made some would-be respondents non-cooperative. A visit to the study area not only to familiarize oneself with the situation obtaining on the ground and to introduce the research team to the would-be respondents, but to also pilot the research tools prior to the actual data collection helped in addressing the challenge. After touring the study area it became clearer that data collection through focus group discussions was not going to be possible. Thus, interviews became the most convenient method of data collection. Prior to conducting the survey, a courtesy call on the Njiru Sub-County Deputy County Commissioner was made to secure permission. The same message was transmitted in writing to the Assistant County Commissioner (ACC) who in turn informed the Ruai ward Chiefs about the survey that was to be conducted in their respective areas of jurisdictions. It is interesting to note two respondents were able to identify some members in the research team while in the field having seen them during a meeting with the Assistant County

Commissioner when the researcher paid a courtesy call and to hand in the introductory letter from the Nairobi County Commissioner, and

iv) The unexpected rains in Nairobi County between early March and early June 2018 rendered some parts of the study area inaccessible by a vehicle. This often forced the research team to either walk for long distances to reach some of the would-be respondents or re-schedule data collection programme. Generally, the rains did not affect data collection.

3.9 Assumptions

The current study was undertaken with the following assumptions:

i) Research participants would be found on their farms and will answer the interview questions in a honest manner,

ii) The physicochemical characteristics and microbiological composition of wastewater used in vegetable production in the study area will remain constant throughout the time of study,

iii) Heavy metals to be analysed in the samples of vegetables produced using wastewater in the study area would be in their stead state condition at the time of sample collection, and

iv) The intervening variables would remain constant at the time of the study.

3.10 Data Processing, Analysis and Presentation

Initial data editing took place in the field, while post-field editing was done thereafter. Field editing was done to fill the gaps, while post-editing was mainly carried out to check all the entries in the survey tools. The next step in data processing was summarizing the responses, which involved coding, data entry in the computer and checking of errors that is data cleaning. The purpose was to look for insufficient variation in responses, missing information, abnormalities, and other errors that could be gotten rid of prior to the analysis. Responses were therefore combined into several items and some categories collapsed for purposes of analysis. Coded data was entered in the Microsoft Excel database, which was then exported to the Statistical Package for the Social Sciences (SPSS) program for analysis. Data generated from the questionnaires processed and returned by 10 out of 12 sampled key informants representing State and non- state organisations was summarised and presented as statements.

The descriptive statistics such as percentages, mean were computed for general description of the data, while the Chi-squire test was used for categorized data which included farmers' places of residence, age, gender, level of education, land tenure, sources and reasons for using it vegetable production, irrigation methods using wastewater and physicochemical characteristics of wastewater used in vegetable production. Observational data was only described without explaining.

The first set of wastewater samples were analysed in the laboratory for pH and concentrations of TDS, Al, Cd, Cr, Co, Cu, Zn and Pb, using standards methods described in Eaton (2005). Determination of pH was done using a pH meter combined with pH electrode, magnetic stirrer, TFE- coated stirring bar and 50 ml. burette, while the reagent used was the Standard pH tablets. The pH meter was calibrated using known standards of 4.0, 7.0 and 9.2. Thereafter, pH measure for 50 ml. of sample was taken and titrated with 0.02 NH_2SO_4 until the pH value of 4.5 was attained.

Total dissolved solids was determined by taking 100 ml. of the sample and filtering in clean dry 250 ml. beaker of a known mass using ashless filter paper number 541 of known mass. The filter paper was oven dried at 105ºC then cooled in a desiccator. Mass of the filter paper was then determined as follows:

TSS = mass of filter taken from the oven – original mass of the filter

The filtrate was evaporated in an oven at 105ºC and cooled in desiccator and the mass of the beaker determined as follows:

TDS = [new mass of the beaker] – [original mass of the beaker]

TSS = (A-B)*1000/volume of sample taken,

Where A = mass of dry filter paper after filtering, B = mass of dry filter paper before filtering.

A = 1.3200g; B = 1.1940

TSS = (1.3200 - 1.1940)1000/ 100 = 2.52 mg/l

This was followed by digesting filtrate on a hot plate to almost dryness. The beakers were then put into an oven at 105ºC to evaporate all the moisture. They were cooled in a desiccator then weighed as follows:

TDS = (A-B)*1000/ volume of sample taken,

Where A = mass of empty dry beaker after filtering and B = mass of dry beaker before filtering.

A = 104.8910 g, B = 104.8821g

TDS = (104.8910 - 104.8821)* 1000/ 100 = 8.9 mg/l

Preparation of wastewater samples for metal ion analysis involved taking 100 ml. of wastewater sample in a 250 ml. beaker followed by adding 5 ml. of concentrated nitric acid. The resultant mixture was digested on a hot plate to bring down the volume to about 10 ml. It mixture was then filtered into a 50 ml. volumetric flask and topped up to the 50 ml. mark. The filtrate sample was ran in a calibrated Atomic Absorption Spectrometer in order to determine Al, Cd, Cr, Co, Cu, Zn and Pb, and their readings recorded in a data sheet. For example, concentration of individual metal was computed as follows:

Concentration of metal = [AAS reading] x [dilution factor] x [stock volume/ volume of sample taken].

For example, if the AAS reading was 1.73 for iron (Fe) in a sample, then; concentration of:

Fe = (1.73 x 1 x 50)/ 100 = 0.865 ppm.

The second set of wastewater samples were analysed in the laboratory for total coliforms and *Escherichia coli* using standard methods described in Eaton (2005). In the laboratory the samples were inoculated aseptically and incubated for 18-24 hours to prevent cross contamination from other sources and to ensure the results obtained were actual. During inoculation coliform organisms were determined using substrate enzyme defined technique method (Colilert -18), which simultaneously detected both total coliforms and *Escherichia coli* in a 250 ml format.

The samples of vegetables delivered to the laboratory were analysed using the method described in Eaton (2005) for concentrations of Ti, Cu, Zn, Pb, Cd, Cr and Co. Samples of individual vegetable type viz. *Brassica* sp., *Spinacia oleracea, Solanum* sp. and *Amaranthus* sp. were separately sliced into small pieces and oven dried for two hours at 100°C. After cooling, each sample was pounded into a homogenous mass using a porcelain and a mortar. Approximately 2.5 g of each sample was then separated out and transferred into a 100 ml. Pyrex beaker followed by adding 10 ml. of concentrated nitric acid and left to stand for at least 40 minutes. Finally, the beaker was heated at 95^{o}C on a hot plate to evaporate the contents to 10 ml. Using Whatman No. 42 filter paper, the resultant concentrate was filtered and the filtrate maintained to 50 ml. with distilled water.

Subsequently the samples were analyzed for Ti, Cu, Zn, Pb, Cd, Cr and Co with the help of Atomic Absorption Spectrometer model Varian SpectrAA- 10 using air-acetylene flame. The instrument was fitted with specific lamp of particular metal and calibrated using manually prepared standard solution of respective heavy metal as well as drift blanks. The samples were read one at a time, while recording the amount of the elements present in the sample displayed in part per million (ppm). What was read from the Atomic Absorption Spectrometer was then converted into grams per kilogram (g/ Kg) to represent the amount of specific heavy metal in grams present in a kilogram of the sample.

Data generated in the study is presented in the following formats for visual interpretation viz. photographs, tabular, statistical and cartographic viz. bar graphs and pie charts. Data analysis methods used are shown in Table 3.3.

Table 3.3: Methods of data analysis and format of presenting findings on risks of using wastewater in vegetable production in Ruai ward, Nairobi City, Kenya

No.	Objective	Measurable indicator	Research design used	Method of data analysis	Format of Presentation
1.	To establish types of vegetables, sources and reasons for using wastewater in production as well as irrigation methods used in urban and peri-urban areas of Nairobi City, Kenya	Types of vegetables and sources of wastewater, categories of reasons for use and methods of irrigation	Descriptive cross-sectional survey	- Descriptive statistical analysis, - Inferential statistical analysis (Chi- squire test)	- Tabular - Photographs - Bar graphs
2.	To determine physicochemical characteristics and microbiological composition of wastewater used in vegetable production in urban and peri-urban areas of Nairobi City, Kenya	Physicochemical characteristics and Microbiological composition.	Correlational	- Descriptive statistical analysis, - Inferential statistical analysis (Chi- squire test) - Correlational	- Tabular - Bar graphs
3.	To determine Ti, Zn, Pb, Cr, Cd, Co and Cu concentrations in vegetables produced using wastewater in urban and peri-urban areas of Nairobi City, Kenya	Heavy metal poisoning.	Correlational	- Descriptive statistical analysis, - Inferential statistical analysis (Chi- squire test) - Correlational	- Tabular - Bar graphs
4.	To examine health and environmental risks associated with wastewater use in vegetable production in urban and peri-urban areas of Nairobi City, Kenya	Health and environmental risks e.g. heavy metal poisoning, bacterial infections.	Evaluation	- Descriptive statistical analysis, - Inferential statistical analysis (Chi- squire test)	- Pie charts - Bar graphs - Photographs

Source: Researcher (2021)

CHAPTER FOUR

WASTEWATER USE IN VEGETABLE PRODUCTION IN URBAN AND PERI-URBAN AREAS OF NAIROBI CITY, KENYA

4.1 Introduction

Chapter four is on the findings and discussion on the respondents' demographic characteristics, types of vegetables produced using wastewater, sources and reasons for using wastewater, methods of irrigation used as well interview results from key informants.

4.2 Demographic characteristics of the farmers

The farmers' demographic characteristics are presented as information relating to where they lived, age, gender, level of education attained, and tenure system.

4.2.1 Farmers' places of residence

Reviewed literature (Mougeot, 2000) showed that apart public health concerns and environmental issues of using wastewater in vegetable production, other public health issues that are of concern are contamination contributed people living in the neighbourhood of production areas as well as those contributed by crop and husbandry inputs, products and byproducts, which can be grouped as nuisances and safety hazards. It is against this background that study sought to know whether the farmers in the study area resided within their farmlands or lived elsewhere after observing no structures during familiarization visit. It was found out that they resided in different places as presented in Table 4.1.

Table 4.1: Residential places of farmers using wastewater in vegetable in Ruai ward, Nairobi City, Kenya

Entry	Place of residence	Frequency	Percentage (%)
1.	Ruai	95	53.7
2.	Siranga	21	11.9
3.	Chokaa	18	10.1
4.	Njiru	12	6.8
5.	Dandora	5	2.8
6.	Shujaa/ Ruai	5	2.8
7.	Kayole	5	2.8
8.	Maili saba	5	2.8
9.	Umoja II	3	1.7
10.	Kayole junction	3	1.7
11.	Komarok	3	1.7
12.	Eastleigh	1	0.6
13.	Ruaraka	1	0.6
	Total	**177**	**100**

Source: Researcher (2021)

Most (54%) respondents reside in Ruai, while 12% reside in Siranga, 10% in Chokaa, 7% in Njiru; 3% each in Dandora, Shujaa/ Ruai, Kayole and Maili Saba, and only 2% each reside in Umoja II, Kayole Junction and Komarok. Only 1% each reside in Eastleigh and Ruaraka. The Chi-Square value ($\chi^2_{12,\ 0.01} = 22.25$) showed a highly significant ($P<0.01$) variation in farmers' places of residence.

4.2.2 Farmers' age groups

Respondents' age groups recorded in the interview guide was analyzed and the results are presented in Figure 4.1.

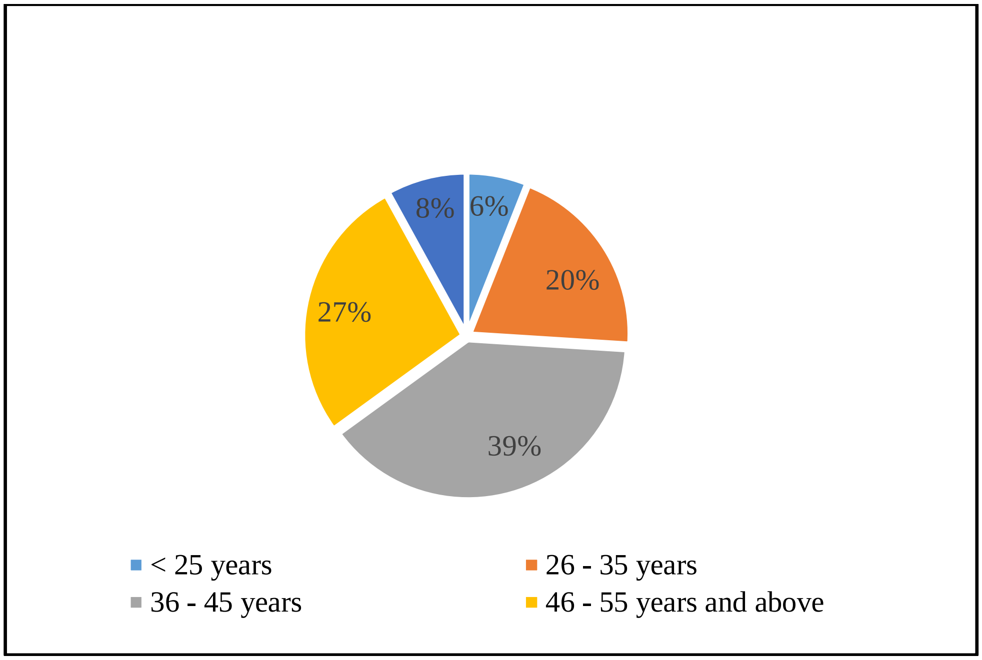

Figure 4.1: Distribution by age of farmers using wastewater in vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

The results show most respondents (39%) belonged to the age category of between 36 and 45 years old, 27% were between 45 and 55 years old, 20% belonged to the 26 and 35 age bracket, 8% were above 55 years old, while 6% were less than 25 years old. The Chi-Square value (χ_32,0.01^2=22.952) showed there was a highly significant ($P<0.01$) variation in the age groups of farmers using wastewater for vegetable production in the study area.

4.2.3 Farmers' gender

The respondents' gender as recorded in the interview guide was analyzed and the findings are shown in Figure 4.2. The results show 63% of the respondents were of male gender, while the rest (37%) were female.

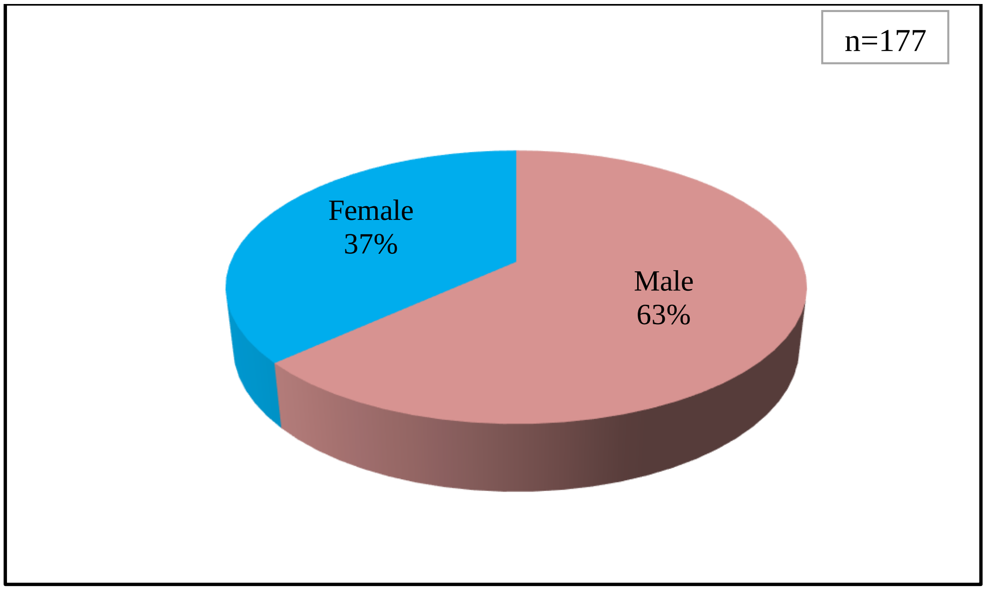

Figure 4.2: Gender of farmers using wastewater in vegetable production in Ruai ward, Nairobi City Kenya

Source: Researcher (2021)

The Chi-Square value (x^2_1, 001 = 23.412) showed there was a highly significant (P<0.01) variation in the respondents' gender. It implies farmers of both gender engaged in vegetable production using wastewater in the study area and that male farmers were two thirds compared to the female farmers.

4.2.4 Farmers' education level attained

The level of education attained by the respondents as recorded in the interview guide was analysed and the results are shown in Figure 4.3. According to the findings, almost half (49%) of the respondents reached secondary level, 31% had certificate of primary education, 9% with tertiary education certificate, while 11% did not have any educational qualification. The Chi-Square value (χ^2 3, 0.01 = 23.72) showed there was a highly significant ($P<0.01$) variation in the respondents' highest level of education attained.

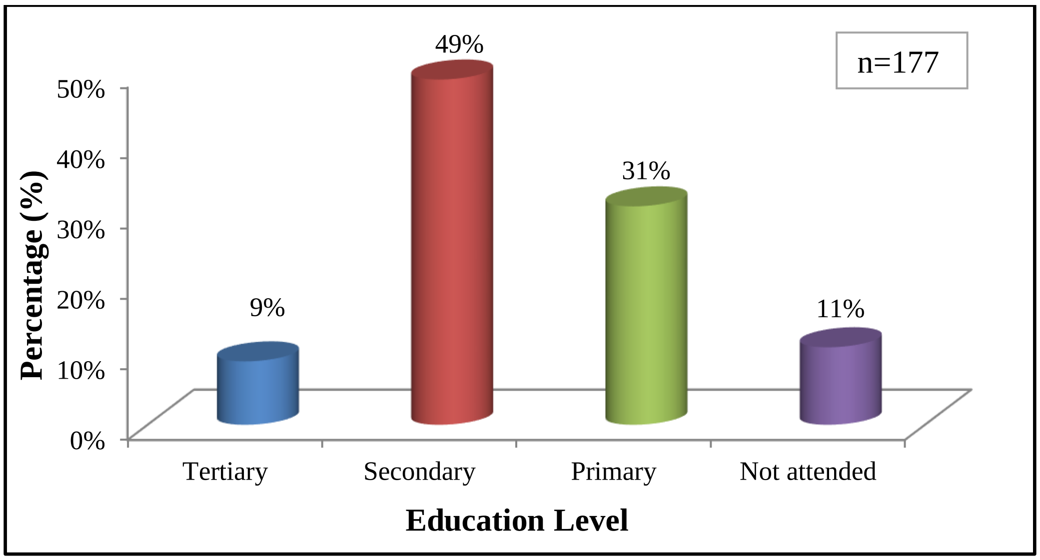

Figure 4.3: Level of education attained by farmers using wastewater in vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

4.2.5 Farmland tenure

Information on land tenancy where farmers use wastewater in vegetable production in the study area as recorded in the interview guide was analyzed and the results are shown in

Figure 4.4. The results showed 41% of the respondents rented the land they cultivated from the owners, 29% had unauthorized use such as those who encroached on the Nairobi River riparian reserve and powerline wayleave, 18% owned the land they cultivated, while 13% did not rent and therefore claimed partial ownership. The Chi-Square value (χ23, 0.01 = 12.92) showed there was a highly significant ($P<0.01$) variation with respect to land ownership amongst farmers using wastewater in vegetable production.

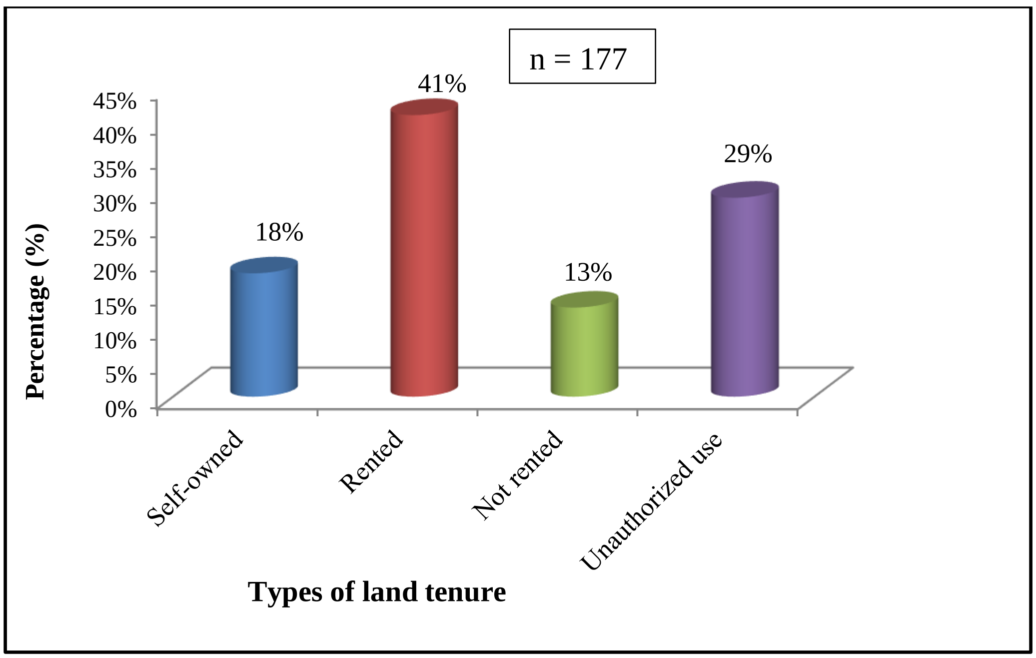

Figure 4.4: Land tenure where farmers produce vegetables using wastewater in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

4.3 Types of vegetables produced in the study area

Farmers in the study area produce different kinds of vegetables because of fast maturity and good prices linked to high demand. Of all the vegetables produced under wastewater irrigation, *Brassica* sp., *Spinacia oleracea*, *Solanum* sp. and *Amaranthus* sp. were the most common and were therefore chosen for the study. Whereas *Brassica* sp. and *Spinacia oleracea* are amongst the introduced vegetable varieties, *Solanum* sp. and *Amaranthus* sp. are examples of African traditional vegetables.

4.4 Wastewater use in vegetable production in the study area

The current study acknowledges the works of Cornish and Kielen (2004), Maluvu (2008), and Ndunda and Mungatana (2013) regarding sources of water used for irrigation by farmers in urban and peri-urban areas. However, the study sought to establish the exact points at which the farmers sourced wastewater they use for vegetable production in the study area. This section therefore is about sources of wastewater, reasons for using it, and methods of irrigation.

4.4.1 Sources of wastewater used in vegetable production in the study area

Sources of wastewater used for vegetable production in the study area are presented in Figure 4.5. The findings showed farmers irrigated their vegetables with wastewater from various sources. Majority (72%) of them used the untreated wastewater from the Nairobi River (Plate 4.1), while 19% used raw influent from a perforated inlet pipe (Plate 4.2). The rest of the farmers used wastewater from other sources for irrigation as follows: the treated effluent (Plate 4.3) from the Ruai domestic wastewater and industrial wastewater treatment plant (5%), the Ngong River (2%), Utawala stream (1%), and water pans and seasonal springs (1%). The Chi-Square value (χ^2_5,0.01 = 15.440) showed there was a highly significant ($P<0.01$) variation in the sources of wastewater used for vegetable production in the study area.

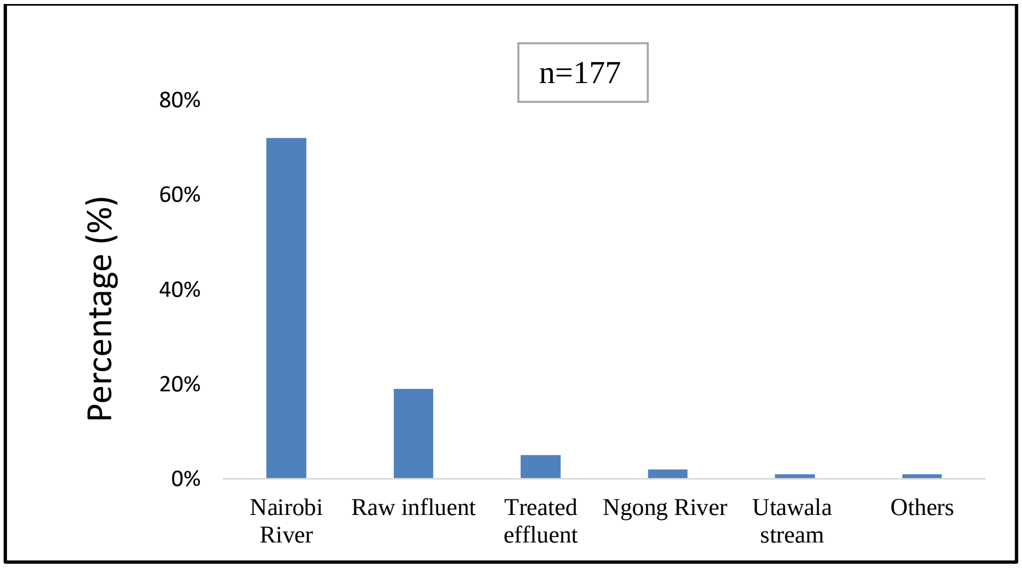

Figure 4.5: Sources of wastewater supply used for vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

The most challenging source of wastewater used for vegetable production in the study area is the raw influent. Farmers have to perforate the inlet pipe in order to access it, a practice that was reported to cause conflict with the City Inspectorate.

Plate 4.1: A section of the Nairobi River used for irrigating vegetables in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

Farmers relying on raw influent faced the challenge of getting adequate supply particularly during droughts when the cartels take control over it and only allow farmers access upon payment of the agreed amount of money.

Plate 4.2: Raw influent used for vegetable Production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

In addition, raw influent because of its nature, users do not have the advantage of using the water pumps like their fellow farmers using other sources of wastewater such as the treated effluent and the wastewater-polluted sources (discharge point, upstream and downstream of Nairobi River. Hence, farmers are in contact with raw influent for longer periods as they have to constantly dilute it with water for ease of flow in the hand-dug furrows.

Plate 4.3: Treated effluent used downstream for vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

4.4.2 Reasons for using wastewater in vegetable production

Respondents' reasons for using wastewater in vegetable production were analysed and the results presented in Figure 4.6. Most (61%) farmers use wastewater because it is available for free that is no cost is incurred for access, 32% of them use wastewater because it constitutes a reliable source of water, 5% of the farmers use it because of plant nutrient content hence no chemical fertilizer requirement, while 2% use it because there is no other water source within reach in the study area. The Chi-Square value (χ^2_3,0.01 = 15.442) showed there was a highly significant (P<0.01) variation regarding reasons for preferred sources of water used for irrigation.

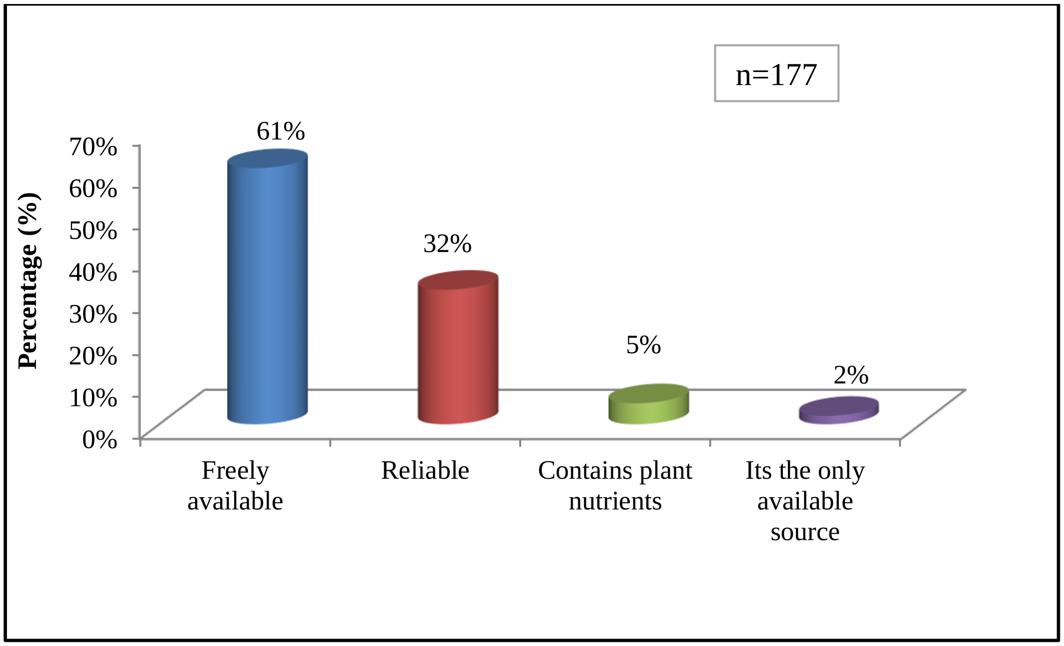

Figure 4.6: Farmers' reasons for using wastewater in vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

4.4.3 Irrigation methods used in vegetable production using wastewater

The Food Agriculture Organization (2001) distinguishes three methods of irrigation viz. surface, sprinkler and drip irrigation. The study sought to establish irrigation methods used by vegetable farmers in the study area considering the nature of wastewater. Respondents' responses were analysed and are presented in Figure 4.7.

The main irrigation methods used in the study area are surface (basin and furrow) and spray. Thus, 72% of the interviewed farmers use basin irrigation method (Plate 4.4), 21% use hand-dug furrows (Plate 4.5) to channel wastewater onto their farmlands, while the remaining 7% use spray method (Plate 4.6). The Chi-Square value (χ22,0.01 = 18.042) showed there was a highly significant (P<0.01) variation in the methods of irrigation used thereby suggesting source of wastewater used influenced mode of its application in vegetable production.

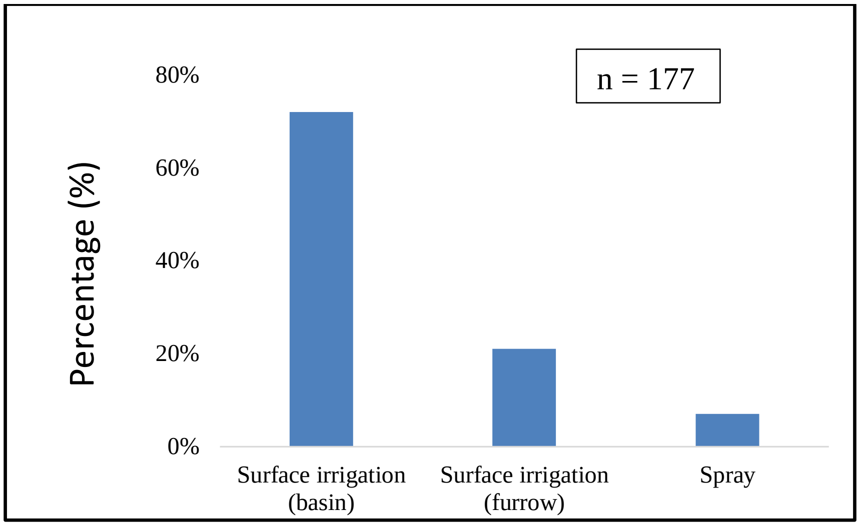

Figure 4.7: Wastewater irrigation methods used by vegetable farmers in Ruia ward, Nairobi City, Kenya

Source: Researcher (2021)

Plate 4.4: Surface irrigation (basin) used in vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

Plate 4.5: Surface irrigation **(**furrow system) used in vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

Plate 4.6: Spray irrigation method used in vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

4.5 Discussion

The findings showed most farmers lived far away from their farms, thereby suggesting they routinely go to their farms in the morning to tend their crops and return to their residential places in the evening. It was observed shelter and associated infrastructure such as schools, pit latrines and road network were conspicuously absent in the fields which confirmed the farmers resided elsewhere. It can be concluded from the finding on the age of farmers that vegetable production using wastewater in the study area was being practiced more by the adults compared to the youth.

The findings on the respondents' ages concur with Githugunyi (2014) who found out in an assessment of urban agriculture's contribution to households' livelihoods in Roysambu ward in Nairobi County that majority (42.2%) of the respondents were between 36 and 45 years old.

The finding on the farmers' gender concurs with Maluvu (2008) who found out in a study conducted to establish the role of agriculture in enhancing food security in the City of Nairobi that both gender engaged in farming. The findings however, conflict Emenyonu *et al* (2010) who discovered in a study conducted to establish the effects of wastewater use on vegetable production in Imo State in Nigeria that female farmers outnumbered male farmers.

The findings on secondary and primary levels of education attained by the respondents are in concurrence with Maluvu (2008) who also found out that similar percentage (44%) of the urban farmers in the city of Nairobi had attained secondary and primary levels of education. However, the findings contradict Muneri (2011) who stated that majority of the farmers who engaged in urban agriculture in Nairobi using wastewater had attained some level of primary education. Perhaps the respondents who had attained tertiary and secondary school qualifications had not been engaged in any gainful employment and therefore had resorted to vegetable production using wastewater as a form of self-employment. This assertion is in consistent with Raschid-Sally *et al*. (2005), that in water-scarce regions of Africa the urban poor take up farming with wastewater due to lack of employment.

It was observed farmers seemed to take advantage of freely available land in the Nairobi River riparian reserve and the power line wayleave, while others leased land from land owners who were yet to develop them. Findings on land tenure concur with Ruma and Sheikh (2010) that non-built up urban areas located along the courses of urban drainage systems in several developing countries are often used for the production of agricultural products such as vegetables that find ready markets from the urban dwellers.

Farmers consume the vegetables they produce using wastewater at the household level, while surplus produce is sold as a source of income for other purposes as pointed out in Raschid-Sally *et al*. (2005) that in water-scarce regions of Africa households consume part of their own produce thereby enhancing food security and enabling them to utilize their income for other purposes.

Farmers experienced the challenge for space as also pointed out in Njenga *et al*. (2011) that land tenure amongst majority of the farmers using wastewater for irrigation were not only in constant conflict with the Nairobi County Government, but also housing developers who were repossessing their leased out land for development. It was observed during survey that an upsurge in land use change from agriculture to housing development was noticeable, thus pushing farming activities further towards the Nairobi River riparian reserve.

The findings on sources of wastewater used for vegetable production in the study area confirm Ndunda and Mungatana (2013) that urban and peri-urban farmers in Nairobi City obtain water used for vegetable production from polluted rivers. Farmers using raw sewage as it was discovered as one of the sources for irrigation, is in concurrence with Ngigi *et al*. (2011). In comparison with Cornish and Kielen (2004) who discovered most irrigators in Nairobi sourced water from river or stream followed by those who use raw influent and non-use of the treated wastewater, the current study showed that the use of the treated effluent and raw influent has increased since Cornish and Kielen's work in 2004.

It was further observed that farmers in the study area did not have access to piped water and in an endeavour to benefit from vegetable farming, they had to use the treated effluent, raw influent and wastewater-polluted Nairobi River for irrigation. The identified wastewater sources are conveniently categorized into the treated effluent, wastewater polluted sources (discharge point, upstream and downstream of Nairobi River), and the raw influent.

Emenyonu *et al* (2010) discovered 50% of the farmers in Imo State, Nigeria used wastewater for irrigation because of plant nutrient content, while close to 25% of them used it due to unavailability or high cost of freshwater. In the study, a small percentage (5%) used wastewater in vegetable production because of plant nutrient content and a further 2% used it because it is the only source of water for irrigation.

Kaluli, *et al* (2011) stated farmers preferred wastewater because it provides not only the soil moisture, but also the nutrients necessary for plant growth, hence no fertilizer application. This is in concurrence with the study's findings on farmers who use wastewater because of plant nutrient thereby avoiding the use of fertilizer.

During interview with farmers, one farmer from Chokaa stated:

> "This water is used by nearly everyone here because there are no other sources of water nearby. Besides, it is free and contains plant nutrients which results in leafy vegetables that attracts customers and even the handlers. Its availability throughout the year enables one to produce vegetables even during drought

> spells when prices for vegetable produce are good. It also enhances vegetable crop maturity, hence quick returns".

The study acknowledges the fact that using the untreated wastewater for agriculture is illegal although the Water Quality Regulations, 2006 provide microbiological quality guidelines for using wastewater in irrigation. The study is therefore justified because information that will be generated on risks that are likely to occur in wastewater irrigation will add to the body of knowledge in wastewater management and reuse in the country.

The farmers' preference for wastewater use in vegetable production because of its availability and being the only source of water further concur with Njenga *et al* (2011) who hold the view that farmers in most developing nations use wastewater for farming because of its availability throughout the year. Farmers who use wastewater in vegetable production because it is the only source of water as pointed out by Gweyi-Onyango and Osei-Kwarteng (2011) that farmers who are in need of water for irrigation in urban and peri-urban areas of most developing countries often resort to using wastewater. It therefore suggests wastewater irrigation not only provide the soil moisture, but also the nutrients necessary for plant growth, thus enabling farmers to maximize produce since they do not have to incur the cost of chemical fertilizer. However, wastewater use for agricultural purposes has to meet the recommended quality standard which the study sought to establish.

A study conducted by Roy *et al* (2013) on the effects of wastewater reuse for crop production in Tejgaon metropolitan area in Dhaka, Bangladesh showed the farmers' first impression was cost saving from fertilizer use and were not aware of toxicity associated with wastewater irrigation, which could affect their economic gains.

In the absence of technical support to farmers using wastewater for vegetable production in the study area, it would be difficult for them to know the nature and composition of heavy metals, and microbiological organisms in the wastewater they use as well as in the vegetables produced using wastewater.

The findings on wastewater irrigation methods showed majority of the farmers use surface (basin) irrigation, while a small percentage of them use spray method. None of them use drip irrigation perhaps due to the nature of wastewater and the capital investment required for the system. It was further observed that in surface (basin) and spray irrigation methods were more common amongst farmers using the Nairobi River for irrigation, while surface (furrow) irrigation was mainly used by raw influent irrigators.

In surface (basin) and spray irrigation methods, farmers use petrol-powered water pump generators to pump and apply wastewater on their vegetable crops, while those using raw influent channeled it onto the farmlands with the help of hand dug furrows because the flow of raw influent is by gravity. It was further observed that farmers did not seem to take into account water conservation measures as long as their crops received adequate supply of moisture, which further confirmed farmers used wastewater because it was freely available. Raw influent irrigators ensured smooth flow and supply of the raw influent from the source downstream by first channeling it into a stream for dilution.

Farmers used rags and recycled synthetic bags filled with pebbles to control raw influent flow in the furrows and in this way they were able to channel from the furrows into their vegetable plots whenever they needed it. The furrows also required regular maintenance. Farmers faced the challenge of receiving adequate supply of raw influent during droughts when cartels were said to take advantage of short supply hence forcing farmers in need to pay in order to be allowed access.

The findings on wastewater irrigation methods concur with Njenga *et al* (2011) and Cornish and Kielen (2004). For instance, in assessing risks associated with urban wastewater irrigation and production of traditional African vegetable seeds in Nairobi, Njenga *et al* (2011) discovered farmers used surface (furrow and flood) and ground seepage irrigation methods.

In addition, the findings are similar to what Cornish and Kielen (2004) who found out that farmers in Mau Mau Bridge in Nairobi City used surface (furrows) and overhead sprinkling. In the study, none of the farmers used watering cans. In the case of surface irrigation through furrow and flood (Alam, 2014), water is not applied directly to the plant canopy and therefore the plant cannot be directly contaminated if unhygienic water is used. In the study most farmers used flood and furrow irrigation which in this regard did not contaminate the vegetable plants.

It was observed that in spray irrigation method, farmers used petrol-powered water pump generators to pump and apply wastewater either directly on the plant canopy or to the root zone and this resulted in some level of contamination in the vegetable produce although this was not investigated in the current study.

It was also observed that farmers did not use protective gear except for a few who used gumboots and masks to protect themselves particularly during spraying. Therefore methods of irrigation used had varying potential of transferring pathogens to crop surfaces. It was also observed that there was no irrigation infrastructure neither was there any established control. It was further observed that most farmers did not bother about possible contamination of vegetable produce once harvested, neither themselves, farmworkers nor the environment while using wastewater in vegetable production as recommended in Valipour and Singh (2016) that factors such as contamination of farm workers, crop and the harvested produce, the environment, salinity, and toxicity hazards have to be taken into consideration when wastewater is used in irrigation.

One respondent from Njiru did amuse the research team upon stating:

> 'Once I pick my vegetables from my plot I take it to my house where I wash then pack in a sack and keep it wet overnight. As early as 4 a.m. I take it to the market where customers come to buy with no concern about the source'.

Based on the findings on wastewater irrigation methods in vegetable production, it can be concluded that surface (basin) and spray irrigation methods were common among farmers who used the Nairobi River and the treated effluent for irrigation, while surface (furrow) irrigation was predominantly used by the raw influent irrigators. In terms of efficiency, basin irrigation was inefficient because the distribution of water was not controlled in any way. However, some effort of water conservation was noticeable amongst raw influent irrigators.

Sources of wastewater used by farmers for vegetable production in the study area were observed to have varying levels of pollution. In addition, the methods of irrigation as found out exposes the farmers and farm workers to chemical and biological risks which need to be addressed. The current study is therefore justified because it sought to establish sources and methods of irrigating vegetables with wastewater in an urban and peri-urban setting of Nairobi City.

4.6 Findings from key informants and discussions

The study sought the views of key informants' organisations concerning wastewater management and status in urban and peri-urban areas of Nairobi City; farmers' reasons and associated impacts of using wastewater in vegetable production. They were also asked to propose policy and technical interventions for safe use of wastewater in crop production in urban and peri-urban areas. Their responses as recorded in the filled questionnaires were analysed and the following were the findings and discussions:

4.6.1 Wastewater management in urban and peri-urban areas of Nairobi city

Wastewater management in urban and peri-urban areas of Nairobi City is vested in several institutions as presented in Figure 4.8.

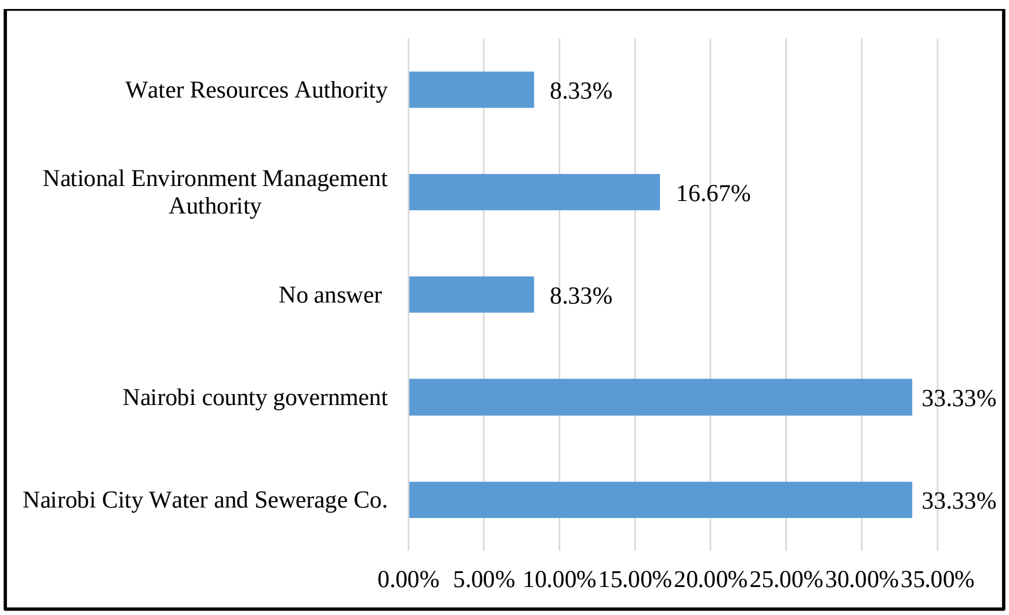

Figure 4.8: Management of wastewater in urban and peri-urban areas of Nairobi City, Kenya

Source: Researcher (2021)

The key institutions in the management of wastewater in urban and peri-urban areas of Nairobi city are Nairobi county government and the Nairobi City Water and Sewerage Company (NCWSC) as reported by 33.33% each by the key informants. Other institutions are NEMA and WRA, each 16.67%, while 8.33% of the key informants abstained from responding to the question.

The key informants hold the view that several institutions are responsible for wastewater management in urban and peri-urban areas of Nairobi. Thus, NEMA regulates effluent discharge to the environment, while Nairobi county government through NCWSC is responsible for ensuring compliance to standards for discharging into wastewater treatment facility. Water Resources Authority on the other hand is responsible for monitoring wastewater that is released into a treatment facility.

4.6.2 Status of wastewater management in urban and peri-urban areas of Nairobi City

The key informants had varied views about the status of wastewater management in urban and peri-urban areas of Nairobi City. Their responses were analysed and the results presented in Figure 4.9. Majority (56.25%) were of the view that it was poorly managed, 25% thought wastewater was causing pollution, 12.5% blamed the residence for wastewater menace in urban and peri-urban areas of Nairobi City, while 6.25% of them stated that farmers were using wastewater for vegetable production in urban and peri-urban areas of the City.

Most key informants expressed their institutional dissatisfaction the way wastewater is managed in urban and peri-urban areas of Nairobi City. Whereas industries have regulations for the content of the effluent, the residential units do not (Mbui *et al* (2016). The key informants blamed those responsible for monitoring compliance to this requirement. It was observed during data collection that the Nairobi River is recipient of both solid and liquid waste from informal settlements and light industries that are located close to the River.

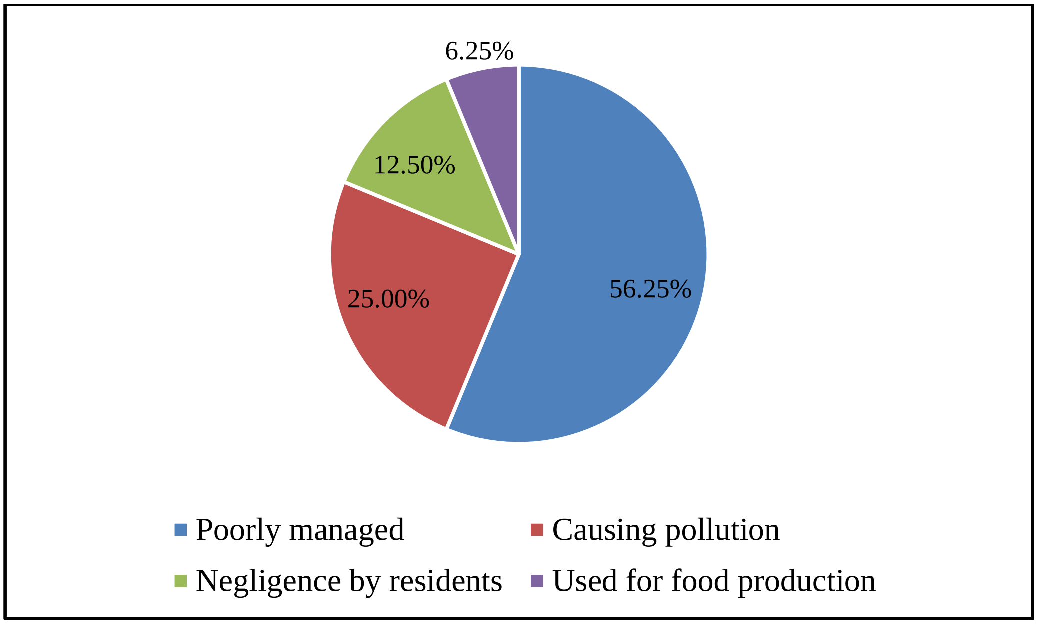

Figure 4.9: Views held by key informants on the status of wastewater management in urban and peri-urban areas of Nairobi City, Kenya

Source: Researcher (2021)

It was further observed during data collection that commercial waste handlers ‘exhausters’ were occasionally noticed discharging effluent directly into the sewer manholes at various points in Njiru. The research team could not, however establish whether this was a regulated activity or not.

The key informants also blamed unsustainable wastewater management in urban and peri-urban areas of Nairobi City on the inefficiency of the Ruai wastewater treatment plant caused by recurrent breakdown of the City’s sewerage system; clogging of sewage system by farmers often resulting in frequent bursting of piping system; premature release of wastewater from the lagoons; the City's population which has outstripped the sewage system; inadequate coverage of sewerage system particularly in the peri-urban areas of the City; ineffective compliance and enforcement of Water Quality Regulations, 2006 on effluent discharge; and lack of awareness creation for households to manage wastewater they generate. Additionally, the key informants pointed out that most wastewater generators lack appropriate pre-treatment facilities and therefore do not comply with Water Quality Regulations, 2006 for effluent discharge.

4.6.3 Reasons why farmers use wastewater for vegetable production in the study area

Based on the choices provided, the key informants were asked to select their institutional reasons why farmers in urban and peri-urban areas of Nairobi City use wastewater for vegetable production. Their responses were analysed and results presented in Figure 4.10. Most (67%) KI held the view that farmers preferred wastewater in vegetable production because it is readily available and a reliable source of water for irrigation. The rest of the KI held the view that farmers preferred it because of plant nutrient content.

The key informants' institutional views were two-fold; most key informants held the view that farmers preferred wastewater because of availability and reliability, while the rest held the view that farmers preferred wastewater because of it contains plant nutrients. It was observed during data collection that indeed wastewater was freely available and reliable, hence can be accessed in all seasons. Farmers in most developing nations (Njenga *et al*., 2011) use wastewater for farming because of its availability throughout the year, which was also found out in the study. Half of the farmers in Imo State, Nigeria (Emenyonu *et al*.,

2010) use wastewater for irrigation because of plant nutrient content. The same was the case in the study, whereby it was found out that a negligible percentage (5%) of the interviewed farmers use wastewater because of plant nutrient which to them was a cost saving since they did not have to purchase chemical fertilizer.

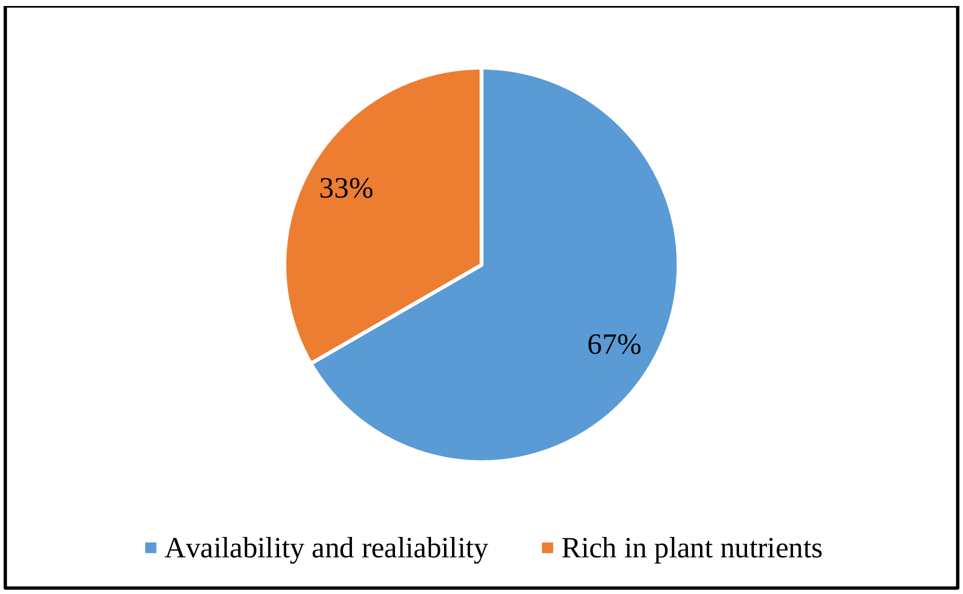

Figure 4.10: Farmers' motivations for using wastewater in vegetable production in urban and peri-urban areas of Nairobi City, Kenya

Source: Researcher, 2021

4.6.4 Impacts of using wastewater for vegetable production in the study area

The study sought to find out from the key informants the impact of wastewater use in vegetable production in urban and peri-urban areas of Nairobi City. Their responses were analysed and the results presented in Figure 4.11. The key informants held different organisationals' views, thus 29.03% of them associated the practice with economic gains, 25.81% held the view that wastewater use in vegetable production has social benefits, while the remaining key informants ranked environmental and health impacts the same at 22.58%

each. Regarding impact of wastewater use in vegetable production in urban and peri-urban areas of Nairobi City, the key informants' views varied. For instance, majority of them held the view that the practice had an economic impact to irrigators. To them wastewater is a resource that should be exploited for economic gains since most households in urban and peri-urban areas of Nairobi City use it to irrigate crops such as vegetables to satisfy their household' dietary needs and surplus sold for income. The key informants' sentiments on the economic impact of wastewater are similar to what the study found out from the interviewed farmers.

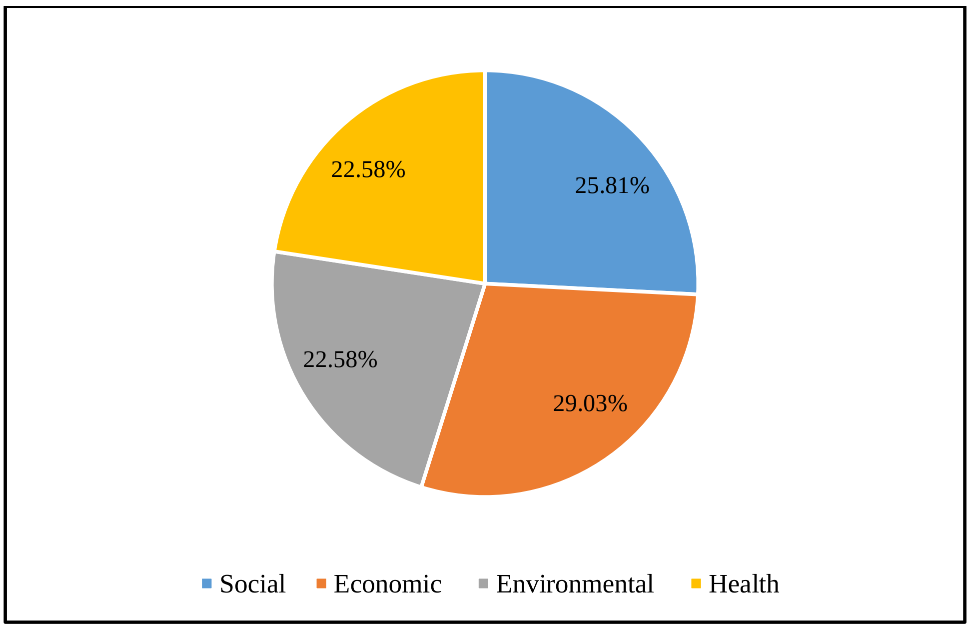

Figure 4.11: Impacts of wastewater use in vegetable production in urban and peri-urban areas of Nairobi City, Kenya

Source: Researcher, 2021

There are those key informants who thought using wastewater for vegetable production in urban and peri-urban areas of Nairobi City had social impacts. It was observed during interviews with the farmers that some of them belonged to different associations with different objectives. For instance, the focus of one group is to conserve a section of the Nairobi River through tree and grass planting. Members also make monthly contributions to a kitty with the aim of saving so that in future they can buy land for development. It is a long term plan aimed at securing every member a plot.

Although wastewater use for irrigation is outlawed unless it meets the standards for irrigation specified in the Water Quality Regulations, 2006, interviews with the farmers showed vegetable production using wastewater is a booming enterprise that not only supports the farmer, but also farm workers because of employment as well as vegetable vendors.

Regarding health risks of using wastewater for vegetable production in urban and peri-urban areas of Nairobi City, the key informants linked the practice with exposure of populations to carcinogens like lead in vegetable produce, and waterborne diseases such as typhoid, cholera and diarrhoea. The KI also called for the need for consumers to adhere to proper washing and cooking of vegetables to reduce potential negative impacts of water borne diseases.

The key informants were also of the view that using wastewater for vegetable production in urban and peri-urban areas of Nairobi City, apart from polluting soil and groundwater resources, it also encourages breeding of mosquitoes. The key informants' views on environmental risks linked to wastewater use for irrigation in urban and peri-urban areas of Nairobi City were also pointed out by the interviewed farmers in the study area.

4.6.5 Proposed policy and technical interventions for safe use of wastewater for crop irrigation

The study sought to know from the key informants their institutional views regarding policy and technical options aimed at enhancing compliance to existing policy and regulatory frameworks for wastewater management including recycling and reusing for crop production in urban and peri-urban areas in the country. Their responses were analysed and presented in Figure 4.12.

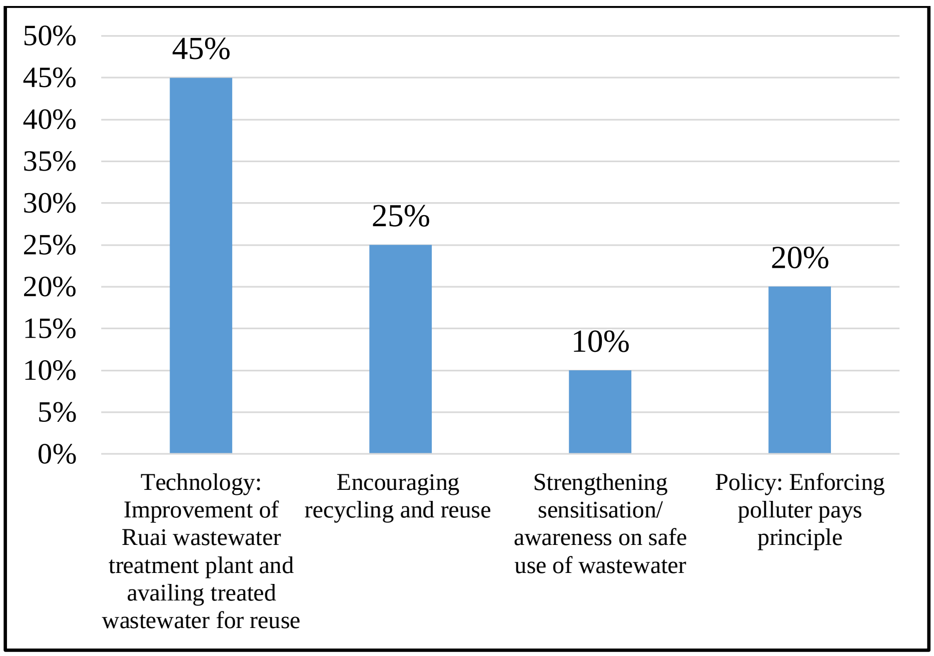

Figure 4.12: Proposed policy and technical interventions for safe use of wastewater in urban and peri-urban areas of Nairobi City, Kenya

Source: Researcher, 2021

Most (45%) organisations proposed a technical intervention targeting improvement of the Ruai domestic wastewater and industrial wastewater treatment plant efficiency, while 25% of the represented organisations were of the view that citizenry in urban and peri-urban areas of Nairobi City should be compelled to recycle and reuse wastewater they generate, 20% called upon NEMA to involve all stakeholders to enforce the 'polluter's pay principle' as provided in the Environmental Management and Coordination Act (CAP 347) of 2015, 10% of the key informants recommended strengthening of programs that are aimed at raising/ creating awareness and sensitising farmers on the need to mitigate potential risks by adopting guidelines for safe use of wastewater in irrigation. Additionally, the KI recommended putting in place a policy that compels use of recycled water in construction and car washing activities to help alleviate pressure on fresh water resources.

CHAPTER FIVE

PHYSICOCHEMICAL CHARACTERISTICS AND MICROBIOLOGICAL COMPOSITION OF WASTEWATER USED IN VEGETABLE PRODUCTION IN URBAN AND PERI-URBAN AREAS OF NAIROBI CITY, KENYA

5.1 Introduction

The Nairobi River is recipient of both solid waste, as well as treated and untreated wastewater. The study considered the section of the River prior to receiving the treated effluent as upstream, while the section after receiving the treated effluent and raw influent as the River's downstream.

Samples of wastewater used for vegetable production in the study area were collected twice from five different georeferenced sampling points viz. treated effluent, discharge point, upstream of Nairobi River, raw influent, and downstream of Nairobi River. The first five samples were analysed for pH and concentration (mg/l) of total dissolved solids (TDS), aluminium (Al), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), zinc (Zn) and lead (Pb). The status was compared with corresponding parameters in the Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water. The second five samples collected from the same sites but different sampling points were analysed for total coliforms and *Escherichia coli*, and their status compared with corresponding microorganisms in the Environmental Management and Coordination (Water Quality) Regulations, 2006 microbiological quality guidelines for wastewater use in irrigation.

Chapter five therefore presents the results and discussions on the analysed physicochemical parameters and microorganisms in the two sets of wastewater samples.

5.2 Physicochemical characteristics of wastewater used in vegetable production in the study area

Values for pH and TDS in all the samples are not presented graphically alongside values for other parameters. This is because unit of measurement for pH is different, while that of TDS, though unit of measure is the same as that of the rest of the parameters, that is milligram per litre (mg/l) TDS values in all the samples were exceptionally high compared to the values for other parameters. However, trends of these two parameters for each of the five samples are included in the explanatory notes, while Appendix 8 shows the analyses results.

5.2.1 Laboratory analysis results for the treated effluent sample

The results for pH, TDS, Al, Cd, Cr, Co, Cu, Zn and Pb in treated effluent sample analysed against corresponding parameters in Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water are presented in Figure 5.1. It shows treated effluent sample had a pH of 7.85 against the recommended range of 6.5-8.5, while TDS was 788 mg/l against the recommended 1200 mg/l. Concentration of other parameters ranged between 3.0 mg/l (instead of 2 mg/l) for Zn, 3.6 mg/l (against of 0.5 mg/l) for Cd, 4.2 mg/l (against 0.05 mg/l) for Cu, 5 mg/l in both Cr and Co (against the recommended values of 1.5 mg/l and 0.1 mg/l, respectively), 6.8 mg/l (instead of 5 mg/l) for Pb, and 13 mg/l (against 5 mg/l) for Al. The Chi-Square value ($\chi^2_{30,0.05} = 35.000$) showed there was a highly significant (P<0.05) relationship between the results for treated effluent sample and the standards for irrigation water.

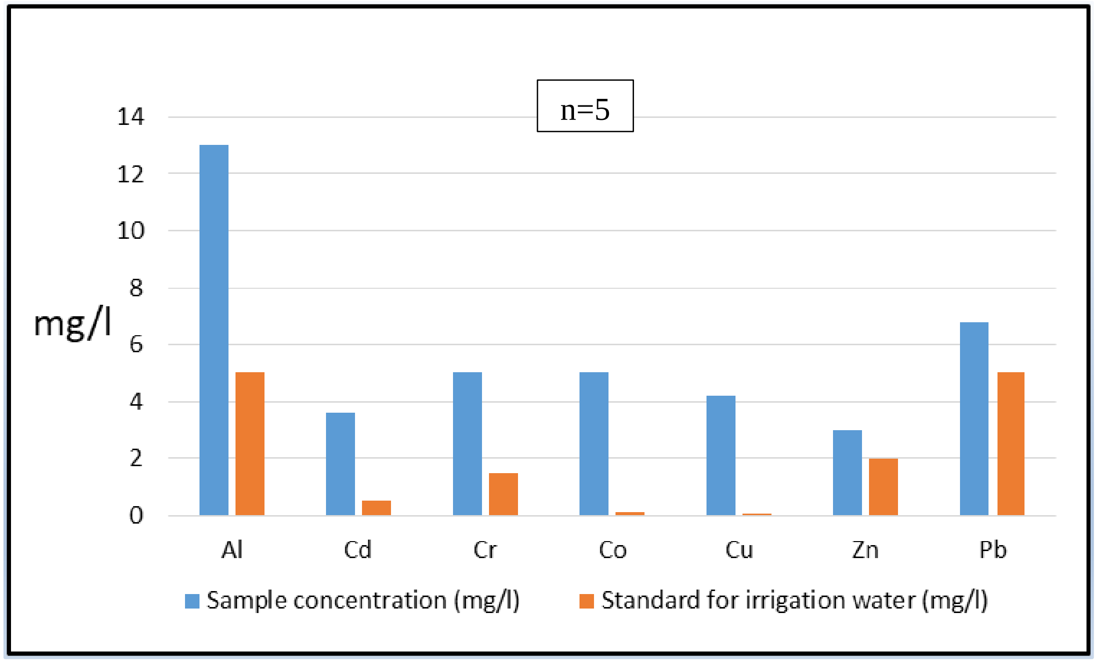

Figure 5.1: Concentration of Al, Cd, Cr, Co, Cu, Zn and Pb in the sample of treated effluent used for vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

5.2.2 Laboratory analysis results for the discharge point sample

The results for pH, TDS, Al, Cd, Cr, Co, Cu, Zn and Pb in discharge point sample analysed against corresponding parameters in Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water are presented in Figure 5.2. The results show the discharge point sample had a pH of 7.06 against the recommended range of 6.5-8.5, while TDS was 581 mg/l against the recommended 1200 mg/l. Concentrations in the rest of the parameters varied from 2.8 mg/l instead of 5 mg/l recommended for Al; 3 mg/l against 0.05 mg/l for Cu; 3.8 mg/l against 0.5 mg/l for Cd; 4 mg/l in both Cr and Co against 1.5 mg/l and 0.1 mg/l, respectively, to 6.8 mg/l instead of 2 mg/l for Zn.

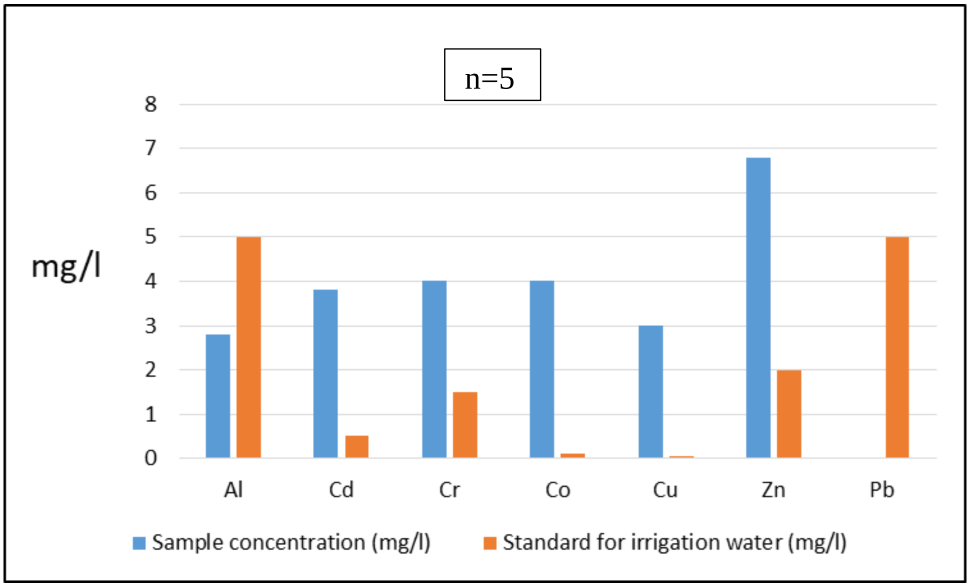

Figure 5.2: Concentration of Al, Cd, Cr, Co, Cu, Zn and Pb in the sample of discharge point wastewater used for vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

Lead was not detected in the sample. The Chi-Square value ($\chi^2_{25,051} = 35.000a$) showed there was no significant (P>0.05) association in the observed values in the discharge point sample and the recommended values in the standard.

5.2.3 Laboratory analysis results for the upstream of Nairobi River sample

The results for pH, TDS, Al, Cd, Cr, Co, Cu, Zn and Pb in upstream of Nairobi River sample analysed against corresponding parameters in Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water are presented in Figure 5.3.

The sample had a pH of 6.77 against the recommended 6.5-8.5, while TDS was 454 mg/l against the recommended 1200 mg/l.

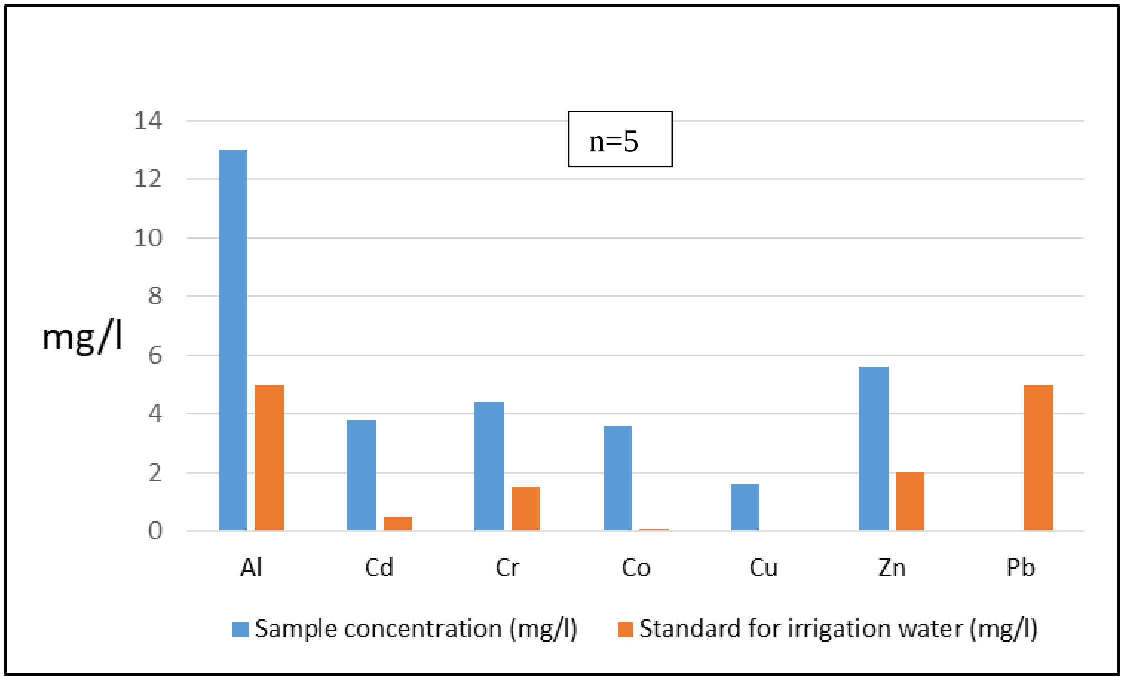

Figure 5.3: Concentration of Al, Cd, Cr, Co, Cu, Zn and Pb in the sample of upstream of Nairobi River wastewater used for vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

Lead was not detected in the sample. The rest of the parameters had the following concentrations: 1.6 mg/l instead of 0.05 mg/l for Cu, 3.6 mg/l against 0.1 mg/l recommended for Co, 3.8 mg/l instead of 0.5 mg/l recommended for Cd, 4.4 mg/l against 1.5 mg/l for Cr, 5.6 mg/l against 2 mg/l in the case of Zn, to 13 mg/l against 5 mg/l recommended for Al. The Chi-Square value ($\chi^2_{25,0.05} = 30.000a$) showed no statistical (P>0.05) relationship between the analysis results for the upstream of Nairobi River sample and the recommended standard for irrigation water.

5.2.4 Laboratory analysis results for raw influent sample

The results for pH, TDS, Al, Cd, Cr, Co, Cu, Zn and Pb in raw influent sample analysed against corresponding parameters in Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water are presented in Figure 5.4. The sample had a pH of 7.12 against the recommended 6.5-8.5, while TDS was 1582 mg/l against the recommended 1200 mg/l.

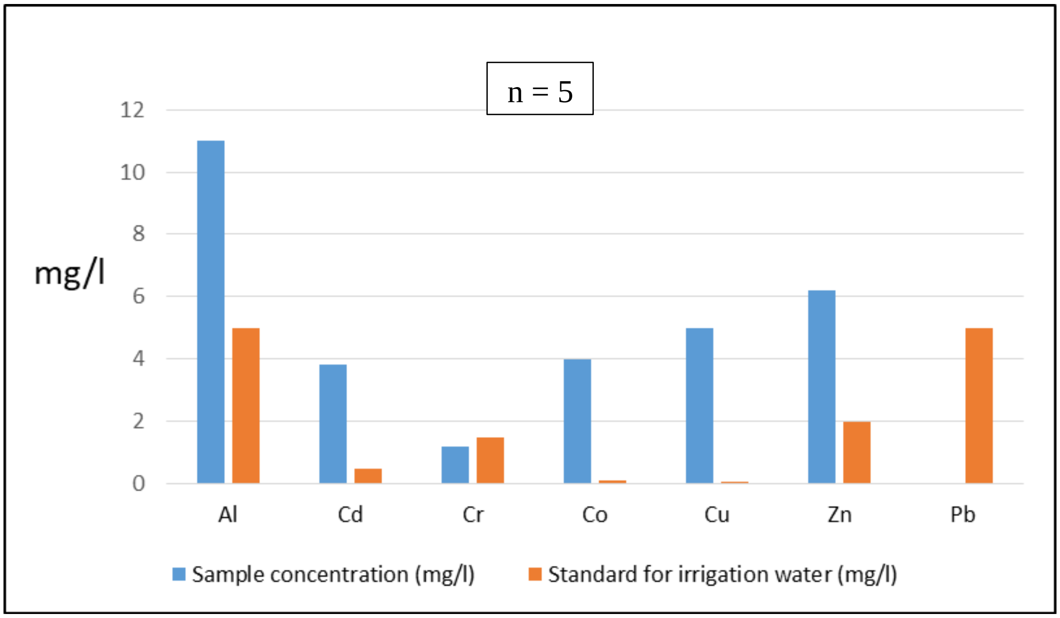

Figure 5.4: Concentration of Al, Cd, Cr, Co, Cu, Zn and Pb in the sample of raw influent used for vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

Lead was not detected in the sample. Concentration of other parameters in the raw influent sample were as follows: 1.2 mg/l against 1.5 mg/l for Cr, 3.8 mg/l against 0.5 mg/l for Cd, 4 mg/l against 0.1 in the case of Co, 5 mg/l against 0.05 mg/l for Cu, 6.2 mg/l instead of 2 mg/l for Zn, to 11 mg/l against 5 mg/l in the case of aluminium. The Chi-Square value

(χ225,001= 30.000a) showed a statistical significant difference ($P<0.01$) between the analysis results and the recommended standard for irrigation water.

5.2.5 Laboratory analysis results for the downstream of Nairobi River sample

The results for pH, TDS, Al, Cd, Cr, Co, Cu, Zn and Pb in downstream of Nairobi River sample analysed against corresponding parameters in Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water are presented in Figure 5.5.

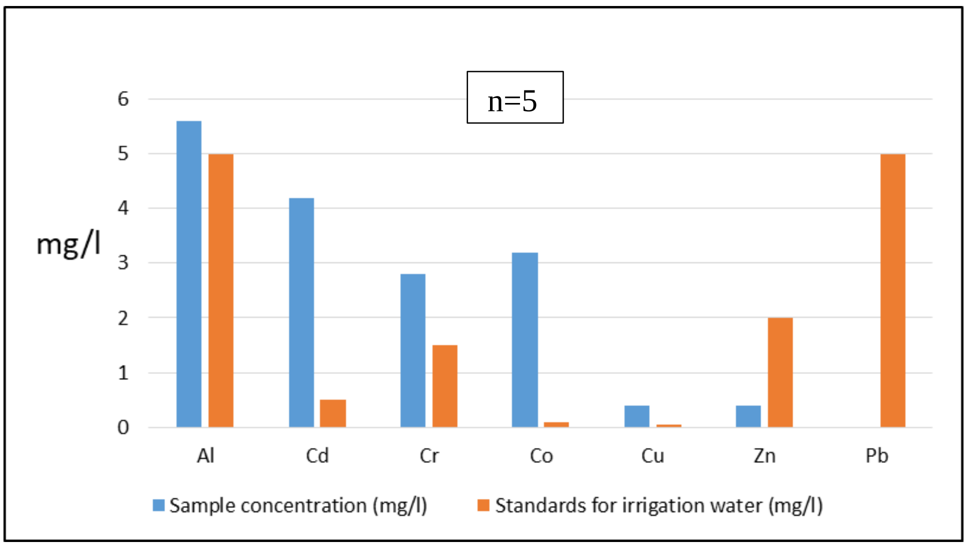

Figure 5.5: Concentration of Al, Cd, Cr, Co, Cu, Zn and Pb in the sample of downstream of Nairobi River wastewater used for vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

The sample recorded a pH of 6.89 against the recommended range of 6.5- 8.5, while TDS was 496 mg/l against the recommended concentration of 1200 mg/l. Lead was not detected in the sample. The rest of the parameters ranged in concentration from 0.4 mg/l each for Cu and Zn against 0.05 and 2 mg/l, respectively; 2.8 mg/l against 1.5 mg/l recommended for Cr, 3.2 mg/l against 0.1 mg/l recommended for Co; 4.2 mg/l instead of 0.5 for Cd; to 5.6 mg/l against 5 mg/l recommended for Al. The Chi-Square value ($\chi^2_{25,0.05} = 2.2372$) showed no significant ($P<0.05$) association between the results of the analysed parameters and the standard provided for irrigation water.

5.3 Microbiological composition of wastewater used in vegetable production in the study area

Concentration of total coliforms and *Escherichia coli* in samples of wastewater used in vegetable production in the study area analysed against Environmental Management and Coordination (Water Quality) Regulations, 2006 microbiological quality guidelines for wastewater use in irrigation are presented in Table 5.1. It shows concentration of total coliforms was highest (2.420×10^8 cells/ 100 ml) in the raw influent and lowest (1.986×10^6 cells/ 100ml) in the downstream of Nairobi River sample against <1000 minimum probable number (Mpn)/ 100 ml recommended for wastewater use in irrigation.

Total coliform concentrations in the rest of the samples were: 1.414×10^7 cells/ 100 ml in the discharge point sample, 1.733×10^7 cells/ 100 ml in the treated effluent sample and 2.420×10^7 cells/ 100 ml in the upstream of Nairobi River sample. Raw influent sample recorded highest concentration (2.420×10^7) of *Escherichia coli*, while downstream of Nairobi River sample recorded lowest (1.733×10^6) concentration.

Table 5.1: Total coliforms and *Escherichia coli* in samples of wastewater used in vegetable production in Ruai ward, Nairobi City

No.	Sample source	Geographical location of sampling point	Total coliforms (Mpn/ L)	*E. coli* (Mpn/ 100 ml)	Environmental Management and Coordination (Water Quality) Regulations, 2006 microbiological quality guidelines for wastewater use in irrigation
1.	Treated effluent	1º 14′ 10″ S (Lat.) 37º 00′ 49″ E	1.733×10^7	1.203×10^7	TC: < 1000 Mpn *E. coli*: Nil/100ml
2.	Discharge point	1º 14′ 6″ S (Lat.) 37º 00′ 50″ E	1.414×10^7	9.2×10^6	TC: < 1000 Mpn *E. coli*: Nil/100ml
3.	Upstream of Nairobi River	1º 14′ 40″ S (Lat.) 36º 57′ 14″ E	2.420×10^7	1.733×10^7	TC: < 1000 Mpn *E. coli*: Nil/100ml
4.	Raw influent	1º 14′ 46″ S (Lat.) 36º 55′ 34″ E	2.420×10^8	2.420×10^7	TC: < 1000 Mpn *E. coli*: Nil/100ml
5.	Downstream of Nairobi River	1º 14′ 36″ S (Lat.) 36º 56′ 06″ E	1.986×10^6	1.733×10^6	TC: < 1000 Mpn *E coli*: Nil/100ml

Mpn- Minimum probable number, TC- total coliforms, *E. coli* - *Escherichia coli*

Source: Researcher (2021)

This is against minimum probable number (Mpn)/100ml recommended for wastewater use in irrigation. Concentrations of *E. coli* in the rest of the samples were 9.2×10^6 cells/ 100 ml in the discharge point sample, 1.203×10^7 cells/ 100 ml recorded in the treated effluent sample and 1.733×10^7 cells/ 100 ml in the upstream of Nairobi River sample.

The Chi-Square value ($\chi^2_{9,0.01} = 12.000$) showed there was no statistically significant (P>0.01) difference between *Escherichia coli* in the samples and the recommended value provided under the microbiological quality guidelines for wastewater use in irrigation. Total coliforms and *Escherichia coli* were not only detected in all the samples, but their respective concentrations exceeded recommended limits of <1000 minimum probable number/ 100 ml, and nil/ 100 ml.

The highest (2.420 x 10^8 mpn/ l) concentration of total coliforms was recorded in the raw influent sample, while the upstream of Nairobi River sample recorded the highest (1.733 x 10^7 mpn/ 100 ml) concentration of *Escherichia coli*. The lowest concentrations of the two microbes viz. 1.986 x 106 mpn/ l for total coliforms and 1.733 x 10^6 mpn/ 100 ml in the case of *E. coli* were both detected in the sample collected from downstream of Nairobi River.

5.4 Discussions

Values for TDS in the samples were generally below the recommended limit of 1200 mg/l in the standards for irrigation water, which confirms findings by Mbui *et al* (2016). Higher TDS value in the raw influent (1582) could be associated with leachate resulting from solid waste disposal into the Nairobi River, while lower TDS values recorded in the upstream and downstream of Nairobi River of 454 and 496 mg/l, respectively, could be linked to reduced erosion of land upstream, and reduced discharge.

Concentrations of Al in the samples was highest (13 mg/l) in both treated effluent and upstream of Nairobi River samples which exceeded 5 mg/l recommended in the standards for irrigation water. Copper, Cd, Cu, Zn, Cr and Pb concentrations in most samples exceeded values recommended for corresponding elements in the Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water contrary to Kaluli *et al*. (2011) who indicated that the wastewater generated in Nairobi was within NEMA quality guidelines except biological oxygen demand (BOD). It however concurs with Gezahegn *et al* (2017) that continuous application of municipal or industrial wastewater for irrigation brings about build-up of trace elements such as in the soil surface and their excessive accumulation not only contaminates the soil but also affect the quality and safety of food.

Jeong, *et al* (2016) are of the view Cd when dissolved in water or soil, it can be accumulated in the crop and becomes harmful to the human body. The mean value for Cobalt in the samples exceeded the recommended cobalt limits in the standards for irrigation water. Excessive accumulation of cobalt in agricultural soils through wastewater irrigation may not only result in soil contamination, but also affects food quality and safety (Naser *et al*., 2018). The elevated Co concentration in the treated effluent could be linked to effluent discharges into the Nairobi River from small and medium enterprises such as vehicle garages.

The mean value for Zn in the samples exceeded the recommended Zn limits in the standards for irrigation water. Elevated levels of trace elements such as Cu and Zn can cause leaf chlorosis and the suppression of root growth as pointed out in Jeong *et al* (2016). Kithure and Musundu (2019) discovered the concentration of Pb in treated effluents from vegetable oils and chemical industries in Nairobi City exceeded the Kenya Bureau of Standards (KEBS) limit of 0.05mg/l. They thought the source of Pb could have resulted the pipe that carries the wastewater to the treatment plant. In the current study Pb with a concentration of 6.8 mg/l against the recommended concentration 5 mg/l) in the Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water was detected only in the treated effluent sample. Perhaps the source of Pb could have been caused by the pipes carrying domestic wastewater and industrial wastewater to Ruai treatment plant as alluded to in Kithure and Musundu (2019).

The Ruai domestic wastewater and industrial wastewater treatment plant could not have been the only contributor of noted elevated levels of the analysed parameters in the samples from five sampling points in the study area. This is confirmed from the upstream of Nairobi River sample, which showed that the River had high concentration of the analysed parameters before reaching the discharge point. The quality of natural water sources used for different purposes should be established in terms of the specific water-quality parameters that most affect the possible use of water (Shah, 2017).

Overall assessment of the analysis results indicates none of the samples from the five different sampling sites met the Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water contrary to Kaluli *et al* (2011). Despite undergoing treatment process, Al, Cd, Cr, Co, Cu, Zn and Pb concentrations in the treated effluent sample surpassed the recommended limits for corresponding parameters in the Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water.

Physicochemical characteristics contribute health and environmental risks. Key sources of chemical pollutants that pose risk to human health are municipal and industrial wastewater (Buechler *et al*., 2006). Using effluents discharged from manufacturing industries, wastewater irrigation systems and municipal sewerage for irrigation results in increased accumulation of heavy metals in food crops and vegetable plants thereby compromising food safety (Verma and Kaur, 2016). Consumption of raw untreated wastewater irrigated vegetables and green salad crops could be linked to diseases like typhoid, cholera, diarrhoea and dysentery (Buechler *et al*., 2006). The untreated wastewater irrigation facilitates transmission of diseases from excreta-related pathogens and skin irritants (Drechsel *et al*., 2010). The study findings on health risks of using wastewater in vegetable production concur with Buechler *et al* (2006) and Drechsel *et al* (2010). Diarrhoea and skin diseases were among the most reported diseases in health facilities visited for triangulation of face-to-face interviews with the farmers in the study area. Other diseases are amoeba and typhoid which were said to be caused by handling and consumption of vegetables produced using wastewater. Poor hygiene due to failure to clean vegetables thoroughly before cooking was also reported to be another cause. These findings concur with Buechler *et al* (2006) and Drechsel *et al* (2010).

Although trace elements such as copper and zinc are essential for crop growth, they can cause harm if they are in excess in irrigation water. Lead and Cd when dissolved in water or soil, they can be accumulated in the crop and become harmful to the human body (Jeong *et al.*, 2016). Heavy metals (Naser *et al*., 2012) have a tendency to bio-accumulate in plants and animals, and bio-concentrate in the food chain and attack specific body organs. Heavy metal contamination can be triggered by irrigation with contaminated water, application of fertilizers and metal-based pesticides, industrial emissions, transportation, harvesting process, and storage and /or sale (Bagdatlioglu *et al*., 2010).

Consumers are rising demand for improved vegetables. Some unpolluted, dark green and large leaves have good quality leafy vegetables. However, exterior vegetable morphology cannot ensure pollution protection. The main pollutants of leafy vegetables include heavy metals. Vegetables absorb metals from contaminated soils and contaminated habitats. Heavy metal contaminated media vegetables can build up significant trace element concentrations and pose a health danger to consumers (Ali and Al-Qahtani, 2012).

Many metals are required for life at low quantities. Trace levels, for example, for plants and higher animals, of specific metallic elements such as Co, Cu and Zn are key micronutrients. Excessive buildup by water irrigation of agricultural soils not only leads to soil pollution but also affects food quality and safety (Naser *et al*., 2018). The impact on agricultural soil from wastewater is due mostly to the presence of high nutrient content (nitrogen and phosphorus), high total dissolved solids (TDS) and other components such as heavy metals, added to soil overtime (Hassan *et al*., 2015).

The study findings confirm Kaluli *et al* (2011) that coliform bacteria in Nairobi's raw influent surpassed the recommended level pursuant to Environmental Management and Coordination (Water Quality) Regulations, 2006 microbiological quality guidelines for wastewater use in irrigation. The study also shows farmers irrigate their vegetables with untreated water and wastewater which in Magnusson and Bergman (2014) is one source of microbial contamination of vegetables along the production chain. The presence of coliforms in the samples confirms wastewater used in vegetable production in the study area is contaminated with disease causing germs and pathogens as pointed out by Abbas *et al* (2015).

In general, analysis results showed of all the five sources sampled, the treated effluent was exceedingly contaminated with high levels of total coliforms and *E.coli* which makes it unsuitable for irrigation because of faecal contamination despite undergoing treatment process. This therefore suggests the vegetables produced using wastewater in the study area had varying levels of microbial contamination although the current study only investigated total coliforms and *Escherichia coli.*

Microbiological composition of wastewater used for irrigating crops such as vegetables contribute health and environmental risks. Municipal wastewater provides a favourable conditions for survival of fungi, viruses and bacteria as well as pathogenic organisms (Bawiec *et al*., 2016).

Irrigation with the untreated water and wastewater is one source of microbial contamination of vegetables along the production chain. Other sources include pathogens in the soil, application of contaminated manure, and cleaning the vegetable produce with polluted water. In addition, the main microbial contamination in vegetables produced in urban areas occurs during primary production and in this case post-harvest processing and handling does not necessarily increase levels of contamination (Magnusson and Bergman, 2014).

Wastewater contains an array of excreted organisms which vary in types and their concentrations according to background levels of disease in the population. Besides ascariasis disease, other diseases related to the use of wastewater include cholera, typhoid, gastric ulcers caused by *Helicobacter pylori*, and amebiasis (Jiménez, 2006).

CHAPTER SIX

CONCENTRATIONS OF SELECTED HEAVY METALS IN VEGETABLES PRODUCED USING WASTEWATER IN URBAN AND PERI-URBAN AREAS OF NAIROBI CITY, KENYA

6.1 Introduction

Heavy metals uptake by leafy vegetables (Akan, 2013) is an avenue of their entry into the human food chain with deleterious effects on health. It is against this backdrop that selected heavy metals viz. titanium (Ti), zinc (Zn), lead (Pb), chromium (Cr), cadmium (Cd), cobalt (Co) and copper (Cu) were analysed using atomic absorption spectroscopy to determine their concentration (g/kg) levels in the samples of four leafy vegetables viz. *Brassica* sp., *Solanum* sp., *Amaranthus* sp. and *Spinacia oleracea* produced using wastewater in the study area, and evaluated status with FAO/ WHO safe limits for corresponding heavy metals in green leafy vegetables. Analyses results are presented in Appendix 9.

Chapter six therefore presents the results and discussions on the analysis results of selected heavy metals in the samples of four different types of mature green leafy vegetables from five different sampling plots corresponding to the sources of wastewater used in their production in the study area.

6.2 Concentrations of selected heavy metals in the samples of the treated effluent-irrigated vegetables

The concentrations (g/kg) of Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of treated effluent-irrigated *Brassica* sp., *Solanum* sp., *Amaranthus* sp. and *Spinacia oleracea* vegetables are given in Figure 6.1. The results show Ti concentration was highest (143g/kg) in the *Amaranthus* sp. sample, followed by 126 g/kg in the *Spinacia oleracea* sample, 115 g/kg recorded in the *Solanum* sp. sample.

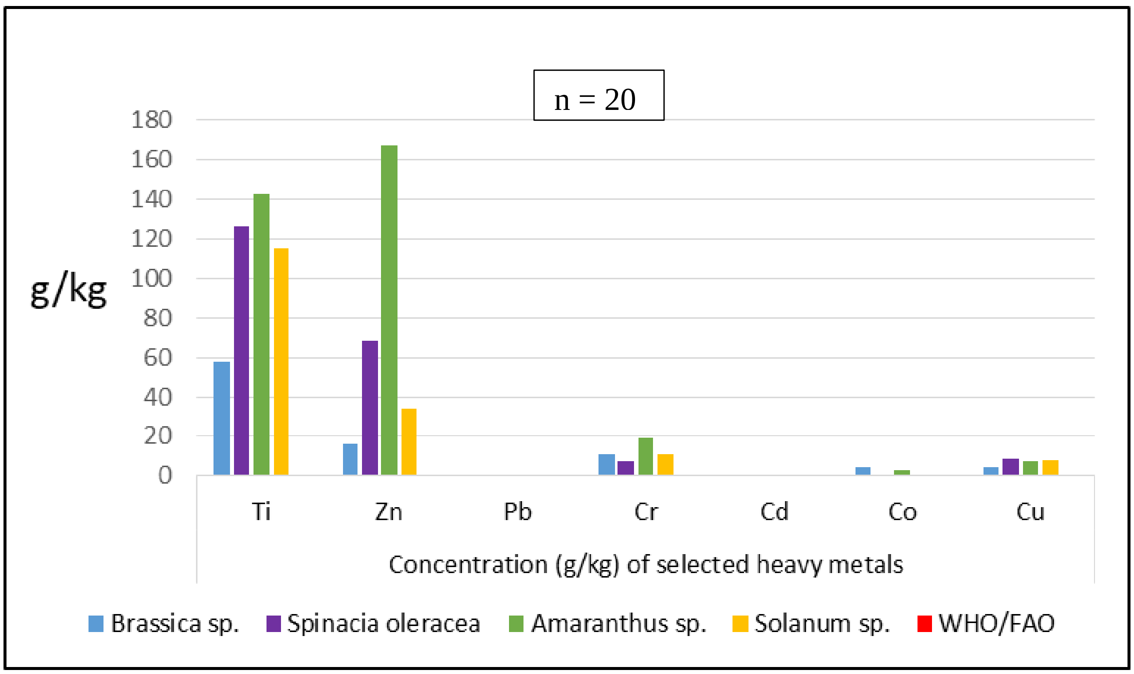

Figure 6.1: Concentration (g/kg) of Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of treated effluent- irrigated vegetables in Ruai Ward, Nairobi City, Kenya

Source: Researcher (2021)

Zinc concentration was highest (167 g/kg) in the *Amaranthus* sp. sample and lowest (16 g/kg) in *Brassica* sp. sample. Zinc concentration in the rest of the samples was 34 g/kg in

Solanum sp. sample and 68 g/kg in *Spinacia oleracea*. Lead was detected only in the *Brassica* sp. and *Amaranthus* sp. samples, each recorded 0.05 g/kg. The concentration of Cr was highest (19 g/kg) in the *Amaranthus* sp. sample and lowest (7 g/kg), in the *Spinacia oleracea* sample, while the *Brassica* sp. and *Solanum* sp. samples, each recorded 11 g/kg.

The highest Cd concentration (0.27 g/kg) was detected in the *Spinacia oleracea* sample, followed by 0.13 g/kg recorded in the *Brassica* sp. sample, 0.07 g/kg in the *Solanum* sp. sample and lowest (0.05 g/kg) in the *Amaranthus* sp. sample. Cobalt, which was detected only in two out of the four samples of vegetables, ranged in concentration between 4 g/kg as the highest recorded in the *Brassica* sp. sample and 3 g/kg as the lowest detected in the *Amaranthus* sp. sample. The highest concentration of Cu (9 g/kg) was detected in the *Spinacia oleracea* sample followed by 8 g/kg in the *Solanum* sp. sample, 7 g/kg in the *Amaranthus* sp. and 4 g/kg being lowest detected in the *Brassica* sp. sample.

6.3 Concentrations of selected heavy metals in the samples of Nairobi River discharge point-irrigated vegetables

The concentrations of Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of *Brassica* sp., *Solanum* sp., *Amaranthus* sp. and *Spinacia oleracea* vegetables produced using wastewater from the discharge point of the Nairobi River are shown in Figure 6.2. The results show the highest (113 g/kg) and lowest (91 g/kg) concentrations of Ti were detected in the *Spinacia oleracea* and the *Brassica* sp. samples, respectively. The *Amaranthus* sp. sample recorded 101 g/kg, while the *Solanum* sp. sample recorded 97 g/kg. Zinc concentration was highest (48 g/kg) in the *Spinacia oleracea* sample and lowest (21 g/kg) in the *Amaranthus* sp. sample. The *Brassica* sp. and *Solanum* sp. samples recorded Zn concentration of 30 and 27 g/kg, respectively. The *Spinacia oleracea* and *Amaranthus* sp. samples, each recorded Cr concentration of 16 g/kg, being the highest, followed by 5 g/kg detected in the *Solanum* sp., while the *Brassica* sp. sample recorded the lowest (2 g/kg).

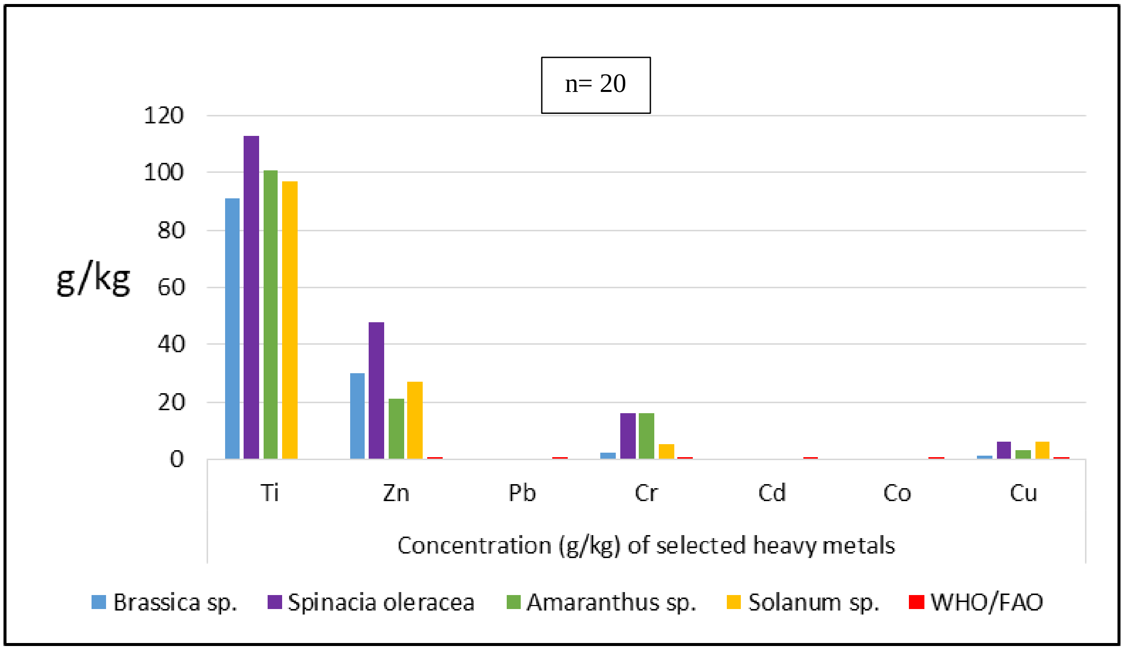

Figure 6.2: Concentration (g/kg) of Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of discharge point- irrigated vegetables in Ruai Ward, Nairobi City, Kenya

Source: Researcher (2021)

Lead, Cd and Co were not detected in the samples. Copper ranged in concentration between 1 g/kg in the *Brassica* sp. sample, 3 g/kg in the *Amaranthus* sp., and 6 g/kg each in *Spinacia oleracea* and *Solanum* sp. samples.

6.4 Concentrations of selected heavy metals in the samples of upstream of Nairobi River-irrigated vegetables

Concentrations of Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of vegetables produced using wastewater from upstream of Nairobi River are presented in Figure 6.3. The results show the *Amaranthus* sp. sample recorded the highest (238.00 g/kg) concentration of Ti, while the *Solanum* sp. sample recorded the lowest (90 g/kg).

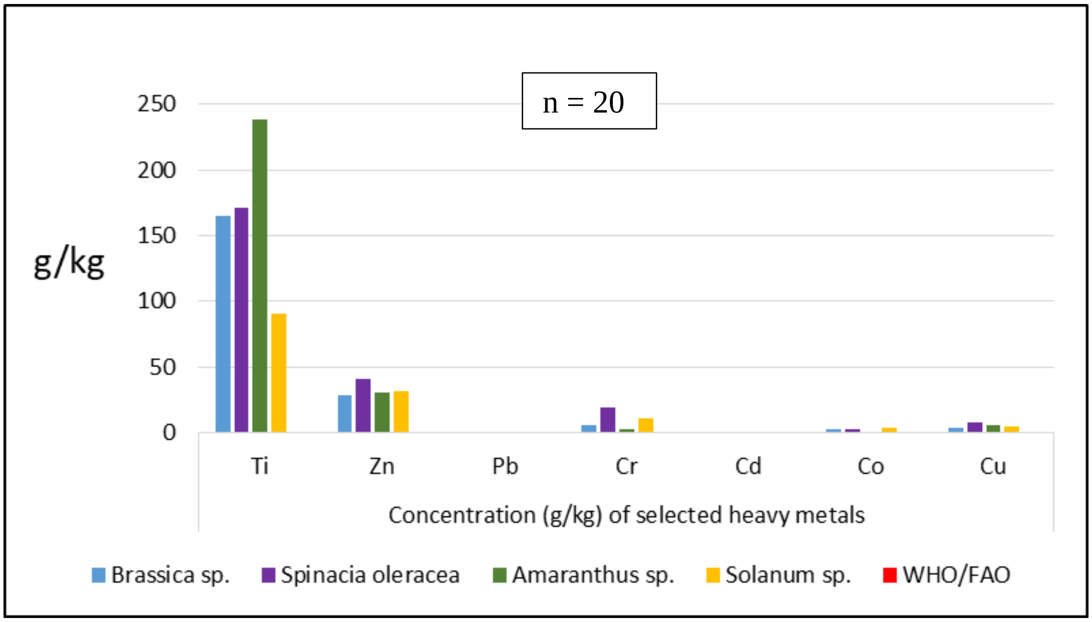

Figure 6.3: Concentration (g/kg) of Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of upstream of Nairobi River-irrigated vegetables in Ruai Ward, Nairobi City, Kenya

Source: Researcher (2021)

Titanium concentration in the *Spinacia oleracea* and the *Brassica* sp. samples was 171 and 165 g/kg, respectively. Zinc concentration in the samples was 41 g/kg in the *Spinacia oleracea* sample, 32 g/kg in the *Solanum* sp. sample, 31 g/kg recorded in the *Amaranthus* sp. sample, and 29 g/kg in the *Brassica* sp. sample. Lead with a concentration of 0.06 g/kg was detected only in the *Amaranthus* sp. sample.

Chromium was detected in all samples and varied in concentration from 3 g/kg in the *Amaranthus* sp. sample, 6 g/kg in the *Brassica* sp. sample, 11 g/kg in the *Solanum* sp. sample to 19 g/kg recorded in the *Spinacia oleracea* sample. Cadmium was not detected in the samples. Cobalt was detected in all the samples except the *Amaranthus* sp. sample. The highest Co concentration (4 g/kg) was recorded in the *Solanum* sp. sample, while the lowest concentration (3 g/ kg) was detected in both *Brassica* sp. and *Spinacia oleracea* samples. The *Spinacia oleracea* sample recorded the highest Cu concentration (8 g/kg), while the *Brassica* sp. sample recorded the lowest at 4 g/kg. The *Solanum* sp. and *Amaranthus* sp. samples recorded Cu concentration of 5 and 6 g/kg, respectively.

6.5 Concentrations of selected heavy metals in the samples of raw influent-irrigated vegetables

Concentrations (g/kg) of Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of raw influent-irrigated *Brassica* sp., *Solanum* sp., *Amaranthus* sp. and *Spinacia oleracea* are presented in Figure 6.4. The results show maximum Ti concentration (216 g/kg) was detected in the *Solanum* sp. sample and minimum (105 g/kg) in the *Brassica* sp. sample. The *Amaranthus* sp. and *Spinacia oleracea* samples recorded 172 and 108 g/kg, respectively. Zinc concentration was highest (50 g/kg) and lowest (30 g/kg) in the *Solanum* sp. sample.

The *Amaranthus* sp. and the *Brassica* sp. samples recorded similar Zn concentration (46 g/kg). Lead with a concentration 0.06 g/kg was detected only in the *Amaranthus* sp. sample. Chromium in the samples ranged in concentration from 8 g/kg recorded in the *Amaranthus* sp. sample, 13 g/kg in the *Solanum* sp. sample, 14 g/kg in the *Brassica* sp. sample to 16 g/kg in the *Spinacia oleracea* sample.

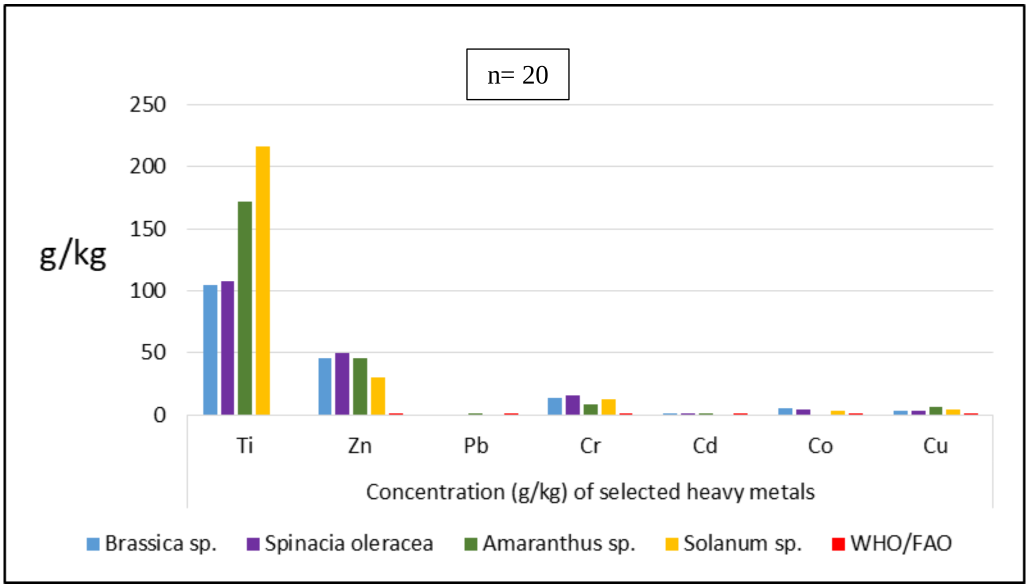

Figure 6.4: Concentration (g/kg) of Ti, Zn, Pb, Cr, Cd, Co and Cu in the Samples of raw influent- irrigated vegetables in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

Concentration of Cd in the samples varied between 0.01 g/kg as the lowest concentration in the *Spinacia oleracea* and 0.23 g/kg as the maximum Cd concentration in the *Amaranthus* sp. sample. The *Brassica* sp. sample recorded Cd concentration of 0.04 g/kg. Cadmium was not detected in the *Solanum* sp. sample. Maximum concentration of Co (5 g/kg) was detected in the *Brassica* sp. sample and minimum (3 g/kg) in the *Solanum* sp. sample. The *Spinacia oleracea* sample recorded Co concentration of 4 g/kg recorded. It was not detected in the *Amaranthus* sp. sample.

6.6 Concentrations of selected heavy metals in the samples of downstream of Nairobi River-irrigated vegetables

The concentrations (g/kg) of Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of downstream of Nairobi River-irrigated *Brassica* sp., *Spinacia oleracea*, *Amaranthus* sp. and *Solanum* sp.

vegetables are presented in Figure 6.5. Titanium content in the samples was maximum (150 g/kg) in the *Solanum* sp. sample and minimum (65 g/kg) in the *Amaranthus* sp. sample. The *Spinacia oleracea* and *Brassica* sp. samples recorded Ti concentration of 115 and 85 g/kg, respectively. Maximum Zn concentration of 202 g/kg was detected in the *Spinacia oleracea* sample, while minimum concentration (29 g/kg) was recorded in the *Brassica* sp. sample. The *Amaranthus* sp. and *Solanum* sp. samples recorded Zn concentration of 49 and 33 g/kg, respectively.

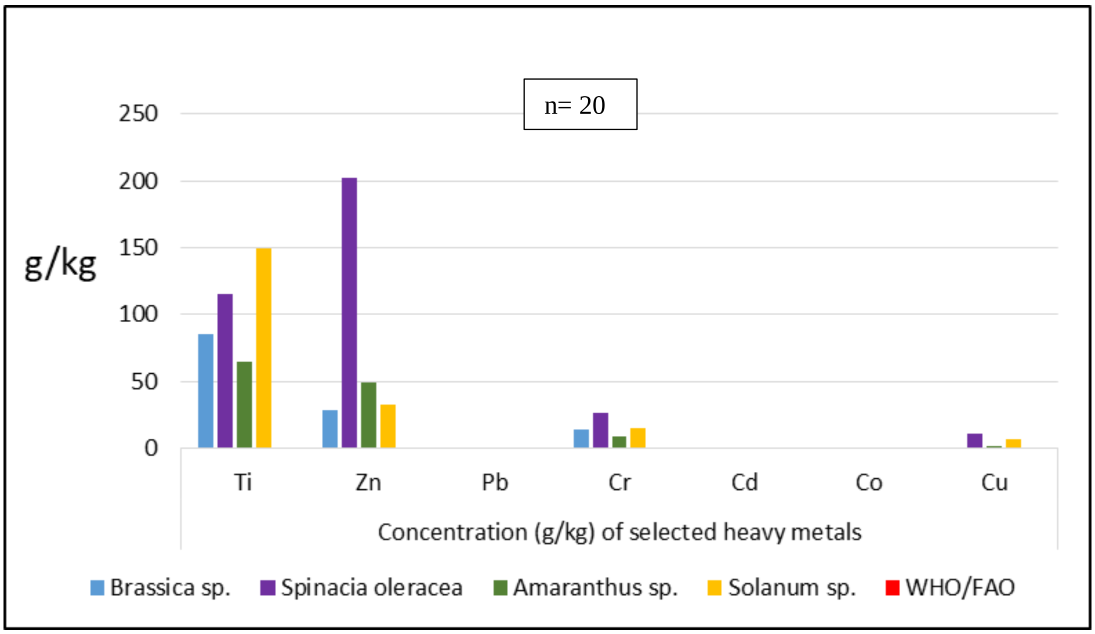

Figure 6.5: Concentration (g/kg) of Ti, Zn, Pb, Cr, Cd, Co and Cu in samples of downstream of Nairobi River- irrigated vegetables in Ruai Ward, Nairobi City, Kenya

Source: Researcher (2021)

Lead and Co were not detected in any of the samples which probably suggests Pb and Co were either absent or below their detection limits. Chromium concentration was maximum (27 g/kg) in the *Spinacia oleracea* and maximum (9 g/kg) in the *Amaranthus* sp. sample.

The *Solanum* sp. and *Brassica* sp. samples recorded Cr concentration of 15 and 14 g/kg, respectively.

Maximum Cd concentration (0.2 g/kg) was detected in the *Spinacia oleracea* sample, while minimum concentration (0.02 g/kg) was recorded in the *Brassica* sp. sample. The *Solanum* sp. and *Amaranthus* sp. samples recorded Cd concentration of 0.14 and 0.11 g/kg, respectively. The highest Cu concentration (11 g/kg) was recorded in the *Spinacia oleracea* sample and minimum (1 g/kg) in the *Brassica* sp. The *Solanum* sp. and *Amaranthus* sp. samples registered Cu concentrations of 7 and 2 g/kg, respectively.

6.7 Discussion

In general, the concentrations of Ti, Zn, Pb, Cr, Cd, Co and Cu in the vegetables produced using wastewater from different sources in the study area varied among different vegetable types. The differences in heavy metal concentrations in samples of vegetables from the same site can be attributed to differences in their morphology and physiology for heavy metal uptake, exclusion, accumulation and retention as opined by Gupta *et al* (2013). Titanium concentration in all the samples was maximum and minimum in the samples of treated effluent-irrigated vegetables. Thus, the *Amaranthus* sp. sample recorded maximum Ti concentration of 238 g/kg, while the *Brassica* sp. sample recorded minimum at 58 g/kg.

Zinc concentration was highest (202 g/kg) in the downstream of Nairobi River-irrigated *Spinacia oleracea* sample and minimum (16 g/kg) in the treated effluent-irrigated *Brassica* sp. sample. Gupta *et al* (2013) upon investigating concentrations of heavy metals in vegetables in Raipur city, India discovered *Spinacea oleracea* had highest concentration of Zn. Similarly in the current study amongst the investigated vegetables, *Spinacea oleracea* recorded the highest Zn concentration. Mean concentration of Zn in the samples viz. 30 g/kg in the *Brassica* sp. sample, 81.8 g/kg in the *Spinacia oleracea* sample, 62.8 g/kg in the *Amaranthus* sp. sample, and 31.2 g/kg in the *Solanum* sp. sample conflict with the findings of Mutune *et al* (2014). The values also exceeded the FAO/ WHO safe limit of 0.099 g/kg for Zn in green leafy vegetables.

Although Zn is essential for biological activities in the body, its presence in high concentration can be a health risk. All living organisms accumulate substantial amount of Zn in their system without any damaging effect as it is essential for carbohydrate metabolism, protein synthesis and inter nodal elongation. Zinc deficiency causes loss of appetite, growth retardation and immunological abnormalities. However, Zn can be toxic when exposures exceed physiological requirements (Shakya and Khwaounjoo, 2013).

Lead was detected in the samples of treated effluent-irrigated *Brassica* sp. and *Amaranthus* sp., each recorded 0.05 g/kg. It was also detected in the samples of upstream of Nairobi River and raw influent-irrigated *Amaranthus* sp., with similar concentration of 0.06 g/kg. It was not detected in the rest of the samples perhaps concentrations were far below detection limit or absent. The presence of Pb in the *Amaranthus* sp. sample is in concurrence with Inoti *et al* (2012). The recorded Pb values, however exceeded the FAO/ WHO safe limit of 0.0003 g/kg for Pb in green leafy vegetables.

Excessive accumulation of Pb in plant tissue impairs various morphological, physiological and biochemical functions with deleterious effects. In turn elevated levels of Pb in the blood is potential of causing kidney dysfunction and brain damage (Gupta *et al*., 2013). Lead causes mental retardation in young children (Mutune *et al*., 2014). Increase of blood pressure in adults is also related to Pb in the human body (Ametepey *et al*., 2018).

The concentration of Cr in the samples was minimum (2 g/kg) in the discharge point-irrigated *Brassica* sp. sample and maximum (27 g/kg) in the sample of downstream of Nairobi River-irrigated *Spinacia oleracea*. The mean concentration of Cr in the samples, which was 9.4 g/kg in *Brassica* sp., 17 g/kg in *Spinacia oleracea*, 12.8 g/kg in the *Amaranthus* sp., and 11 g/kg in *Solanum* sp. surpassed FAO/WHO safe limit of 0.0023 g/kg for Cr in green leafy vegetables.

Chromium is a non-essential metal potential of causing adverse health effects even at low concentrations (Gupta *et al.*, 2013). Hussain *et al* (2002) hold the view that both Ti and Cr, which were detected in all the vegetable samples and their concentrations exceeded the FAO/ WHO safe limits, posed minimum risk because they are not taken up to any extent by plants.

Although Cd was not detected in all samples from discharge point and upstream of Nairobi River-irrigated vegetables, it was detected in all samples of treated effluent and downstream of Nairobi River-irrigated vegetables. It was further detected in three out of four samples from raw influent-irrigated vegetables. Maximum (0.27 g/kg) Cd concentration was recorded in the sample of treated effluent-irrigated *Spinacia oleracea*, while the sample of raw influent-irrigated *Spinacia oleracea* recorded minimum (0.01 g/kg) concentration. In comparison with FAO/ WHO permissible limit of 0.0002 g/kg for Cd in green leafy vegetables, the two values were higher. Due to its nature, Cd is non-essential and has no nutritional value to plants, animals and human beings (Latif *et al*., 2018).

Cobalt, which was detected in more than half of the samples, varied in concentration from 3 g/kg, each in the samples of treated effluent-irrigated *Amaranthus* sp., upstream of Nairobi River- irrigated *Brassica* sp. and *Spinacia oleracea*, and raw influent-irrigated *Solanum* sp., 4 g/kg each, in the treated effluent *Brassica* sp., upstream of Nairobi River-irrigated *Solanum* sp., and raw influent-irrigated *Spinacia oleracea*, to 5 g/kg being maximum Co value in the raw influent-irrigated *Brassica* sp. Cobalt is essential to human beings because it forms part of vitamin B_{12} also known as cobalamin. However, exposure to elevated levels results in lung and heart diseases and dermatitis (Oladeji and Saeed, 2015). Symptoms of Co deficiency (Gezahegn, 2017) include loss of appetite, emaciation, weakness and anemia.

The concentrations of Cu in the samples ranged from 1 g/kg in the samples of discharge point and downstream of Nairobi River- irrigated *Brassica* sp. to 11 g/kg in the downstream of Nairobi River- irrigated *Spinacia oleracea*. The mean Cu concentration in the samples of 2.6 g/kg in *Brassica* sp., 7.4 g/kg in the *Spinacia oleracea* sample, 4.8 g/kg in the *Amaranthus* sp. sample, and 6 g/kg in the *Solanum* sp. sample surpassed the FAO/ WHO safe limit of 0.073 g/kg for Cu in green leafy vegetables.

Concentrations of all the target heavy metals viz. Ti, Zn, Pb, Cr, Cd, Co and Cu in the samples of vegetables varied from below detection limit to above FAO/ WHO permissible limits for corresponding heavy metals in green leafy vegetables, depending upon the source of wastewater used in their production. Their mean concentrations were 126.2, 51.45, 0.055, 12.1, 0.12, 3.625 and 5.2 g/kg, respectively. This shows different vegetables have different capacities to absorb and bio- accumulate heavy metals.

The findings showed concentrations of nearly all the heavy metals in the samples of vegetables exceeded respective FAO/ WHO safe limits and therefore posed potential risk to the consumers of such vegetable produce. The findings also concur with Verma and Kaur (2016) and Gezahegn *et al* (2017) that continuous application of municipal or industrial wastewater for irrigation can cause accumulation of trace elements like Cd, Cu, Zn, Cr and Pb in surface soil.

The presence of heavy metals in the edible parts of analysed vegetables in the current study is similar to what Mutua *et al*. (2010) discovered when they investigated public health and environmental hazards associated with wastewater irrigation in Nairobi's urban agriculture that revealed the presence of heavy metals mainly in the stem and leaves, which raised health concerns as the plant parts were harvested for human consumption. The order of metal contents in the samples of vegetables produced using wastewater from different sources in the study area was found to be Pb > Cd > Co > Cu > Cr > Zn > Ti.

The study area is located close to the busy Nairobi- Kangundo road and it is expected that vehicular emissions could also be linked to heavy metal deposition in the analysed vegetables. In addition, the Nairobi River which is one of the main sources of water used for vegetable production in the study area traverses an area characterized by the presence of informal settlements as well as small and medium scale industries which could also be associated with the deposition of heavy metals in the soil and subsequent deposition in the analysed vegetables.

Heavy metals in wastewater irrigated vegetables pose health and environmental risks. For instance, accumulation of heavy metals and their uptake by different plant parts depend on the concentrations of available heavy metals in the soil and form of metals (Agrawal *et al*., 2007). Soil acts as a medium for plant growth which can recycle nutrient and resources that plants need. Heavy metals that are attached with soil water and soil particles will be absorbed by plant roots and accumulated in vegetables. Using water which is contaminated by heavy metals for irrigation is another pathway through which heavy metals get into vegetables (Aweng *et al*., 2011).

Transfer of heavy metals from water to soil and finally uptake from soil and accumulation in edible parts of vegetative tissue (Bashir *et al*., 2009) represents a direct pathway through which they get incorporated into the human food chain. Vegetable plants growing on a medium contaminated with heavy metal have the potential to accumulate trace elements in high concentration to cause health risk to consumers (Ali and Al-Qahtani, 2012). Heavy metals such as Cr, Zn and Cu (Shakya and Khwaounjoo, 2013) though essential for biological activities in the body, their presence in high concentration can be a health risk. Leafy vegetables (Asdeo and Loonker, 2011) are capable of accumulating heavy metals than other vegetables.

Assessment of leafy vegetables viz. *Amaranthus* sp. and *Solanum villosum* grown in Thika town by Inoti *et al* (2012), revealed the two vegetable species accumulated Pb in their stems and edible leaves but the stems accumulated the highest concentration. The concentration of heavy metals on the surface and within plants are influenced by several factors including climatic conditions, atmospheric deposition, application of fertilizers, type of soil on which the plant is grown, and irrigation with wastewater (Shakya and Khwaounjoo, 2013).

Excessive accumulation of Pb in plant tissue impairs various morphological, physiological and biochemical functions in plants often with deleterious effects (Tasrina *et al*., 2015). Elevated levels of Pb in the blood is potential of causing kidney dysfunction and brain damage (Gupta *et al*., 2013). There is relationship between Pb in the human body and the increase of blood pressure of adults as pointed out by Ametepey *et al* (2018). Lead also causes mental retardation in young children (Mutune *et al*., 2014).

Concentrations of heavy metals in the analysed vegetables may not be sufficient for determining health implications since this depends on the dietary pattern of the consumers as well. The study did not investigate the dietary patterns of the consumers as this was not part of the study objectives.

CHAPTER SEVEN

RISKS OF USING WASTEWATER IN VEGETABLE PRODUCTION IN URBAN AND PERI-URBAN AREAS OF NAIROBI CITY, KENYA

7.1 Introduction

The study sought to establish from the farmers and key informants health and environmental risks associated with wastewater application in vegetable production in the study area. Chapter seven therefore presents the findings and discussions on health and environmental risks of using wastewater in vegetable production as found out from the farmers and the key informants.

7.2. Risks of using wastewater in vegetable production in the study area

Wastewater contains harmful chemical constituents and pathogens that pose risk to health and environment (Shakir *et al*., 2016). It is against this background that the study sought to know from the farmers and the key informants health and environmental risks associated with wastewater use in vegetable production in the study area.

7.2.1 Health risks

The study sought to know from the farmers any wastewater related infections in their households within two months prior to the survey. This was asked because farmers using wastewater for crop irrigation were exposed to various types of diseases as expound by Akhtar *et al* (2018) and Shakir *et al* (2016). The infections reported by the respondents (Figure 7.1) are injuries (21%), skin infections (13%) and stomach upsets especially amongst children under five years old (18%). Majority (48%) of the respondents did not report any infection.

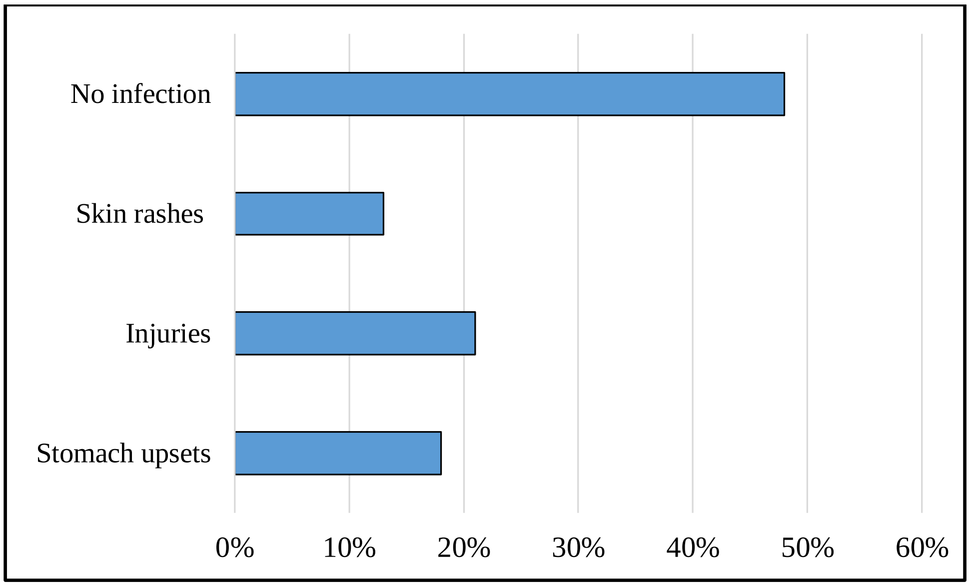

Figure 7.1: Reported infections in the farmers' households linked to wastewater use in vegetable production in Ruai Ward, Nairobi City, Kenya

Source: researcher, 2021

Farmers' responses to health risks they exposed themselves to in using wastewater for vegetable production was triangulated by visiting and interviewing medical personnel-in-charge of health facilities in the study area. Given the sensitivity of the survey and nature of reception, four health facilities (3 privately owned and one managed by Nairobi County Government) out of 8 located within the study area were visited.

Skin and waterborne diseases also known as enteric diseases such as typhoid, *Escherichia coli*, *Escherichia histolytica* and *Giardia lumbricoides* are amongst the most reported cases in all the four health facilities visited. Details about health facilities visited viz. names and management, common diseases, as well as observations and recommendations by the medical personnel in-charge are shown in Appendix 10.

7.2.2 Environmental risks

The study sought to know from the farmers the environmental risks of using wastewater in vegetable production in the study area. Their responses were analyzed and the results presented in Figure 7.2. Most (31%) farmers linked wastewater application in vegetable production with bad smell, 25% of them stated it encroached onto the Nairobi River with resultant riverbank erosion, 23% associated it with pollution of the Nairobi River, while 21% were of the view that the accumulation of wastewater was not only encouraging breeding of mosquitoes but also a nuisance.

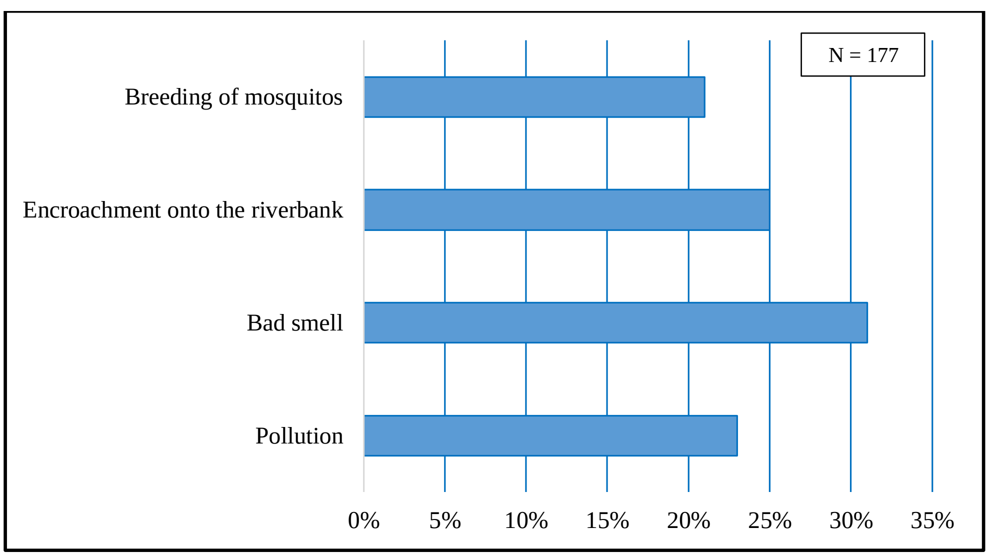

Figure 7.2: Environmental risks of using wastewater in vegetable production in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

7.3 Discussion

Antwi-Agyei *et al* (2016) are of the view that field-based evidence on the success of risk reduction actions targeting on-farm measures, hygienic food marketing and food preparation at markets, homes and kitchens is inadequate in low and middle-income countries. The study concurs with the above assertion; for instance the mushrooming of roadside food outlets particularly in urban areas in the country, makes it difficult to prove whether such restaurants do not serve wastewater-irrigated vegetables. If, indeed this is the case, then there is a possibility that the people who frequent such places for meals are predisposed to health risks. What is more worrying is the fact that most of the open air eating facilities are not regulated by the relevant authorities which gives the owners a leeway to operate without subscribing to the set food safety standards.

The findings on environmental risks associated with wastewater use in vegetable production in the study area were confirmed by what was observed during survey. For instance, farmers used wastewater-polluted water sources with bad odour for irrigation. It was further observed that farmlands encroached onto the Nairobi River banks with evident soil erosion at various points. It was also evident that developers in the neighbourhood of farmlands were at various stages of repossessing their plots for housing development. This has exacerbated competition for space for farming and development of housing, thus pushing farmers further towards the Nairobi riverbank with resultant pollution.

It was observed that wastewater application in vegetable production posed risks to the farmers and farmworkers. For instance, spent syringes with needles were spotted in one of the vegetable plots. This shows medical waste is dumped together with garbage into the

Nairobi River and some like the syringes, plastic bottles and polythene paper end up getting trapped in vegetable plots (Plate 7.1).

Plate 7.1: Unappealing vegetable field littered with garbage in Ruai ward, Nairobi City, Kenya

Source: Researcher (2021)

One respondent residing in Komarok said:

> "Often there are injuries from pieces of broken glass and even medical needles. I remember I was once pricked by a piece of glass and my leg took a very long time to heal".

Another respondent residing in Njiru said:

> "Whenever adults consume the vegetables we produce using wastewater they do not complain but usually children under five years often complain of stomach upsets whenever they eat the vegetables."

During interviews, one respondent from Siranga said:

> “Here we have so many risks while using this type of water. At times, during high humid days, the smell is so strong, and it is very difficult to work in such conditions’’.

In India, the Government runs sewage farms near treatment plants around Madurai, South India and around Hyderabad, which are rented out to farmers for cultivation (Buechler *et al*., 2006). This is not the case in Kenya where any form of cultivation near the Ruai domestic wastewater and industrial wastewater treatment plant as well as using treated effluent for crop irrigation is outlawed.

Urban farming Owusu *et al* (2012) provide income as well as serving as one of the means for solving urban food insecurity. The current study discovered that farmers satisfied their households’ vegetable dietary requirements and surplus produce sold for livelihood, thus concurring with Owusu *et al* (2012).

Most farmers complained of poor prices during certain periods of the year when some of the targeted markets receive an oversupply of vegetables from outside the City. Poor access roads in the study area further contributed to the poor prices particularly during wet season when some parts become inaccessible.

Qadir *et al* (2010) found out that farmers irrigating with wastewater had higher rates than farmers using freshwater in comparing helminth infections among farmers. In development countries, many farm households irrigating with wastewater are unaware of the risks or environmental impacts. Members of the household may not be sufficiently informed and have been exposed for long enough to poor health conditions. In the broader context of their living conditions where wastewater contact through irrigation can be merely one among a number of sanitary issues, many farmers therefore accept these health risks.

In the same context farmers in the current study did not mention any health risk linked to either contact with wastewater or consumption of vegetables produced using wastewater. However, visits to the clinics in the study area showed reported cases of skin and waterborne diseases like typhoid and diarrhoea which the personnel-in-charge of the facilities associated with contact of wastewater and consumption of vegetables produced using wastewater.

Wastewater contains harmful chemical constituents and pathogens that pose risks to health and environment. Risks can either be short term impacts like microbial pathogens or longer-term impacts such as salinity effects on soil that increases with intensity of wastewater use (Shakir *et al*., 2016). Untreated wastewater irrigation (Muneri, 2011) is a major threat to public health, food safety, and environmental quality. Inadequacy of protective clothing while irrigating with wastewater in urban agriculture in Nairobi contributed to health risks (Muneri, 2011). It was observed during survey that majority of the respondents did not use protective gear during farm operations including wastewater application and hence exposed themselves to risks such as injuries and diseases as pointed out by Muneri (2011).

CHAPTER EIGHT

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

Chapter eight presents a summary of the study findings, conclusions, recommendations and suggestions for further research based on research findings of each specific objective of the study conducted in Ruai ward, Nairobi City.

8.2 Summary of the findings

Farmers in the study use treated effluent, raw influent and wastewater-polluted water sources viz. upstream, discharge point and downstream of Nairobi River to produce four main types of vegetable viz. *Brassica* sp., *Spinacia oleracea*, *Solanum* sp. and *Amaranthus* sp. among others. Wastewater is preferred by farmers because of free access, reliable source of water, plant nutrient content and being the only sources of water in the study area. Ii is applied on the vegetables using surface (basin and furrow) and spray irrigation methods.

The pH and concentration of TDS in the analysed samples of wastewater used for vegetable production in the study area met the standard for irrigation. Aluminium, Cd, Cr, Co, Cu, Zn and Pb concentrations surpassed the recommended levels for corresponding parameters in the Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water. Total coliforms and *Escherichia coli* concentrations in the analysed wastewater sample exceeded the recommended levels in the Environmental Management and Coordination (Water Quality) Regulations, 2006 microbiological quality guidelines for wastewater use in irrigation of <1000 minimum probable number/ 100 ml, and nil/ 100 ml., respectively.

The mean concentrations of heavy metal contaminants viz. Zn, Pb, Cr, Cd, Co and Cu analysed in the samples of vegetables produced using wastewater in the study area were 51.45, 0.055, 12.1, 0.12, 3.625 and 5.2 g/kg, respectively. The order of metal contents in all the vegetable samples was found to be Pb > Cd > Co > Cu > Cr > Zn. The FAO/ WHO safe limits for Zn, Pb, Cr, Cd, Co and Cu in green leafy vegetables are 0.099 g/kg, 0.0003 g/kg, 0.00023 g/kg, 0.0002 g/kg, 0.005 g/kg and 0.073 g/kg, respectively.

The study showed using wastewater for vegetable production has health and environmental risks. Health risks from wastewater use irrigation is linked to skin and waterborne diseases also known as enteric diseases such as typhoid, *Escherichia coli*, *Escherichia histolytica* and *Giardia lumbricoides*. Other health risks are occasioned by injuries caused by broken classes and medical waste such as spent syringes. Wastewater application also provides conducive environment for breeding of mosquitoes. Personnel-in-charge of health facilities in the study area associated confirmed wastewater-related diseases was either as a result of contact with wastewater or handling or consumption of vegetables produced using wastewater. Environmental risks of using wastewater that was observed during data collection is the bad odour, pollution of the Nairobi River and encroachment onto the Nairobi River with resultant riverbank erosion.

8.3 Conclusion

Farmers in the study area use wastewater to cultivate *Brassica* sp., *Spinacia oleracea*, *Amaranthus* sp. and *Solanum* sp., among other vegetable types in the study area. They do so in defiance of the ban on reuse of wastewater for agriculture by Nairobi county government. Farmers seemed to be aware of the risks involved but they are more interested in the economic gains.

(i) Wastewater used for vegetable production is sourced from the treated effluent, raw influent and wastewater-polluted water sources viz. discharge point, and upstream and downstream of Nairobi River, which they are preferred because of plant nutrient content, free access, reliability and being the only sources of water supply in the study area. Methods of irrigation used are surface (basin and furrow) and spray. Raw influent is the most challenging source. Farmers using it have to stand the bad odour. They also have to dilute it first before using. Whereas farmers using other sources of wastewater can use wastewater pumps, raw influent irrigators cannot given the nature of raw influent.

(ii) Aluminium, Cd, Cr, Co, Cu, Zn and Pb as well as total coliforms and *Escherichia coli* investigated in wastewater used in vegetable production in the study area ranged in concentration from below detection limits to above recommended limits for corresponding parameters in the Environmental Management and Coordination (Water Quality) Regulations, 2006 standard for irrigation water and microbiological quality guidelines for wastewater use in irrigation. This finding suggests that wastewater that is used for vegetable production is unsuitable.

(iii) Vegetables grown using wastewater from different sources were found to contain elevated levels of investigated heavy metals which exceeded the limits for corresponding heavy metals in green leafy vegetables. The order of metal contents was found to be Pb > Cd > Co > Cu > Cr > Zn > Ti.

(iv) Production of vegetables using wastewater is associated with health and environmental risks. Heavy metal contaminants such as lead, chromium, zinc and cadmium that were detected in the vegetables produced using wastewater can be a health risk if such contaminated vegetable produce are continually consumed. Environmental risks of using wastewater for irrigation in the study area are bad odour and encroachment onto the Nairobi Riverbank with resultant riverbank erosion. It also causes land salinity and land sealing which could cause increased runoff and land erosion.

8.4 Recommendations

The study proposes four recommendations in accordance to the specific objectives of the study. These are:

(i) Nairobi county government can in short term sensitise/ educate the farmers on potential risks of using wastewater in vegetable production, while in the long term it can improve the efficiency of Ruai treatment plant and availing the treated effluent for crop irrigation in urban and peri-urban farming.

(ii) Periodic evaluation of wastewater quality in terms of physicochemical characteristics and microbiological composition to confirm its suitability for crop irrigation.

(iii) Monitoring heavy metal contaminants in vegetable produce in view of public health concerns in the value chain, and

(iv) Development and implementation of wastewater reuse policy guidelines grounded on the World Health Organization wastewater reuse guidelines and Environmental

Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water.

8.5 Suggestions for further research

The following suggestions for further research are made:

1. Conducting similar study in wet and dry seasons for comparison purposes.
2. Monitoring contamination levels in vegetable produce at different stages before and after harvest.
3. Gathering large data set of farmers and consumers and where possible their blood samples and other health indicators be taken to see the impact of wastewater.

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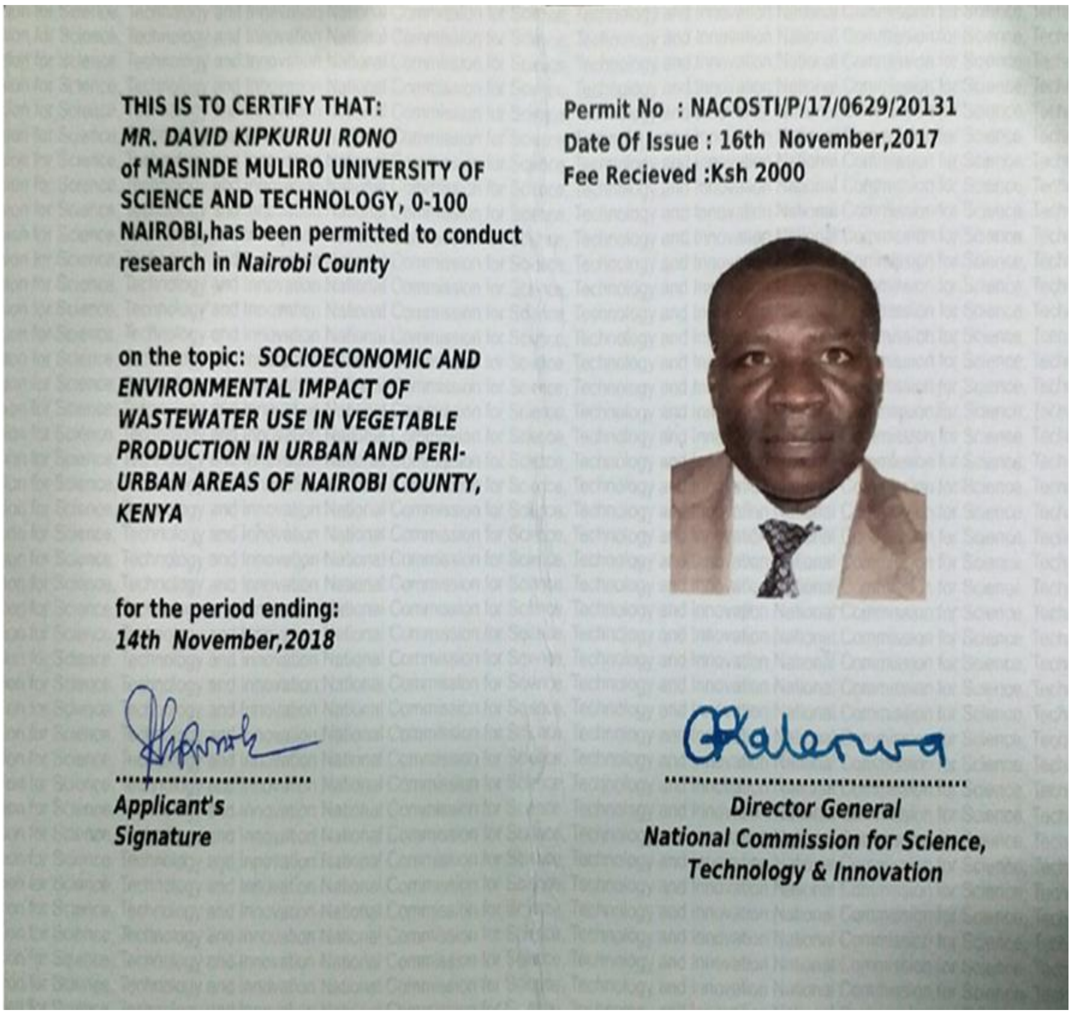
APPENDICES

Appendix 1: Research permit for Mr. David K. Rono from the National Commission for Science, Technology and Innovation (NACOSTI)



THIS IS TO CERTIFY THAT:
MR. DAVID KIPKURUI RONO
of MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY, 0-100 NAIROBI,has been permitted to conduct research in *Nairobi County*

on the topic: *SOCIOECONOMIC AND ENVIRONMENTAL IMPACT OF WASTEWATER USE IN VEGETABLE PRODUCTION IN URBAN AND PERI-URBAN AREAS OF NAIROBI COUNTY, KENYA*

for the period ending:
14th November,2018

Permit No : NACOSTI/P/17/0629/20131
Date Of Issue : 16th November,2017
Fee Recieved :Ksh 2000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

Appendix 2: Research authorization letter from the State Department of Basic Education, Ministry of Education

Research authorization letter for Mr. David K. Rono from the State Department of Basic Education, Ministry of Education granting approval to do research on health and environmental risks of using wastewater in vegetable production in Ruai ward, Nairobi City, Kenya.

Republic of Kenya
MINISTRY OF EDUCATION
STATE DEPARTMENT OF BASIC EDUCATION

Telegrams: "SCHOOLING", Nairobi
Telephone: Nairobi 020 2453699
Email: rcenairobi@gmail.com
cdenairobi@gmail.com

When replying please quote

Ref:RCE/NRB/GEN/VOL.1

REGIONAL COORDINATOR OF EDUCATION
NAIROBI REGION
NYAYO HOUSE
P.O. Box 74629 – 00200
NAIROBI

DATE: 15th February, 2018

David Kipkurui Rono
Masind Muliro University of Science
and Tachnology
P O Box 190-50100
KAKAMEGA

RE: RESEARCH AUTHORIZATION

We are in receipt of a letter from the National Commission for Science, Technology and Innovation regarding research authorization in Nairobi County on "**Socioeconomic and environmental impart of wastewater use in vegetable production in urban areas of Nairobi County, Kenya"**

This office has no objection and authority is hereby granted for a period ending **14th November, 2018** as indicated in the request letter.

Kindly inform the Sub County Director of Education of the Sub County you intend to visit.

MAINA NGURU
FOR: REGIONAL COORDINATOR OF EDUCATION
NAIROBI

c.c.

Director General/CEO
Nation Commission for Science, Technology and Innovation
NAIROBI

Appendix 3: Interview guide for face to face interviews with farmers using wastewater in vegetable production in Ruai ward, Nairobi City, Kenya.

Introduction (Interviewer)

Good morning/ afternoon. My name is ……………………………… I am conducting a survey to establish **'health and environmental risks of using wastewater in vegetable production in urban and peri- urban areas of Nairobi City, Kenya'** by David K. Rono, a post graduate student in the Department of Disaster Management and Sustainable Development, MMUST. You have been selected in a random process and I would appreciate if you would spare a few minutes of your time to answer the questions about vegetable production using wastewater. You are, however, free to interrupt during interview session should you feel uncomfortable answering certain questions or opt not to participate at all. The responses of this survey will be presented as an aggregate of findings and that your identity will be treated in confidence.

Interviewer's name and contact: ……………………………………………………………

Date of interview: --

Section A: General information about the respondent

Q.	Respondent's No.:	
1.	Respondent's Name:	
2.	Respondent's place of residence:	
3.	Respondent's age bracket:	a) < 25 […], b) 26 - 35 […] c) 36 - 45 […], d) 45 - 55 […] e) > 55
4.	Respondent's gender:	Male […], Female […]
5.	Respondent's household size	
6.	Respondent's highest level of education attained:	a) Tertiary [..], Secondary […] b) Primary [...], Never attended school […]
7.	Ownership of land used for vegetable production:	a) Self-owned […] Rented […] b) Not rented […] Unauthorized use […]
8.	What makes you grow vegetables?	
9.	Size of land used for vegetable production:	

Section B: Sources, reasons, and mode of applying wastewater in vegetable production

10. Use the table provided for responses to question 10.

a) What type of water do you use for vegetable production?

b) What is the source of water used in vegetable production?

c) How do you apply water in vegetable production?

No.	**Type of water used**	**Source**	**Mode of application in vegetable production**
1.	Treated wastewater		
2.	Untreated wastewater		
3.	Other (specify)		

11. Reasons for using type of water stated in question 10. Probe from the following and tick appropriately:
    a) Freely available [...].
    b) Contains plant nutrients hence, no fertilizer requirement [...]
    c) It is reliable (available throughout) [...].
    d) Other (specify) ………………………...

12. Do you have difficulty/ challenge in <u>accessing</u> source of water used in vegetable production? Yes [...] No [...].
    If yes, specify nature of difficulty/ challenge faced……………………………………
    …………………………………………………………………………………......

13. Do you apply fertilizer/manure or both?
    a) Fertilizer [...]
    b) Manure [...]
    c) Both (fertilizer and manure) [...]
14. Do you often seek technical advice/ assistance in vegetable production?
    Yes [...] No [...]
    If yes, state service provider(s), service(s) offered and cost if charged:

No.	Service provider	Service offered	Cost (KSh)
1.			
2.			
3.			
4.			

Section C: Physical characteristics of wastewater used in vegetable production:

15. Wastewater contains non-biodegradable material such as plastic bags/bottles, rags, broken glasses, medical waste such as spent syringes, which are likely to be introduced into the vegetable farms.
    a) Strongly agree [...] b) Agree [...]
    c) Disagree [...] d) Don't know [...]

16. What benefits do you get from vegetable production?
    ………………………………………………………………………………………………
    ………………………………………………………………………………………

17. Interviewer to record:

Physical characteristics of water used in vegetable production		
Colour:	Odour/ smell:	Solid waste:

Section D: Health risks of using wastewater in vegetable production in the study area

18. What do you do with the vegetables you produce using wastewater? Probe from the following:
    a) Consumed at home […]
    b) Surplus sold to individual retailers/ handlers […]
    c) Other (specify) ………………………………………………………………...

19. Do you face any challenge whenever you want to sell your vegetables? Probe from the following:
    a) Perception […]
    b) Preference […]
    c) Price fluctuation […]
    d) Competition from other sellers […]
    e) Other (specify)…………………………………………………..

20. Has any member of your household ever fallen sick during last six (6) months? If **yes**, name type of illness suffered, medical facility visited for treatment and state whether illness was associated with either contact with wastewater or consumption of vegetables produced using wastewater.

Entry	Illness suffered	Name of medical facility visited for treatment	Illness due to contact with wastewater	Illness due to consumption of vegetables produced using wastewater
1.				
2.				

Section E: Environmental risks of using wastewater in vegetable production

21. What are the **<u>disadvantages</u>** of using wastewater in vegetable production? Probe from the following:
    a) It is a nuisance […]
    b) Bad odour/ smell […].
    c) Pollutes surface water […]
    d) Other (specify) ………………………………………………….

22. What **<u>precautions</u>** do you take during farm operations? Probe from the following:
    a) Using protective gear such as cloves, gumboots, masks […...].
    b) Using recommended rates when applying agro-chemicals […...].
    c) Washing hands with clean water after spraying […...].
    d) Washing bucket and sprayer with clean water after spraying […...].
    e) Burning chemical containers after emptying […...].
    f) Other (specify) ………………………………………………………………

Thank you for participating in the survey.

Appendix 4: Interview guide for face to face interviews with medical personnel-in-charge of health facilities visited in Ruai ward, Nairobi City, Kenya

1. Self-introduction by the interviewer.
2. Purpose of interview.
3. Management of the facility if Private, FBO or Nairobi county government:

   ----

4. Are you aware farmers use wastewater for vegetable production in Ruai ward? If yes, what is your opinion about the practice? ---

   ----

   ----

5. Which are the most commonly reported diseases in your health facility?

   ----

6. Do you associate the diseases with either contact with wastewater or consumption of vegetables produced using wastewater? ---

   ----

   ----

7. Some diseases can be controlled through management of hygiene. What do you recommend to the patients whenever they visit your facility to seek treatment?

Appreciate the interviewee for accepting to be interviewed.

Appendix 5: Questionnaire for key informants representing State and non-state actors relevant to the current study

Introduction

Mr. David K. Rono, a post graduate student in the Department of Disaster Management and Sustainable Development, Masinde Muliro University of Science and Technology (MMUST) is conducting research on health and environmental risks of using wastewater in vegetable production in urban and peri- urban areas of Nairobi City, Kenya. The purpose of the study is to improve an understanding of health and environmental risks associated with wastewater use in vegetable production in urban and peri- urban areas of Nairobi city.

Your organization has therefore been selected in a random process to participate in view of its relevance to the study. Kindly fill and return to the sender the research questionnaire on behalf of your organization.

The responses of this survey will be presented as an aggregate of findings and that your identity or that of your organization will be treated in confidence.

Name and contact: ……………………………………………………………………...

Organisation's name and mandate (specify if State or non-state entity):

…………………………………………………..

1. In your organisation's opinion, whose responsibility is the management of wastewater in urban and peri-urban areas of Nairobi city? ……………………………..

   ....

2. What is the view of your organisation concerning the status of wastewater management in urban and peri- urban areas of Nairobi city?

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

   ……………………………………………………………………………………

3. According to your organisation, which of the following could best explain why farmers use wastewater for vegetable production in urban and peri-urban areas of Nairobi City?

   a) Freely available [……]

   b) Reliable [……]

   c) Rich in plant nutrients [……]

   d) Piped water is scarce [……]

   e) Fresh/ piped water is too costly [……]

   f) Ready market [……]

   Other (specify) …………………………………………………………………

4. In your organisational point of view, what impact does wastewater use in vegetable production in urban and peri-urban areas of Nairobi city has?

…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………………

5. State **health** and **environmental risks** of using wastewater in vegetable production in urban and peri- urban areas of Nairobi city.

Potential risk	
Health	Environmental

6. Acknowledging the competing needs for freshwater, what <u>policy</u> and <u>technological</u> options would your organisation recommend to make wastewater safe and readily available for reuse in urban and peri- urban agriculture?

   Policy:…………………………………………………………………………………

   ……………………………………………………………………………………

   Technology:……………………………………………………………………...…

   ……………………………………………………………………………………

7. Provide additional information not covered in the questionnaire that in your view might add value to the current study.
   ………...……………………………………………………….…….………...…..
   ………...…………...……………………………………………………………...
   ………………………………………………………………………………………

End

Your organization's participation in the study is appreciated

Appendix 6: Datasheet for entering preliminary information on wastewater and vegetable samples

Datasheet for entering preliminary information on wastewater and vegetable samples viz. sampling points coordinates, physical characteristics, identification label, number of samples, details of pre-treatment done and time and date for use in a study on health and environmental risks of using wastewater in vegetable production in urban and peri-urban areas of Nairobi City, Kenya.

Entry	Information required	Sample	
		Water	Vegetable
1.	Sampling site/ point		
2.	Time and date sample collected		
3.	Coordinates		
4.	Physical characteristics		
5.	Identification number/ label		
6.	Number of samples taken		
7.	Details of pre- treatment done		
8.	Any additional information		

Samples collected by: -------------------------- Contact --------------------------------------

Signed: -- Date: --

Appendix 7: Observation checklist for recording visual observations during data collection in Ruai ward, Nairobi City, Kenya

The checklist was used during data collection for collecting observable information on the farmlands, sanitation facilities, water used in vegetable production and the immediate and surrounding environment in the study area. That which were visually observed were recorded in the second column of the matrix and the corresponding interpretation recorded in the last column right hand side of the matrix as the findings. The person entering the information provided his/her name, signature, date and a brief comment for traceability.

Entry	Status	Observations	Remarks
1.	Farmlands		
2.	Sanitation facilities		
3.	Water resources		
4.	Vegetation		

Information entered by: ………………………………………………… (Name)

Signed: ……………………………………….. Date: ……………………………………

Brief comment (if any): ……………………………………………………………...

…………………………………………………………………………………..………

…………………………………………………………………………………..………

…………………………………………………………………………………..………

Appendix 8: Concentration (mg/l) of Al, Cd, Cr, Co, Cu, Zn, Pb and TDS in samples of wastewater used in vegetable production in Ruai ward, Nairobi City, Kenya against corresponding parameters in the Environmental Management and Coordination (Water Quality) Regulations, 2006 standards for irrigation water

Entry	Sampling point	Sampling point coordinates	Parameter	Sample concentration (Mg/ L)	Permissible level
1.	Treated effluent	1º 14′ 24″ S (Lat.) 37º 00′ 25″ E (Long.)	Al	13.0	5
			Cd	3.6	0.5
			Cr	5.0	1.5
			Co	5.0	0.1
			Cu	4.2	0.05
			Zn	3.0	2
			Pb	6.8	5
			TDS	788	1200
2.	Discharge point	1º 14′ 35″ S (Lat.) 37º 00′ 27″ E (Long.)	Al	2.8	5
			Cd	3.8	0.5
			Cr	4.0	1.5
			Co	4.0	0.1
			Cu	3	0.05
			Zn	6.8	2
			Pb	ND	5
			TDS	581	1200
3.	Upstream of Nairobi River	1º 21′ 46″ S (Lat.) 36º 58′ 48″ E (Long.)	Al	13	5
			Cd	3.8	0.5
			Cr	4.4	1.5
			Co	3.6	0.1
			Cu	1.6	0.05
			Zn	5.6	2
			Pb	ND	5
			TDS	454	1200
4.	Raw influent	1º 15′ 08″ S (Lat.) 36º 55′ 35″ E (Long.)	Al	11	5
			Cd	3.8	0.5
			Cr	1.2	1.5
			Co	4	0.1
			Cu	5	0.05
			Zn	6.2	2
			Pb	ND	5
			TDS	1582	1200
5.	Downstream of Nairobi River	1º 14′ 30″ S (Lat.) 36º 55′ 53″ E (Long.)	Al	5.6	5
			Cd	4.2	0.5
			Cr	2.8	1.5
			Co	3.2	0.1
			Cu	0.4	0.05
			Zn	0.4	2
			Pb	ND	5
			TDS	496	1200

NB: ND- Not detected

Source: Researcher, 2021

Appendix 9: Concentration (g/kg) of selected heavy metals in samples of vegetables produced using wastewater in Ruai ward, Nairobi City, Kenya against FAO/WHO permissible limits in g/kg for corresponding heavy metals in green leafy vegetables

Entry	Sampling point	Sampling point coordinates	Vegetable type	Concentration (g/kg) of selected heavy metals						
				Ti	Zn	Pb	Cr	Cd	Co	Cu
1.	Treated effluent	1º 14′ 24″ S and 36º 00′ 51″ E	*Brassica* sp.	58	16	0.05	11	0.13	4	4
			Spinacia oleracea	126	68	ND	7	0.27	ND	9
			Amaranthus sp.	143	167	0.05	19	0.05	3	7
			Solanum sp.	115	34	ND	11	0.07	ND	8
2.	Discharge point	1º 14′ 06″ S and 37º 00′ 51″ E	*Brassica* sp.	91	30	ND	2	ND	ND	1
			Spinacia oleracea	113	48	ND	16	ND	ND	6
			Amaranthus sp.	101	21	ND	16	ND	ND	3
			Solanum sp.	97	27	ND	5	ND	ND	6
3.	Upstream of Nairobi River	1º 14′ 37″ S and 36º 57′ 10″ E	*Brassica* sp.	165	29	ND	6	ND	3	4
			Spinacia oleracea	171	41	ND	19	ND	3	8
			Amaranthus sp.	238	31	0.06	3	ND	ND	6
			Solanum sp.	90	32	ND	11	ND	4	5
4.	Raw influent	1º 16′ 40″ S and 36º 47′ 37″ E	*Brassica* sp.	105	46	ND	14	0.04	5	3
			Spinacia oleracea	108	50	ND	16	0.01	4	3
			Amaranthus sp.	172	46	0.06	8	0.23	ND	6
			Solanum sp.	216	30	ND	13	ND	3	4
5.	Downstream of Nairobi River	1º 14′ 30″ S and 36º 55′ 53″ E	*Brassica* sp.	85	29	ND	14	0.02	ND	1
			Spinacia oleracea	115	202	ND	27	0.20	ND	11
			Amaranthus sp.	65	49	ND	9	0.11	ND	2
			Solanum sp.	150	33	ND	15	0.14	ND	7
			Range	*58- 238*	*16- 202*	*0.05-0.06*	*2 -27*	*0.01-0.27*	*3-5*	*1-11*
			FAO/WHO (g/kg)	*	***0.099***	***0.0003***	***0.0023***	***0.0002***	***0.005***	***0.073***

* FAOWHO permissible limit of the heavy metal was missing; **NB:** Ti - Titanium, Zn - zinc, Pb - lead, Cr – chromium, Cd – cadmium, Co – cobalt, Cu – copper and ND- not detected.

Appendix 10: Findings from the medical facilities visited to triangulate information on health risks of using wastewater in vegetable production in Ruai ward, Nairobi City, Kenya

Entry	Facility name and location	Management	Common diseases	Remarks by interviewed medic-in-charge
1.	Spring Valley (Kayole North)	Private	Typhoid, diarrhoea (worm and amoeba infections)	**Comments:** • Water purchased from handlers and source often unknown • Bottled water sold locally often contains impurities • Vegetables produced using water from polluted river **Recommendations:** • Ban on wastewater irrigation (benefits only a few producers but affects the majority (consumers) who spent a lot in medication • Vegetable handlers should sell vegetables on clean raised structures to prevent contamination • Vetting of water handlers especially i.e. those using hand cards • Encouraging patients to boil drinking water.
2.	Uwezo Health Care Ltd. (Kayole North)	Private	Upper respiratory infections e.g. pneumonia, tonsillitis in adults and children; urinary tract infections; hypertension in adults mainly; enteric fever (typhoid) among adults mostly; gastritis and Amebiasis	**Comments:** • Amoeba is due to poor hygiene i.e. failure to clean vegetables thoroughly before cooking • Piped water in the vicinity available only on Fridays, other days water is purchased from handlers and source of which is unknown • Due to water shortage vegetable handling by handlers is poor **Recommendations:** • Encouraging people to boil drinking water • Discouraging taking meals sold in the open • Provision of clean water • Nairobi County Government to put up proper structures for vegetable handlers (to avoid contamination of vegetables)

Entry	Facility name and location	Management	Common diseases	Remarks by interviewed medic-in-charge
3.	Njiru Health Center (Njiru)	Nairobi County government	Reported cases of 10 top diseases during 2019. <u>Under 5 years old</u> Upper respiratory tract infections (URTI) = 5836 Skin disease= 876 Diarrhoea = 692 Respiratory system disease = 296 Pneumonia = 154 Asthma = 122 Eye infection = 101 Malaria = 46 Chicken box = 31 <u>Above 5 years old</u> URTI = 7695 Skin disease= 1136 Diarrhoea = 718 Arthritis = 1103 Other diseases of respiratory system = 943.	**Comments:** • Diarrhoea is rampant in the area and could be attributed to more than one cause including handling and consumption of vegetables produced using wastewater. • Health workers involved in community sensitization programmes e.g. hand washing, cleaning vegetables before cooking, boiling drinking water • Conducting community dialogue programmes with clinical officers and nurses as resource persons where common diseases are discussed with point of entry being through area Chiefs, village elders who are responsible for sourcing meeting venues and community mobilization. **Recommendations:** • Vegetable production using wastewater requires a multidisciplinary approach in addressing. Thus, stakeholders in agriculture, health/ public health, water, environment and security as well as farmers and the local community.
4.	Ultimate Medical Care (Chokaa)	Private	1. Waterborne diseases are enteric diseases such as typhoid, Amebiasis (*Escherichia coli*), Entremoeba (*Escherichia histolytica*) and *Giardia lumbricoides*, 2. Water washed diseases e.g. eye infections common in arid and semi-arid lands (ASALs), Trachoma and skin diseases like scabies. 3. Water-related diseases are	**Comments:** • Hospital's catchment: Ruai, Chokaa and Njiru. • Waterborne diseases: Typhoid and Amebiasis (*Escherichia coli* and total coliforms) **Recommendations:** • Observance of hygiene • Meals should be properly cooked

Entry	Facility name and location	Management	Common diseases	Remarks by interviewed medic-in-charge
3.	Njiru Health Center (Njiru)	Nairobi County government	Reported cases of 10 top diseases during 2019. <u>Under 5 years old</u> Upper respiratory tract infections (URTI) = 5836 Skin disease= 876 Diarrhoea = 692 Respiratory system disease = 296 Pneumonia = 154 Asthma = 122 Eye infection = 101 Malaria = 46 Chicken box = 31 <u>Above 5 years old</u> URTI = 7695 Skin disease= 1136 Diarrhoea = 718 Arthritis = 1103 Other diseases of respiratory system = 943.	**Comments:** • Diarrhoea is rampant in the area and could be attributed to more than one cause including handling and consumption of vegetables produced using wastewater. • Health workers involved in community sensitization programmes e.g. hand washing, cleaning vegetables before cooking, boiling drinking water • Conducting community dialogue programmes with clinical officers and nurses as resource persons where common diseases are discussed with point of entry being through area Chiefs, village elders who are responsible for sourcing meeting venues and community mobilization. **Recommendations:** • Vegetable production using wastewater requires a multidisciplinary approach in addressing. Thus, stakeholders in agriculture, health/ public health, water, environment and security as well as farmers and the local community.
			Malaria, Tsetse flies, Bilharzia which is common in irrigated areas.	